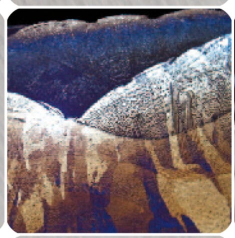
INTERNATIONAL INSTITUTE OF WELDING

A world of joining experience

White Paper

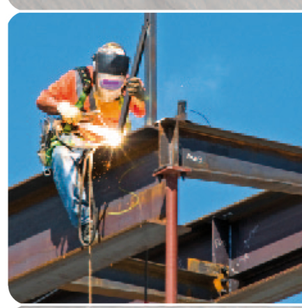
Edited by :

Chris Smallbone & Mustafa Koçak



Improving Global Quality of Life

Through Optimum Use and Innovation of Welding and Joining Technologies



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The following IIW Member Societies are proud to have sponsored the printing of the **IIW White Paper** and wish all readers success in using the IIW White Paper to further "*Improving Global Quality of Life Through Optimum Use and Innovation of Welding and Joining Technologies*".

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Improving Global Quality of Life

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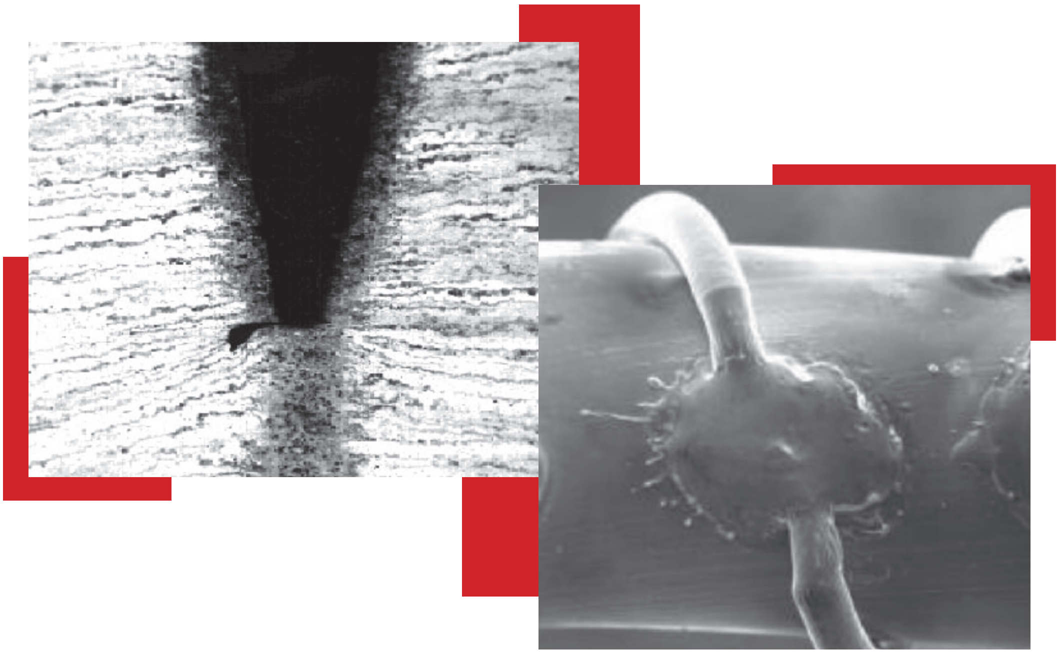
First Edition



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Chris Smallbone and Mustafa Koçak

INTERNATIONAL INSTITUTE OF WELDING
A World of Joining Experience
www.iiwelding.org

The IIW White Paper

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International Institute of Welding
Secretariat
Chief Executive Officer
E-mail: c.mayer@iiwelding.org
Fax: + 33 1 49 90 36 80
Phone: + 33 1 49 90 36 08, + 33 1 49 90 36 79
Mail: Paris Nord 2 - 90 rue des Vanesses
BP 51362 – VILLEPINTE
95942 ROISSY CHARLES DE GAULLE Cedex
FRANCE

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Foreword

Dr Baldev Raj

Mr Chris Smallbone

Dr Mustafa Koçak

Since being founded in 1948, the now 56 Member Country International Institute of Welding (IIW) has focused on helping all industries which utilise welding as an enabling technology, as well as organisations, governments and academia to improve the quality of life in all countries of the world through enhanced weld quality, design and performance of welded structures while reducing the cost of the fabrication, improving safety and ensuring environmental sustainability.

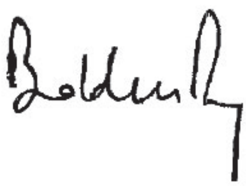
Innovation in joining and welding sciences and technologies has been creating significant contributions to the improvements in performance and safety of welded structures operating under challenging conditions. It has also led to reduced environmental impact of the fabrication process and improved working conditions of the welding personnel.

The impact on global quality of life through the application of appropriate welding technologies in countries with emerging economies and economies in transition can be enormous with respect to safety, productivity and enhancing competence in vital technologies. Guiding principles for IIW Members include the sharing of knowledge to enable technology diffusion, networking and the promotion of welding education, training, qualification and certification of people throughout the regions of the world to help nations improve everyday life of their people.

Our Institute believes that best practices are rarely enough to create lasting value and that positive change requires new insights and vision into welding and joining technologies and markets found in both the developed and emerging world.

The concept for this paper originated with Mr Chris Smallbone during his term as IIW President 2005-2008, and was then developed by Dr Mustafa Koçak and Mr Smallbone, with the input and support of over 60 experts from around the world. I express my gratitude and appreciation to Mr Chris Smallbone, Dr Mustafa Koçak and all the experts for their time, efforts and vision.

IIW believes that this White Paper can contribute to the development of a vision for a sustainable future of our globe and all its citizens. The tangible benefits of this paper could include attracting bright young persons to careers in welding science and technology, inspiring professionals and generating a framework for policy makers to strengthen and enhance welding science and technology for meeting national and global challenges.



Dr Baldev Raj
IIW President 2011-2014

Panel of Expert Contributors

In alphabetical order

C. P. Ang, Shell, SINGAPORE
S. Ambrose, Welding Technology Institute of Australia, AUSTRALIA
N. Ames, Edison Welding Institute, USA
S. Asai, Toshiba Corporation Power Systems Company, JAPAN
E. Asnis, E.O. Paton Electric Welding Institute, UKRAINE
A. Bhaduri, Indira Gandhi Centre for Atomic Research, INDIA
W. A Bruce, DNV Columbus Inc., USA
R. Boekholt, ICWET, SPAIN (deceased)
T. Boellinghaus, Federal Institute for Materials and Testing (BAM), GERMANY
H. Castner, Edison Welding Institute, USA
N. A. Chapman, University of Sheffield, UK
O. Celliers, Alcoa World Alumina, AUSTRALIA
H. Cerjak, Graz University of Technology, AUSTRIA
D. Chauveau, Institut de Soudure, FRANCE
C. Conrardy, Edison Welding Institute, USA
L. Costa, Instituto Italiano della Saldatura, ITALY
C. E. Cross, Federal Institute for Materials and Testing (BAM), GERMANY
B. De Meester, Université Catholique de Louvain, BELGIUM
U. Dilthey, Aachen University, GERMANY
G. Dobmann, Fraunhofer-Institute IZFP, GERMANY
P. Doubell, Eskom, SOUTH AFRICA
N. Enzinger, Graz University of Technology, AUSTRIA
S. E. Eren, GKSS Research Centre, Germany
R. R. Fessler, BIZTEK Consulting Inc., USA
D. Fink, The Lincoln Electric Company, USA
C. C. Girotra, Weldwell Specialty Pty Ltd, INDIA
P. Goswani, Ontario Power Generation Inc, CANADA
P. Grace, Welding Technology Institute of Australia, AUSTRALIA
Y. Gretsky, E.O. Paton Electric Welding Institute, UKRAINE
I. Harris, Edison Welding Institute, USA
H. Herold, Otto-von-Guericke-University Magdeburg, GERMANY (deceased)
T. Jessop, TWI Ltd., UK
K. Ikeuchi, Osaka University, JAPAN
T Iljima, IHI Corporation, JAPAN
J. Jennings, Edison Welding Institute, USA
D. Jordan, The Lincoln Electric Company, USA
R. King, Consultant, UK
M. Koçak, Gedik Welding, TURKEY
S. Kralj, Professor, University of Zagreb, CROATIA
E. Kozeschnik, Graz University of Technology, AUSTRIA
D. Kotecki, The Lincoln Electric Company, USA

In alphabetical order (Continued)

E. Levert, Lockheed Martin Corporation, USA
D. Luciani, CWB, CANADA
Y. Makino, Toshiba Corporation, JAPAN
H. Matsui, Auto Parts Welding Laboratory Inc., JAPAN
C. Mayer, IIW/Institut de Soudure, FRANCE
P. Mayr, Graz University of Technology, AUSTRIA
C. Mehmetli, Edison Welding Institute, USA
K. Middeldorf, DVS e.V., GERMANY
D. Miller, The Lincoln Electric Company, USA
T. Miyata, Nagoya University, JAPAN
D. Moore, S.A. Water, AUSTRALIA
A. Mukherjee, Indian Institute of Welding, INDIA
P. J. Mutton, Monash University, AUSTRALIA
T. O'Neill, TWI Ltd., UK
A. Palmer, National University of Singapore, SINGAPORE
B. Pekkari, BePe Konsult, SWEDEN
M. Prager, Welding Research Council, USA
L. Coutinho, Instituto de Soldadura e Qualidade, PORTUGAL
B. Raj, Indian National Academy of Engineering, INDIA
G. R. Razmjoo, TWI Ltd., UK
A. Rorke, Welding Technology Institute of Australia, AUSTRALIA
M. Sato, Japan Welding Engineering Society, JAPAN
D. Shackleton, ISO3834.com Ltd, UK
B. Schambach, DIN e. V., GERMANY
C. Shiga, Joining and Welding Research Institute, Osaka University, JAPAN
R. W. Shook, American Welding Society, USA
C. Smallbone, Welding Technology Institute of Australia, AUSTRALIA
R. Smith, TWI Ltd. Technology Transfer Services, UK
N. Stockham, TWI Ltd., UK
D. von Hofe DVS e.V., GERMANY
K. K. Verma, Federal Highway Administration, USA
J. Weber, American Welding Society, USA
S. Webster, Corus Group, UK
D. Weizhi, Jingong Steel Building, PR CHINA
R. West, Alcoa Global Primary Products, AUSTRALIA
C. S. Wiesner, TWI Ltd., UK
K. Yushchenko, E.O. Paton Electric Welding Institute, UKRAINE
H. G. Ziegenfuss, American National Standards Institute, USA
J. L. Zeman, Vienna University of Technology, AUSTRIA
Y. N. Zhou, University of Waterloo, CANADA
R. Zwaetz, GSI Gmbh, GERMANY (deceased)

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Executive summary

> *Welding is an enabling technology that plays a critical role in almost every industrial sector in every country of the world, whether developed, emerging or in transition.*

The International Institute of Welding (IIW) brings together experts from industry - large, small and medium sized enterprises, universities, research centres, training providers, welding associations and public authorities in the field of welding and joining and allied processes. A non-profit organisation, the IIW, founded in 1948, currently has 56 member countries, representing 80% of global GDP, and ranging through developed, emerging and transitional economies worldwide.

IIW provides a unique platform to enhance excellence in the fields of welding and joining sciences and technologies, and their uptake and implementation through education, training, qualification and certification worldwide. It also contributes to the global awareness of environmental and workplace health and safety imperatives, and plays an important role in global standardisation.

This White Paper, compiled by the members of IIW, has the following five primary objectives:

- To identify the challenges for welding and joining technology in the global arena.
- To recommend the implementation of strategies to find solutions to meet these challenges.
- To agree on directions to arrive at solutions.
- To promote the implementation of identified directions for solutions on a national, regional and international basis through greater collaboration, shared knowledge and partnerships.
- To improve overall global quality of life i.e. health, safety, food, water, fair trade, environment, education opportunities.

Needs and challenges for the global industry are detailed in the paper, while “Hot topics” are identified for each industry sector in Chapter 9 to highlight the specific challenges which need to be met along with potential solutions.

Chapter 10 details short, medium and long-term strategic agendas to meet these identified needs and challenges.

Common challenges identified in all sectors and throughout the world include:

- Environmental sustainability including addressing global warming, CO_2 emissions, waste disposal, decommissioning and recycling.
- Rapid increase of energy and commodities consumption world wide related to population growth, with associated demands for manufactured products and resources. Forecasts of global growth indicate that vast amounts will be spent on infrastructure projects alone, with enormous economic growth taking place in countries such as PR China, India, Indonesia, Africa, etc.
- Workplace health and safety including management of welding to minimise hazards.
- Product quality, fitness for purpose and compliance with standards, codes and/or specifications.
- Effective technology transfer to industry in developed, emerging and in transition countries.
- Development of skilled personnel in countries to implement appropriate technologies – though not necessarily leading-edge technologies. Part of this challenge is to improve the image of welding as a career so that it will attract young people.
- Establishment of national and regional Educational Support Centres Networks and Technology Support Centres Networks to support technology transfer and implementation.
- Research and development in welding and joining technologies, to generate continuous innovation in areas such as arc welding, high power beam welding technologies (laser and electron beam), friction stir welding, hybrid welding etc., to provide solutions for various production systems.
- Research and development in materials and their weldability, modelling, light-weight design, structural assessment and extension of the life cycle of structures.
- Integration of information technology for knowledge management, modelling, technology diffusion, data storage and communication.
- Promotion of international cooperation and harmony for the achievement of these goals, linking with the IIW Project "To Improve the Global Quality of Life through the Optimum Use of Welding Technology".

Editors' Preface

Improving Global Quality of Life Through Optimum Use and Innovation of Welding and Joining Technologies

In today's world, no country or organisation can remain in isolation. Issues such as climate change, natural disasters, population growth and global economics are common to us all, as nations strive to achieve sustainable development in a sustainable environment. We are brought closer together by modern communications, information technology and travel, and are aware of our role and responsibilities in a cooperative and converging global community.

With world population having reached 7 billion in 2011 and 9 billion by 2045, the pressures on manufacturing, infrastructure and power generation, not to mention basic needs such as food, water, shelter and education, will become enormous common challenges.

Welding - as an enabling technology that plays a critical role in almost every industry sector - is critical to the world's ability to cope with these pressures and changes. Whether joining 6 micron in the Cochlear Ear Implant or welding the 480 metres long, 74 metres wide, 600,000 tonne world's first floating liquefied natural gas plant, welding makes significant contributions to the global quality of life. Welding technologies, whether basic or sophisticated, and the people skilled in their implementation and application, are thus the cornerstones to improved quality of life for all.

This IIW Vision 2020 document, the IIW White Paper (WhiP), has been developed by IIW experts in the fields of materials welding and joining technologies, training and education, as well as design and assessment of welded structures, to highlight future opportunities, needs and challenges worldwide.

The WhiP describes strategic challenges and agendas for the welding industries, personnel, scientists and end-users through the next 10 years (2012 to 2021). The strategic agenda of the WhiP is ambitious and visionary. It provides strategies for "Improving Quality of Life" through the use of new materials, design and advanced joining technologies to reduce manufacturing cost and improve structural performance and life-cycle via better personnel, inspection and integrity assessment rules while meeting the societal expectations in health, safety, environmental and growth issues. It provides the visions, major challenges, and opportunities of the welding industries, science and technologies that we will face in 2020. Most of the products in modern society, from medical devices, cars, ships, pipelines, bridges, computers, aircrafts, amongst many others, could not be produced without the use of welding.

This WhiP is based on inputs provided by invited representatives from the industry and academia as well as several IIW member organisations and experts who have kindly provided contributions. Previously developed vision or roadmap documents of the American Welding Society (AWS) and Canadian Welding and Joining Industries, as well as several Strategic Research Agendas (SRA) of the European Technology Platforms, have been used as a reference for the development of this WhiP.
The IIW WhiP will be updated and improved as and when IIW experiences a paradigm change, or after three years when there is enough additional collective experience and knowledge to revise it.

Mr Chris Smallbone, Chief Executive Officer, Welding Technology Institute of Australia,
IIW President 2005-2008
Dr Mustafa Koçak, Chief Executive Office, Gedik Holding, Turkey

The editors thank Mrs Anne Rorke and Dr. Cécile Mayer for their significant assistance.

1. Scope and objectives

This white paper (WhiP) is a common vision document agreed and prepared by the experts of the International Institute of Welding (IIW). It is not intended to provide a comprehensive coverage, but it is representative, precise and inspiring.

WhiP identifies the current and future challenges and needs for welding and joining technologies, base and filler materials, weld design and structural assessment as well as future demands and requirements of resources.

Here, the term joining is used for the manufacture of all material-locking joints between materials, such as welding, soldering and brazing, adhesive bonding and thermal coating, as well as for thermal cutting and mechanical joining apart from joining with screws.

At the same time, it identifies the potential methods, innovations and solutions for complex problems of joining sciences and industrial applications while taking into account regional and national differences in strategic agendas. It is widely recognised that there exist different priorities for developing and developed nations and nations with economies in transition with respect to the value and benefit of welding and joining. This document takes into account the differences of priorities in basic and applied research and development (R&D), commercial enterprise, occupational health and safety (OHS), training, education, qualification, certification and a sustainable environment.

WhiP aims:

- To recommend the implementation of strategies to find solutions to meet identified challenges of different industrial sectors and nations for the next 10 years.
- To promote the implementation of innovations and solutions on a national, regional and international basis through greater collaboration, shared knowledge and partnerships.
- To contribute to the improvement of the global quality of life through use and innovation in welding and joining technologies.

It should be noted that significant changes, including the use of new technologies, are underway in the practices of material development, welded structures design, welding/joining processes, structural erection, inspection, repair and inspection and testing of welds world-wide. While these developments are satisfying some of the industry's needs, others remain as challenges still to be tackled.

This document aims to identify remaining and newly emerging needs and challenges as well as establish strategies to develop solutions.

It is true that new materials have significantly contributed to improving the standards of living of mankind as a whole and this would continue to be so in the future. Joining these materials would definitely be

an important issue in the successful use of these materials and present trends indicate a shift from the conventional joining techniques to new ones. Whether it is the development of new materials or joining or processing them for new applications, it is important to ensure that the ultimate objective of better quality of life through development of these initiatives shall cover all the citizens of the world, including the poor and those deprived of opportunities to contribute and enjoy the beautiful and mind enriching blessing available on this planet earth. We shall not forget that not only the existing generation but also future generations have a right to live in and enjoy our planet.

As testing and inspection becomes difficult and expensive, one often has to depend on modelling and simulation for evaluation of the joints for their structural performance. These are not replacements, however, for testing, as minimum tests have to be carried out both for the generation of physical property data and for verification and validation of the models. Additionally, advanced analytical procedures for engineering assessment of critical welded structural components are needed to provide support for material selection, design and fabrication, in-service assessment and failure analysis.

With the increasing application of new materials and their joints in every walk of life, there is a need to widen the scope of welding education and training by including the science and technology of joining of these materials in the curriculum. In the present welding education systems, irrespective of whether they are for welders, supervisors or engineers, the emphasis is on the welding of the present metals and alloys. There is scope to introduce certification programmes for special joining techniques employed for the new structural and advanced materials.

Having these in mind, with this White Paper (WhiP), the leading experts of the IIW have identified current and future challenges and opportunities of the welding and joining sciences and technologies in all industrial sectors to meet the industrial, environmental and societal needs to improve the quality of life.

An excellent example of future challenges and opportunities is the recent commitment by Shell to the building of the Prelude Floating Liquefied Natural Gas Facility (FLNG) Project which will be the world's largest man-made floating object and has the potential to revolutionise the way natural gas resources are developed. Once complete, the facility will have decks measuring 488 by 74 metres, the length of more than four soccer fields. Fully ballasted it will weigh roughly six times as much as the largest aircraft carrier.

Figure 1.1 *Shell's Prelude Floating Liquefied Natural Gas Facility (Reproduced courtesy: Royal Dutch Shell)*

The floating facility will chill natural gas produced at the Prelude gas field to -162˚C, shrinking its volume by 600 times so that it can be shipped to customers in other parts of the world. The LNG, LPG and condensate produced will be stored in tanks in the hull of the facility. Ocean-going carriers will moor alongside and load the LNG as well as other liquid by-products (condensate and LPG) for delivery to market.

Welding industry in the world

2

2. Welding industry in the world

2.1 Historical perspective: welding as problem solver

Evidence suggests that the joining of metals was reasonably common around **3,000 BC**, or even earlier than that, and that civilisations of the Bronze, Iron and Middle Ages worked metals together by heating and hammering to form adornments and other implements. This was the first means of welding, as opposed to brazing and soldering, and its use spread to other communities throughout Europe, the Middle East, and into SE Asia.

During the **18th** and **19th Centuries** critical advances in the applications of electricity and the creation and storage of gases were to profoundly influence welding and its capability to join metals together.

In **1800**, Sir Humphry Davy discovered that an electric arc could be produced between two carbon electrodes and in **1836** Edmund Davy was credited with the discovery of acetylene. The most significant work on new processes for the production of oxygen proved to be the fractional distillation of liquefied air which was achieved in the late **1800s**.

The production of steel from molten iron in **1860** was also another step forward since it produced a material with high strength and ductility that was compatible to the welding process. Here, at last, was a material that could be used for the construction of bridges, ships, boilers etc that would bring in a new era in the service of metals to man.

In **1895** it was found that acetylene gas, when burnt with an equal volume of oxygen, gave a flame with a temperature of 3,130°C, 470°C higher than the oxy-hydrogen flame. To harness the effects of this high temperature flame a device was needed to mix the gases at high pressure and the first high-pressure oxy-acetylene torch was produced in **1900**.

At first, oxy-fuel welding was one of the more popular welding methods due to its portability and relatively low cost. As the **20th Century** progressed, however, it fell out of favour for industrial applications. It was largely replaced with arc welding, as coverings (known as flux) for the electrode that stabilise the arc and shield the base material from impurities continued to be developed.

The production and storage of gases were essential developments in the evolution of metal working, for cutting and welding and, with the introduction of automated welding in **1920**, in the critical role of shielding the arc from air, to protect welds from the effects of oxygen and nitrogen in the atmosphere. Porosity and brittleness were the primary problems, and the solutions that developed included the use of hydrogen, argon, and helium as welding atmospheres.

In **1885** the first arc-welding machine was invented and a patent was issued to the Russian and Polish research workers, Bernodos and Olzeweski, who were working in France while Lincoln Electric in the US produced the first arc welding set for general usage in **1909**. Other variants of welding were also being developed and the Thermit welding process made its appearance around the turn of the century.

The advent of Word War 1 gave great impetus to the application of welding, when quick repair and construction, especially of ships, was paramount. Arc welding was first applied to aircraft during the war as well, as some German airplane fuselages were constructed using the process.

Welding started to take gradual precedence in shipbuilding as a preferred technique during the **1920s** when it was used primarily for bulkheads and decking; however, the all-important hull still remained riveted. The arguments on welding versus riveting still did not lessen even though welding offered considerable benefits. These differences of opinion were to continue until the **1940s**, or even later, when the economic benefits of welding finally won.

1930 saw the release of stud welding, which soon became popular in shipbuilding and construction. Submerged arc welding was invented the same year, and continues to be popular today. Further advances allowed for the welding of reactive metals like aluminium and magnesium. This, in conjunction with developments in automatic welding, alternating current, and fluxes fed a major expansion of arc welding during the **1930s** and then during World War II.

After decades of development, gas tungsten arc welding was finally perfected in 1941, followed in 1948 by gas metal arc welding, both processes allowing fast welding of non-ferrous materials but requiring expensive shielding gases.

Shielded metal arc welding using a flux coated consumable electrode quickly became the most popular metal arc welding process **by the 1950s**. In **1957**, the flux-cored arc welding process was released, resulting in greatly increased welding speeds as the self-shielded wire electrode could be used with automatic equipment. Plasma arc welding was invented that same year, electroslag welding was introduced in **1958**, followed by electro-gas welding in **1961**.

Other developments in welding include the **1958** breakthrough of electron beam welding which, undertaken under vacuum conditions, makes deep and narrow welding possible through the concentrated heat source. The laser has also made significant contributions to both cutting preparation and welding and has proved to be especially useful in high-speed, automated welding. Friction-stir welding, a solid-state joining process where the metal is not melted during the process, was invented and experimentally proven at The Welding Institute UK and patented in **December 1991**.

An enabling technology in so many applications and industry sectors, welding continues to evolve. Micro-joining and nano-welds actively contribute to manufacturing for the electronics, medical and aerospace industries, and are leading to the future of joining technologies.

Welding contributes positively to all human endeavour and the quality of life of all. It does this in numerous ways, whether through creating power for lighting and cooking; potable water and safe sanitation; national infrastructure; efficient and effective transportation; accommodation both for living and working; a multitude of machines for different industrial applications, medical, health and safety devices or by many other ways. Without welding, people around the world could not switch on a light, turn a tap to access water, travel by train, road or air, or use a computer.

Nowhere is this more apparent than in developing countries, where the provision of basic infrastructure and services is critical to the wellbeing of millions of people. The application of appropriate welding technologies, as opposed to leading edge technologies, and the training of people to correctly apply welding technology in a safe manner is a major goal of the IIW.
International cooperation, networking and innovation through the IIW WeldCare programme, discussed in the following sections, is a keystone to the future quality of life for people around the globe.

2.2 Today's welding industry and its structures

The cost of welding, as an industrial process, plays a crucial role in manufacturing decisions. Many different variables affect the total cost, including equipment cost, labour cost, material cost, and energy cost.

In recent years, in order to minimise labour costs in high production manufacturing, industrial welding has become increasingly more automated, most notably with the use of robots in resistance spot welding (especially in the automotive industry) and in arc welding. In robotic welding, mechanised devices both hold the material and perform the weld, and at first, spot welding was its most common application. Robotic arc welding, however, has been increasing in popularity as technology has advanced.

Other key areas of research and development include the welding of dissimilar materials (such as steel and aluminium, for example) and new welding processes, such as friction stir, magnetic pulse, conductive heat seam, and laser-hybrid welding. Specialised processes such as laser beam welding are now continually finding new practical applications in industry sectors such as aerospace and automotive.
The modelling of weld properties such as microstructure and residual stresses, and the application of rapid advances in IT and computer science to process development and automation provide a rapidly expanding frontier for the modern welding industry.

Throughout the life of IIW, the scope of its technical programme has been continually expanded to include new technologies. Such have included more recently, the joining of plastics and composites, the capabilities of computers in design, process control, inspection and information handling, welding in a variety of environments and under remote control, new concerns for the health and safety of those working in industry and the environment and the education, training, qualification and certification of personnel and companies.

2.3 Organisations, institutes, communication and networks

2.3.1 Early welding societies

The welding fraternity has enjoyed a long history of cooperation through the formation and networking of numerous organisations, both at national and global levels.

The German Welding Society, Deutscher Verband für Schweißen (DVS), formed in 1897 from a number of smaller organisations, was one of the earliest technical-scientific non-profit-making societies. It now offers a network of 86 district branches (BVs), 14 state branches (LVs) and approximately 400 DVS® educational facilities. The first German welding training and testing establishment, Schweißtechnische Lehr- und Versuchsanstalt (SLV) was formed in Berlin-Brandeberg in 1927, later to join the 2003 amalgamation of SLVs to form a national network under the banner of Gesellschaft für Schweißtechnik International (GSI).

The development of welding took place very rapidly from the time of World War I and consequently in many countries there was a feeling among those in the welding fraternity that some kind of forum was required to represent the views and aspirations of those working in the industry.

One of the first countries to respond was the United States, and the American Welding Society (AWS) was formed on March 28, 1919. It was incorporated, specifically, as a multifaceted organisation with a goal to advance the science, technology and application of welding and related joining disciplines. The AWS had its origins in the Welding Committee of the Emerging Fleet Corporation, set up in 1917 by Woodrow Wilson and chaired by a Harvard professor, Comfort A. Adams. The AWS published its first technical publication in 1919 and this provided the groundwork for the first issue of a journal by AWS which appeared in 1922. The society then expanded rapidly and in that year had established chapters in eight American cities.

Other countries around the world also responded to change in a similar fashion. In the UK the Institution of Welding Engineers was formed in 1923. In Australia, the Victorian Institute for Welding Engineers was formed on 29 July 1925. The E.O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine was founded in Kiev in 1934.

In the 1940s in Japan, the official, academic, and industrial sectors began to think that they should work together to reconstruct Japan's industry from the devastation of World War II. The Japan Welding Engineering Society (JWES), was formed on August 30, 1948 to deal with the academic aspects of welding while the Japan Welding Society (JWS) was formed on March 7, 1949 to address issues related to industry.

2.3.2 International cooperation

The IIW was founded in 1948 by the welding institutes or societies of 13 countries, which felt the need to create it to make more rapid scientific and technical progress possible on a global basis.

Currently welding associations in 56 countries make up the members and more and more are indicating interest. There are now 14 members in Western Europe, 15 in Eastern Europe, 5 in the Americas and 22 in Africa/Asia/Oceania.

From the beginning, the IIW set up international groups of specialists to study collectively the scientific phenomena associated with welding and allied processes, their more efficient industrial application and the means of communicating information about them. It has therefore become the global body in the science and application of joining technology, providing networking and knowledge exchange as part of its mission. Its mission is to "Act as the worldwide network for knowledge exchange of joining technologies to improve the global quality of life".

Some key IIW objectives, amongst others, are:

- Identify, create, develop and transfer world's best practices.
- Identify, develop and implement the IIW Education, Training, Qualification and Certification (ETQ&C) Programmes on a global basis.
- Promote IIW, its Member Societies and services in various regions of the world to the mutual benefit of all.
- Implement the IIW's outcomes.
- Provide quality services to IIW members and other organisations.

To achieve these objectives in practice, experts from around the world are voluntarily working in 16 Commissions, 5 Select Committees, 2 Study Groups and a host of Working Groups or other units on a permanent basis to stimulate and co-ordinate research and technology diffusion, and to diffuse information on welding technology, its application in terms of materials, processes, design and inspection and other associated subjects such as health and safety, education, training, qualification and certification, terminology and documentation.

Each year about 400 papers emanate from the IIW working units of which about 60 are published in the IIW journal "Welding in the World ". In addition, a total of some 100 books dealing with recommended practices or the results of international enquiries have been published mainly in two or more languages.
IIW has compiled a number of works of reference such as the Multilingual Collection of Terms for Welding and Allied Processes (9 volumes mostly containing 16 or more languages), the International Welding Thesaurus developed over 40 years in conjunction with the TWI bibliographic database Weldasearch, the Index of Welding Standards and a collection of radiographs illustrating weld defects. More recently the IIW Database, referencing all IIW technical documents since 1950, has been made available online through the IIW website.

IIW's virtual library constitutes one of the world's largest online sources of welding information available today. IIW Members can consult and share technical documents, white papers, publications and articles through a database of around 18,000 documents, of which more than 6,800 may be downloaded from the IIW web site www.iiwelding.org. Bibliographic reference to documents can be searched by all visitors to the website, and hard copies acquired through the IIW Secretariat.

2.3.3 Regional benefits

During the 1980s, discussions took place within IIW on how the benefits of IIW could be promulgated to countries in the different regions of the world through the activities of Member Societies, or the IIW as an entity. The facilitation of the establishment of Welding Societies in developing nations, and the linking into the global IIW network, was seen as an important step, enabling emerging economies to lever their development from existing technologies appropriate to their needs, standards, training programmes and experience.

It was felt that the three key areas by which IIW could assist regions, developing countries and economies in transition to improve the quality of life of all people were through implementing:

- Appropriate welding technology.
- Education, training, qualification and certification.
- Occupational Health and Safety (OH&S).

To start implementing this strategy, it was agreed to hold Regional (now called International) Congresses with the following specific objectives:

- To expose delegates from industry in the host countries in the region, to the work of IIW.
- To identify the needs of the surrounding countries in the region and produce IIW supported programmes to help meet those needs particularly through the efforts of the host country.
- To have aid organisations such as the United Nations Industrial Development Organization (UNIDO), International Atomic Energy Agency (IAEA) and the European Union (EU) formally involved in the Congress and subsequent programmes.
- To have authors from the less developed, surrounding countries presenting papers.
- To form regional commissions of the IIW using representatives of the regional countries that could then provide input to the main IIW commissions.

A major success of these Congresses has been to assist technology development and diffusion in regions sometimes far removed from the locations of the majority of Annual Assemblies and to encourage IIW membership in developing countries in these regions.

An important approach since 1993 has been to have a more systematic approach to regional activities with the compilation of a strategic business plan for the Working Group with the Goal "To promote IIW and its member societies to the countries in the various regions of the world to the mutual benefit of all", and four key objectives:

- To promote the holding of IIW supported events throughout the Regions of the World.
- To introduce the IIW WeldCare Programme for take-up by Developing Countries and Economies in Transition.
- To continually promote and market IIW in different Regions of the World.
- To harmonise IIW's efforts with other organisations' efforts in each Region.

Over 20 detailed strategies support this Goal and Objectives.

3 Significance of welding and joining

3. Significance of welding and joining

Welding is one of the most commonly used technologies for the assembly of metallic materials, where it ensures a metallurgical bond between two elements/parts of a given component. Numerous welding technologies are utilised in fabrication, repair and maintenance in a wide range of industrial applications, from steam generator to aircraft to high precision equipment, in almost every industrial sector.

3.1 Major industrial sectors utilising welding and joining

Today, welding is used by preference in the industrial sectors which manufacture products made of weldable materials. These are metallic materials, above all steels, aluminium, magnesium, titanium and nickel as well as their alloys and thermoplastics. Composite materials and material compounds are increasingly playing a major role. In this respect, welding frequently plays an essential role in product design and constitutes an essential step in the value added at the manufacturing companies. In the particularly welding-intensive sectors, the following average value added by welding may be assumed as the proportion of the total value added:

Mechanical and apparatus engineering, including

Construction of metal and plastic pipelines:	approx. 3 %
Metal construction:	approx. 5 %
Vehicle construction (motor and rail vehicles):	approx. 7 %
Shipbuilding:	approx. 8 %
Aerospace construction: (incl. allied joining technologies):	approx. 8 %

Although the main coverage is metals and their alloys, industry specific coverage does include challenges in non-metallic materials joining and future directions e.g. electronics, medical devices, aerospace, polymers, plastics and nano-joining of dissimilar materials.

The welding processes being applied and the respective degrees of mechanisation are very variable. They are extremely dependent on the material to be processed and on the wage level in the region concerned. For example, manual electrode welding and partially mechanised gas shielded arc welding are very widespread in regions with low wage costs, while fully mechanised gas-shielded arc welding with robots or welding gantries, submerged-arc welding and beam welding with a laser or electron beam tend to be the exception in these regions. This is due to high equipment investment costs for mass production and the lower availability of suitable specialist personnel. It must also be borne in mind, however, that even in regions with low wage costs, the degree of automation of the joining processes being utilised increases when more stringent requirements are placed on reproducibility and precision, e.g. with regard to the positioning of attached parts.

Other sectors which use welding are the white goods appliances industry and metal furniture as well as the electrical and electronics industries. Furthermore, allied joining processes are frequently applied in these sectors. Soldering is very widespread in the electrical and electronics industries. Another important sector in which welding technology is applied is the packaging industry. The welding process is used for producing cans made of metal (aluminium and coated steel - tinplate) and plastic packaging made of thermoplastic films. Fully automatic welding installations working according to the principle of resistance roller seam welding, laser welding or heated tool welding are utilised as a rule.

In addition to welding, soldering, brazing, high-temperature brazing, adhesive bonding and thermal coating and mechanical joining processes with riveting and clinching systems, bolting and flanging are used as further joining processes.

3.2 Social aspects and improvement of quality of life

Welding was developed for industrial and handicraft utilisation at the end of the 19th century, initially as oxyacetylene fusion welding and then as arc welding at the beginning of the 20th century. At first, the work was carried out exclusively as a manual process.

In order to produce defect-free, high-quality welded joints however, the welder must receive practical and theoretical training related to the process and must be familiarised with regard to the product. Specially set up training facilities in companies and at training providers with workshops and qualified trainers are available for this purpose.

Building upon experience from member organisations, IIW has developed an internationally harmonised education, training, qualification and certification programme for welding technology personnel, which is implemented by its member organisations in compliance with uniform standards. Not only welders but also operators of welding installations, welding instructors/trainers, welding coordinators/supervisors/foremen, welding inspectors, technicians, technologists and engineers are qualified according to this programme.

Manual welding was, and even today, is still seen to be connected with adverse effects on the welders due to heat, fumes and dust as well as radiation. This has led to the opinion that *welding is dirty, dusty and dangerous*.

Today, welders are protected from these issues with special protective clothing and equipment. For example, safety goggles and/or safety helmets with corresponding protective glasses and screens protect welders and co-workers from arc radiation and breathing protection and extraction installations protect from fume and dust. Regulations for health protection and safety at work of welders are issued in the respective countries and must be complied with by employers.

Increasing mechanisation of welding work reduces the deployment of welders and permits improvement in protection from radiation as well as the extraction of fumes and dust in the area close to the welding in order to minimise adverse effects on all workers in the surroundings. Today, personal protection is mainly utilised for welders working in the fabrication of extra small-scale series or single parts as much large scale production is mechanised.

In the last one hundred years, welding technology has not only become cleaner, due to the refinement of the materials and improvement in process technologies and facilities for welding, it has also resulted in better joining quality and reliability. Refinements of non-destructive test procedures and improvement in the monitoring of welded products have supported this development.

Therefore, it can be said today that welding is characterised by the three Cs: *Cool, Clean and Clever* - as it is being called increasingly in the American linguistic usage.

3.3 Welding and joining in sustainable growth and environment

The development of materials (metals and non-metals) is making enormous progress, with material properties being optimised in areas such as higher strength, higher toughness, longer temperature resistance, good corrosion resistance as well as the ability for economically viable recycling and harmless final disposal.

For the product under consideration, the designer has the possibility of selecting the material that is optimally appropriate for the stresses in each case depending on its specific weight. If suitable joining processes are available, the designer can combine these materials in such a way that the material, which is optimally appropriate for the stresses in each case, is used at every location on the product. This results in the so-called "*multi-material design*" but has its limits, on the one hand, in the technical feasibility and, on the other hand, in the economic viability.

Such a combination of different and dissimilar materials is only possible, however, with suitable and reliable joining technologies. New ones are supplementing the established technologies and processes. In particular, ever more significance has been attached to the so-called hybrid processes in recent years. These are the combination of joining processes, e.g. adhesive bonding with resistance welding or mechanical joining in automobile construction or the combination of gas-shielded arc welding with laser welding in shipbuilding and other sectors.

Friction stir welding which, in current practice, is only economically viable to use on components made of aluminium or its alloys, non-vacuum electron beam welding which may possibly compete with laser welding in individual applications and refinements in laser technology (e.g. fibre lasers) for welding are examples of new processes. The increased sensitivity of the materials to heat input by the welding must, however, also be taken into account. As a result of modern possibilities in electronics, energy input into the component via the arc or the material supply can be controlled in such a way that, even in the low-power short-circuiting arc, the metal is transferred from the electrode to the material in a spatter-free and nevertheless reliable process.

Today, some very different materials can also be joined with each other in a material-locking form, e.g. aluminium with steel by means of arc brazing or laser riveting, steel with nickel-base alloys by means of pulsed-arc welding or copper with aluminium. There is not yet any optimum joining technology, however, for many other material combinations conceivable today. Lap joints, for example, which are necessary for riveting, bolting or adhesive bonding, do not lead to the optimum force flow and need additional material in the joint, which often conflicts with the desired weight reduction. On the other hand, these joints have an additional safety potential due to the crack arresting capacity in the joint.

3.4 Value and benefits of welding

Welding and joining are not only important economic factors during manufacturing of technical products. Often the only possible way to manufacture large parts is by applying welding or allied processes as these parts cannot be manufactured in one piece, or various materials must be used in one part in order to guarantee the service capability of the product.

Other areas of economic interest are the manufacturers of products utilised during welding and joining (such as equipment, machines and filler materials), and for the necessary weld tests, and also the service providers which qualify the required personnel. Figure 3.1 shows the macroeconomic effect in the form of the value added in the European market[1] for these goods and services. The global market can be assessed

[1] *Belgium, Bulgaria, Denmark, Germany, Estonia, Finland, France, Greece, United Kingdom incl. Northern Ireland, Ireland, Italy, Croatia, Latvia, Lithuania, Luxemburg, Netherlands, Norway, Austria, Poland, Portugal, Romania, Sweden, Switzerland, Slovakia, Spain, Czech Republic, Hungary.*

as four times as large as the European market. Therefore, the world market for products relating to the application of joining technologies may be estimated to have been approximately 80 billion EURO in 2007.

The economic significance of the application of welding and joining technology by the manufacturers of joined products is substantially greater. It is difficult to estimate this for a national economy because corresponding statistical data is only rarely available. Similarly, with the cost due to weld failures, poor in-service performance, repair and maintenance.

One feasible path is to use the value added during the manufacture of the products and the proportion of welding and joining technology in the production. The data required for this purpose is acquired (amongst other means) from the number of employees collaborating in the manufacture, broken down according to the utilised or applied technologies. As an example of this, reference may be made to a calculation for the German national economy, which was based on a scientifically validated macroeconomic model (*see Figure 3.2)*. The corresponding values for welding only are: 56 Billion EURO for the gross value added for both the manufacture of goods and services for welding and the application of welding technology, and 1,320,000 employees in both sectors. Since very different structures exist all over the world and statistical data is not available or has not yet been coordinated, it is not possible to make any conclusions for the world based on these values from the European economy.

	Equipment		Filler Materials Auxiliary Materials Health and Safety Qualification	TOTAL
Production Value (BIL. EURO)	7.50	⟷	12.480	**19.980**
Total Added Value (BIL. EURO)	2.55	⟷	4.040	**6.590**
Employees (Man Years)	55,000	⟷	68,000	**123,000**

Figure 3.1 *Value added in 2007 in Europe by goods for joining for companies manufacturing joined products (Reproduced courtesy: DVS, D. von Hofe)*

- The production of joined goods and services for joining (equipment, filler materials, auxiliary materials, health and safety as well as training and education) influence the whole line of added value and the European political economy.

→ Total added value: 6.6 BIL. EURO
→ Employees: 123,000 persons

86 BIL. EURO

- The use of joining technologies is instrumental in generating added value in a lot of branches.

→ Total added value: 79.12 BIL. EURO

2,027,000 employees

→ Employees: 1,904,000 persons

- The overall total added value of 86 BIL. € of joining (manufacturing of goods for joining and application) corresponds to about 6% of total added value of all producing trades (including civil building) in Europe.

Figure 3.2 *Value added by joining in 2007 in Europe (Reproduced courtesy: DVS, D. von Hofe)*

An example of the value of welding to a small economy is shown by this example from New Zealand (NZ) (population 4.4 million) undertaken by an industry-based research organisation the NZ Heavy Engineering Research Association (HERA).

The study has produced some interesting results, such as:

- An estimated 6,500 people's work involves welding, and a further 800 people are involved as welding supervisors, engineers, or inspectors.
- The value added of welding and joining technology in 2007 was estimated as NZ$813 million.
- In 2008, around 4,000 tonnes of welding consumables (imported and locally manufactured for the local market) with an estimated total value of NZ$15 million was available on the NZ market.

3.5 Failures of welded structures

Structural performance of the welded components strongly depends on the local joint quality. The welded structures are often fabricated to satisfy conflicting requirements (low cost and weight, long life and performance, limits of the technology) of material/design/technology. Additionally, welded or joined components inherently contain micro- and macro heterogeneities and stresses at the joint areas, which may contribute to the failures of the components. Prevention of failures and ensuring long and safe life of welded structures (such as offshore platforms, pipelines, steel constructions, bridges etc.) also depends on the effectiveness of the corrosion protection. Fatigue is a serious problem (*see Figure 3.3*) for welded structures subjected to repeated or fluctuating loading in service. Advanced design and flaw assessment guidelines are now available, however, to prevent failure of a component and ensure structural safety. Regarding the corrosion resistance of welded structures, the current guidelines and standards are predominantly related to base materials. This provides future challenges and tasks to adopt the respective practices to welded components. Furthermore, there is a need to describe the effects of the various weld microstructures and residual stresses on the resistance of components against corrosion damage and cracking.

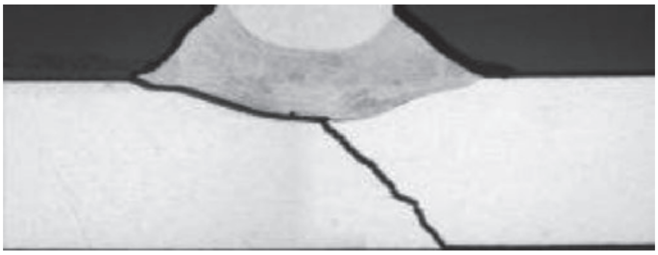


Figure 3.3 *Fatigue crack propagation in laser welded aerospace Al-alloy (Reproduced courtesy: GKSS, M. Kocak)*

Failures of the welded components are usually due to the deterioration of the material/weld properties (development of a crack or local damage under fatigue, creep, corrosion or their combinations etc.) and/or an increase in loading and/or localised external damage and/or change in function of the component. A satisfactory life-cycle of the welded structures requires a correct assessment of the stress levels and cycles as well as correct determination of the weld joint local properties. When weld joint failures are experienced in service (due to fatigue), it is often in cases where the acting stress levels (and overloads) are not known or have increased during the service life by far more than was foreseen at the design and fabrication stages.

Strength mismatch (*see Figure 3.4*) between weld deposit and base metal as well as weld width (2H) play significant roles on crack tip deformation and failure behaviour of welds with respect to residual strength. This feature has now been taken into account in new codes and standards dealing with structural integrity assessment of welded structures.

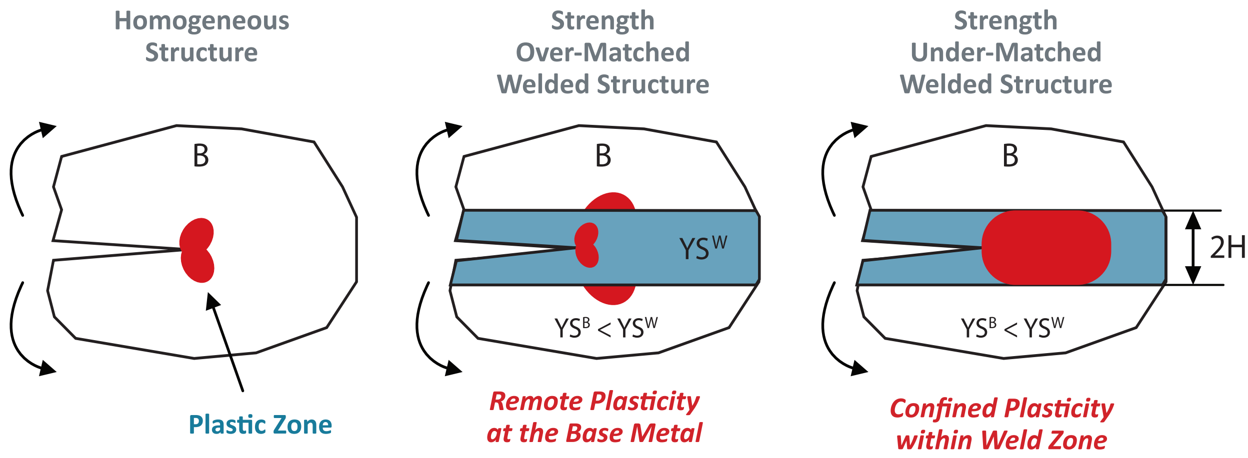


Figure 3.4 *Schematic showing the significance of yield strength mismatch on deformation and fracture behaviour under static loading (Reproduced courtesy of: GKSS, M. Kocak)*

In general, cause and development stages of any damage or failure process of welded structures are complex. Various factors may interact at different stages of any damage occurrence. Use of advanced modelling tools and fitness-for-service procedures at the design stages of complex welded structures could ensure structural integrity and safe operation while contributing to the economic fabrication and inspection scheme.

Development of Structural Health Monitoring (SHM) systems for welded structures is still a challenge for the designers and plant operators. Furthermore, use of wireless, remote sensors with sufficient reliability to monitor large and complex structures to prevent development of a critical situation at any part of the structure require further research. This offers new opportunities and challenges for structural and other engineering disciplines.

Needs and challenges in welding and joining technologies

4. Needs and challenges in welding and joining technologies

4.1 New materials, weldability and testing

Traditionally welding science and technology are associated with joining of metals and alloys as they form a substantial part of the material consumed by mankind. Steels, aluminium alloys, nickel-base super alloys and titanium alloys constitute the major share of these metals and alloys and development in welding science and testing have been in improving the weldability of these materials and for understanding the basic metallurgy of their welds. Similarly, processes employed to weld these materials have been confined predominantly to the arc welding processes and, as in automotive industries, to resistance welding. Today, however, many more new materials and design methods (e.g multi-material) are available and accordingly the science and technology of joining them have also undergone revolutionary changes.

The need to improve the quality of life, conserve the natural resources, protect the environment etc. has been the major driving force for innovations in the field of materials and their application. Some of these were driven by the desire to take the conventional structural materials like steels, Al alloys etc. up to the upper limits of their performance. Transformation Induced Plasticity (TRIP) steels used in automobile industries, advanced ferritic steels in fossil power plants, super austenitic and super duplex stainless steels for corrosion resistance applications, Al-Li alloys and maraging steels for aerospace applications are successful examples of these innovations. A paradigm shift in the way the materials are chosen for different application is another factor that triggered innovation in this field. The choice of ceramics, composites, fibre reinforced plastic etc. for structural applications, often for very extreme operating conditions, resulted in significant advances and developments in these new structural materials. These materials now find applications in gas turbines (structural ceramics), space vehicles (composites) windmills (composites and fibre reinforced plastics) etc. Development of new technologies, information, communication and bio-technology, triggered the development in a new generation of materials called advanced materials which are used more for their special physical properties like biocompatibility, magnetic, electrical and optical properties.

Weldability and performance of the welds in service have been important issues that have to be considered while developing new structural materials. Often, the welding processes employed for their traditional counterparts may not be suitable for these new alloys. A good example for this case is the new generation oxide dispersion strengthened (ODS) ferritic martensitic steels being developed for high temperature applications in nuclear (both fusion and fission) reactor and fossil power plants. In the case of conventional ferritic martensitic steels (Cr-Mo steels) weld metals produced by any of the fusion welding processes possess the desired properties. In contrast, one has to necessarily use solid state welding processes to join the ODS alloys to ensure that fused weld metal is avoided so that weld joints retain the properties of the base metal, inherently achieved through dispersion of Y_2O_3 based nano particles in the steel. Similarly in materials like TRIP steels and maraging steels, improved properties are attained by controlled thermo-mechanical processes which produce the desired microstructure in the base metal. Such a microstructure is destroyed in the weld metal and the heat affected zone (HAZ) during welding and this has necessitated use

of welding processes like electron beam (EB) welding and laser beam welding (LBW) which produce narrow weld metal and HAZ for joining these processes. Similarly, in the case of heat treatable Al alloys, use of the friction stir welding process can improve the properties of weld joints. Thus, one can observe a shift from conventional fusion welding processes to advanced and solid state processes in the case of these alloys developed by alloy and microstructural modification of the conventional structural materials.
The testing and evaluation of weld joints of these materials would include structural integrity assessment and ageing management as these aspects are directly linked with safety of the plants or components using these alloys and conservation of the natural resources (by extending the life of the existing plants and components).

Use of new structural materials like ceramics, composites and fibre-reinforced plastics necessitates joining them to themselves as well as to metals. None of the conventional welding processes are suitable for this purpose and one has to depend on processes like active brazing, adhesive joining, transient liquid phase (TLP) bonding etc. Weldability issues involved in these joints are considerably different from those present in welding of metals and alloys. Similarly, tests, characterisation and evaluation conducted on these joints for understanding the performance also differ considerably from those employed for conventional weld joints. The emphasis here is on the nature of the bond interface and strength of the joint, effect of thermal cycling, etc. unlike susceptibility to cracking in the case of welding of metals and alloys.

Joining of advanced materials like bio-materials, electronic or magnetic or optical materials etc., throws up challenges that are not familiar to a conventional welding engineer or a materials scientist. Emphasis in this case shifts to preserving special physical properties like bio-compatibility, conductivity, magnetism etc. by employing micro-joining techniques, soldering and brazing. The processes and alloys chosen for soldering of semiconductor materials like Si differ considerably from those used in conventional soldering. Procedures like metallisation with layers of active elements like Cr or Ti and noble metal gold, and subsequent soldering using In-Bi alloys have been developed for joining Si wafers. In the case of bio-materials, encapsulation of medication implants is an area where joining is a critical issue. Often, metals like Ti have to be joined to organic compounds like polyamide to produce a hermetically sealed joint. Low power laser beam joining techniques have been developed to produce bond width as low as 200 µm for these applications. Thus, one can see the science and technology of joining also has its share in the advances that take place in communication, electronics, information technology and biotechnology that have significantly improved the quality of life.

Use of new joining techniques for new materials and applications brings to the fore the need for testing, characterisation and inspection of these joints. Often components or weld joints made of these materials and processes are so small that miniature specimens and testing devices have to be used for the determination of local properties and testing. Furthermore, these joints need to be characterised for their physical properties in addition to mechanical and chemical properties. Conventional non-destructive evaluation tools, developed and optimised for large metallic structures would be grossly inadequate in evaluating these micro-joints made from new materials and joining techniques. Hence, often new probes, techniques and standards have to be developed for their inspection.

Furthermore, an increasing use of multi-material joints and life cycle extension techniques (including repair) of welded structures and components will represent key technologies for the future. This does not only require new interface design technologies where the assessment of the optimum weldability (joinability) and the evaluation of the service performance have to be linked much more closely, if both have to be assessed together. Careful evaluation of the interaction between selected materials, design and fabrication method, (*see Figure 4.1*), is one of the key factors towards a successful avoidance of failures of welded components in service. It is of particular interest to develop advanced test techniques to determine the local property gradient of such joints to understand the deformation behaviour and hence establish the design parameters better. Mechanical characterisation (including corrosion resistance) and flaw assessment of such hybrid joints are not a straightforward issue and still create challenges for the welding mechanics.

Welding thick walled steel components (such as pressure vessels) generates residual stresses that can be the cause of brittle fracture and stress corrosion cracking. Current codes for the fabrication of pressure vessels, boilers and piping specify that PWHT is required if the thickness of the components being welded exceeds a specified value. The use of fracture mechanics approaches can provide the decision whether or not PWHT is necessary to avoid the risk of failure by fracture or plastic collapse. The results of the fracture mechanics assessment (using FITNET FFS or BSI 7910 or R6 or API 579 procedures) can demonstrate that the assumed flaw(s) in the as-welded condition may be acceptable (i.e. are non-critical in terms of fracture or plastic collapse). This kind of approach can technically justify the avoidance of costly PWHT.

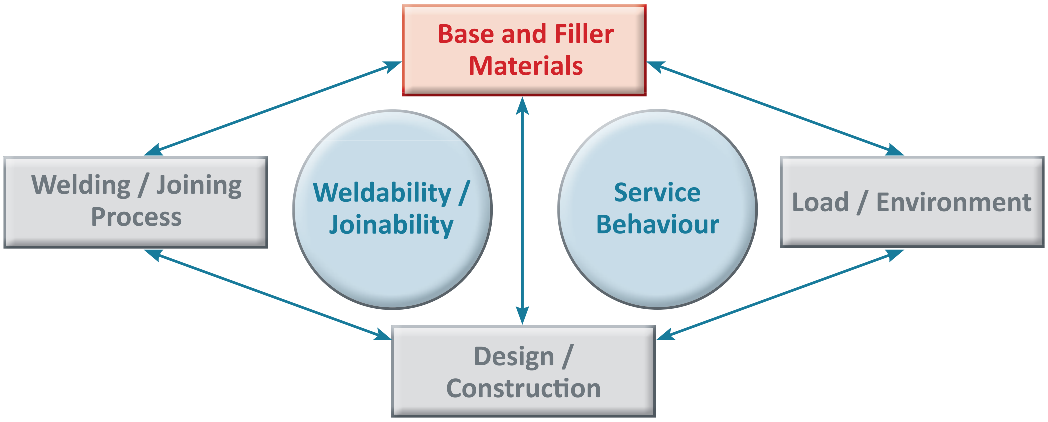


Figure 4.1 *Schematic showing the interrelationship between key factors of welded structures (Reproduced courtesy: M. Koçak)*

4.1.1 New materials and weldability

The term weldability (joinability) is treated in this chapter in accordance with the German Standard DIN 8528 and to the ISO Technical Report 581 as a component property influenced by the material, the joining process and the respective design/fabrication methods.

Steels

As in the past, and in future, the increase of the strength levels will be the most important goal in the development of all weldable steel types to achieve further economic benefits with respect to weight and cost reduction. The decrease in dimensions of the components and hence mass of material to be handled permits the use of smaller handling equipment (machine tools, cranes, heat treating furnaces, quenching equipment etc.). Additionally, a reduction in the amounts of welding consumables can be achieved with the use of higher strength steels in structures. Such well-known advantages, however, can only be exploited if the cracking resistance of the respective joints remains an acceptable level in the weld metal and in the HAZ. It can only be emphasised that existing guidelines, specifications and standards cannot easily be transferred to welds of novel high strength steels. The correct evaluation of the fracture toughness as well as the corrosion and hydrogen cracking resistance of the joints will thus represent a major challenge for welding of high strength steels in all industrial branches in future.

In shipbuilding and submarine fabrications, for instance, thin steel plates with strength levels of up to 700 MPa have recently been introduced to increase the topside carrying capacity. The respective welds should provide excellent fatigue resistance and high rate loadings and no strength reduction during flame straightening or post weld heat treatments. Hence, there is a need for high strength/high toughness/high fatigue life weldable steels with matching consumables for structural, maritime and naval applications. This scientific challenge needs to be tackled by material scientists, design and welding engineers together.

High strength structural steels with strength levels of up to 1,100 MPa are increasingly used for fabrication of mobile cranes and bridges. Here, matching the ultra high strength of the base materials can only be achieved by very fast cooling rates of the joints providing additional needs regarding tolerable toughness levels. As an application with respect to welded pipelines, such materials having a strength level of up 900 MPa are increasingly applied to hydro power plants. Since the high strength levels in such materials are usually associated with a ductility reduction, minimisation of the risk of weld failure by hydrogen assisted cold cracking will represent a major challenge in the near future. Furthermore, potential use of high strength steel grades (X80 and up to X120) for seam and girth welded pipeline applications create serious challenges with respect to the control and prediction of unstable ductile fracture.

Regarding stainless steels, four major driving forces can be identified in development: industry needs for improved performance, improvements in steel making technology, weldability aspects and last but not least costs. With greater attention being paid to achieving low long-term maintenance costs, increasing environmental awareness and greater concern with life cycle costs, the market for stainless steel continues to improve rapidly. The cost relative to alternative materials, however, will definitively continue to be an important factor in particular in order to find new markets in the rapidly developing regions.

It is difficult to identify one main line in stainless steel development and resulting challenges to weld these materials, since the group as such is so diversified. Quite a number of different stainless steel types, as for instance duplex stainless steels, have first been introduced into offshore technology before they were applied to other industrial branches. The materials used in offshore technology, in particular for subsea applications, generally provide the highest innovation grades, since increasing strength levels can only be utilised by a persistent corrosion resistance under the harsh and aggressive conditions to avoid any failure cases which are under no circumstances tolerable in the very sensitive environments. In recent years, martensitic, duplex and high-nitrogen austenitic stainless steels have been introduced into the offshore industry, mainly for flowlines as well as for downhole and top-site equipment.

The introduction and increased use of leaner less expensive grades, such as lean duplex and 11-13Cr ferritic-martensitic grades, will contribute to pressure on a reduction of prices and also to finding new applications where currently mild steel is used. On the other hand, there is also continuous development of new specialised highly alloyed grades intended for very corrosive environments and high temperatures. Nitrogen is definitely increasing in popularity, being probably the least expensive of all alloying elements, and is not unlikely to be introduced to a larger extent also in standard grades in an attempt to improve properties and decrease alloying costs.

The success of new grades is inevitably connected to weldability issues. With the continuous striving towards more efficient, higher productivity welding procedures and processes, some old topics remain important and some new ones arise. Hot cracking, in particular in fully austenitic materials needs to be studied further. Due to cases of failures in the past, hydrogen effects during welding and in-service remain an issue for martensitic, duplex and ferritic grades. Effects of high heat input on highly alloyed grades (precipitation of deleterious phases) and ferritic materials (HAZ grain growth) need to be well understood to define weldability limits. With newer processes such as laser and laser-arc-hybrid methods there are also less possibilities to modify weld metal composition through addition of filler metal making it more difficult to optimise, for example, phase balance and corrosion resistance.

The trend towards light-weight design is widely established in the automotive industry where steels with very high ultimate tensile strength are thus increasingly applied, (*see Figure 4.2)*. This is partly due to the new European regulation which established a fleet-average CO_2 emission target of 130 g/km to be reached by 2015. Modern car bodies contain approximately 50% weight of high strength steels (HSS), which impose new challenges regarding conventional resistance spot welding of such steel grades in similar and dissimilar joints.

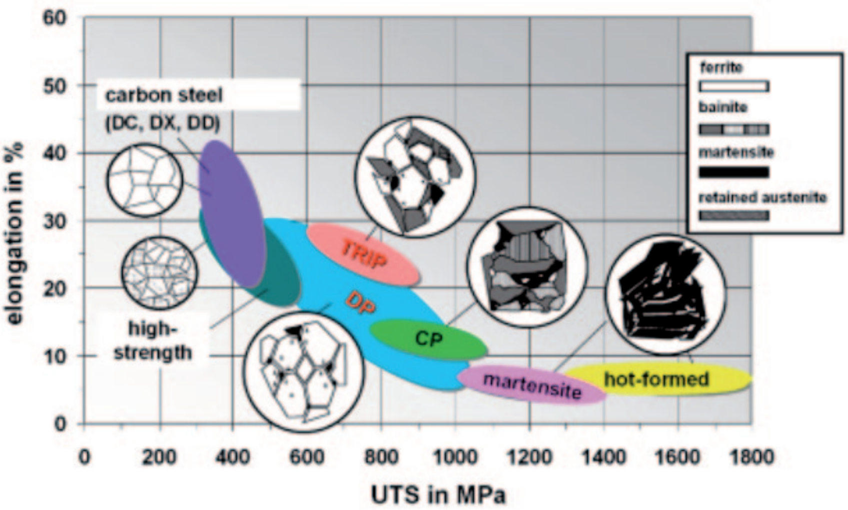


Figure 4.2 *New steel grades in the automotive industry (Reproduced courtesy: Arcelo Mittal)*

The high strength levels are reached by alloying systems and controlled phase-transformation. During the whole production process very accurate temperature control is needed to obtain these properties. Today, such high strength levels cannot be maintained within welding, especially not for the hot formed materials. Joint properties with only 30% strength during tensile testing compared to the base metal have to be considered when using standard welding technologies and procedures. Therefore a major challenge in the near future will be the adaptation of the construction and the new welding processes (*see Figure 4.3 for cross section of the laser spot welding)* to reach acceptable levels of strength, elongation and toughness of the components. Furthermore, the effects that occur when joining dissimilar steel grades have to be investigated. Additional problems appear because of the zinc or other anti-corrosion coatings such as AlSi or MgZn which lead to the formation of pores or intermetallic phases. Also the testing methods for welded components of the new steel grades have to be adapted.

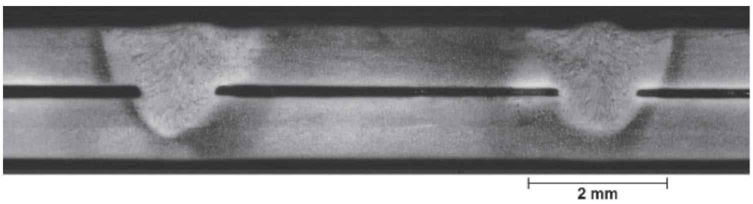


Figure 4.3 *Laser spot welded TRIP800 steel sheets of 1.0 mm thickness (Reproduced courtesy: GKSS, M. Kocak)*

Aluminium alloys

Weldability of components made of aluminium alloys is defined in terms of resistance to hot cracking and porosity. Resistance to hot cracking, which for aluminium includes both solidification cracking and liquation cracking, can vary significantly from one alloy to another. Solidification cracking occurs in the mushy zone trailing the molten weld pool when low melting eutectic films are pulled apart at grain boundaries. Liquation cracks form in the heat affected zone as grain boundaries become partially melted. Porosity comes from dissolved hydrogen, picked up from moisture contaminated shielding gas or oil deposits on the weld joint. Due to the little understanding about the formation of these defects at present, future research work has to concentrate on in-depth clarification of such failure phenomena.

Alloy extrusions containing magnesium and silicon (6xxx type) are among the most common form of wrought aluminium, and are widely used in welded constructions. These alloys can be welded, but only when using the correct filler alloy (e.g. Al-Si 4xxx or Al-Mg 5xxx alloys). When welded autogenously, these alloys are highly prone to solidification cracking. Work is ongoing to define how much filler is needed to avoid cracking, and under what conditions of restraint. These alloys are also highly susceptible to liquation cracking, producing very fine micro-cracks in the heat affected zone. As another research gap, the effect of these micro-cracks on mechanical behaviour is not well known and, because they are hard to detect without metallography, their presence often goes undetected.

Use of extruded aluminium alloys in modular space frame constructions has become commonplace in the automotive industry. Box frames can be constructed by piecing together extrusions joined at nodes, where they are typically gas-metal arc welded. Aluminium body panels are commonly attached using resistance spot welding. Future developments have to match the growing desire to replace this process with more effective methods, including friction stir spot welding and laser welding. Adhesives and adhesive-weld combinations are also becoming attractive alternatives. Joints made with these new processes require considerable development to characterise their performance, meanwhile aluminium designs face stiff competition from new pre-coated high strength-low alloy steels.

In the skin-to-stringer fabrication (*see Figure 4.4*) of an aircraft fuselage, the use of mechanical riveting has partially been replaced by laser beam welding. New weldable 2xxx (e.g. AA2139 and Al-Li 2198) and 6xxx (e.g. AA6013, AA6056, AA6156 etc.) alloys have been successfully welded using 12%Si containing filler wires (4047) by using CO2 and Nd:YAG lasers for airframe applications. Furthermore, the riveting process may also be partially replaced by the friction stir welding process even for the non-weldable Al-alloys since this process does not involve melting and hence there cannot be any solidification cracks. FSW may introduce new types of flaws which need to be taken into the consideration, however. Aerospace fuel tank construction typically involves arc welding, although FSW is also making inroads into this area. Because of safety concerns and the need for high quality welds, variable polarity arc welding is often employed, using either plasma or gas-tungsten arc processes. New high strength lithium-containing alloys have been used on the Space Shuttle for fuel tanks (e.g. alloy 2195), specifically developed for both strength and weldability.

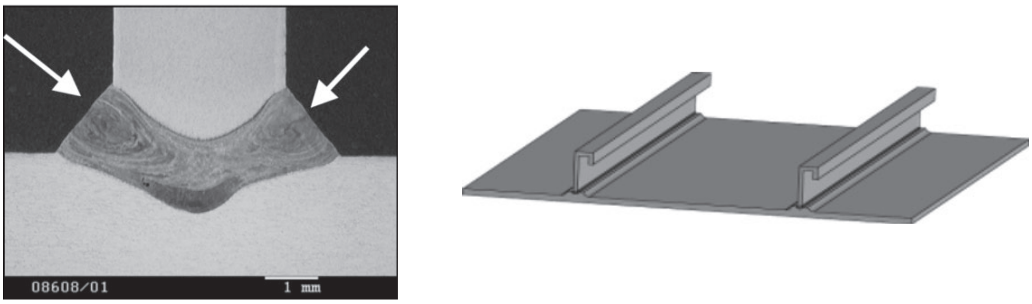


Figure 4.4 *Laser beam welding of skin-stringer joints for aircraft fuselage applications (Reproduced courtesy: GKSS, M. Koçak)*

Ti-alloys

Most titanium alloys can be welded achieving quite good quality of the joints, provided that special procedures are followed to avoid contamination with oxygen and hydrogen. Under normal conditions, problems with hot cracking are seldom encountered. With contamination, however, serious problems with cold cracking and porosity can be experienced. Both oxygen and hydrogen readily dissolve in titanium as interstitials at high temperature (above 500°C), reducing the ductility of HCP alpha-titanium. In addition, hydrogen can form titanium-hydrides that further embrittle the material. Future research is required to determine how much hydrogen can be tolerated in different alloy weldments (e.g. a, α/ß, and ß), before mechanical properties are compromised.

Up-to-date, titanium alloys have been used primarily in high performance fighter aircraft. They are now also being considered for structural material in new composite wrapped commercial aircraft (e.g A350). Titanium could replace aluminium, which is known to have a compatibility problem with graphite composites. Many new approaches to joining are likely to be employed, including riveting, arc and laser welding, and friction stir welding. Friction stir welding of titanium, however, posses a unique problem regarding tool wear, making it much less attractive than with aluminium. Due to its exceptional corrosion resistance, commercial grade titanium has been used as a replacement for stainless steel piping in heat exchangers for power plants. Similarly, beta alloys have been used as a drill pipe for sour oil wells due to their resistance to H_2S environments. Such pipe applications typically involve gas-tungsten arc welding. Titanium has also been given serious consideration for use as armour on military tanks. This would require multi-pass arc welding of thick sections using the gas-metal arc process. Such welding leads to large columnar grains in the weld metal, continuous from one pass to another, that significantly reduces toughness. These difficulties which are peculiar to titanium alloys have to be investigated more thoroughly in future. The extent to which Ti-alloys will be used in the future, in the applications discussed above, depends to a large part upon the availability of relatively inexpensive grades of titanium. One of the ways of reducing costs is to tolerate higher impurity levels, such as iron. It has to be investigated, however, how this might affect weldability or joint properties, including strength and corrosion resistance.

Mg-Alloys

Most magnesium alloys can be welded reasonably well, but present some unique problems with regard to bead control, spatter and oxidation. Due to a lower density, magnesium weld pools react differently to the arc, gravity and surface tensions acting on them, resulting in unconventional bead shapes. Due to magnesium's high vapour pressure and the small interval between melting and vaporising (600-1100°C), wire transfer during gas-metal arc welding can result in explosive expulsion of material (i.e. spatter). Also, like aluminium and titanium, magnesium has a high affinity for oxygen. For welds made with arc processes using electrode negative polarity, surface oxides must be removed prior to welding in order to avoid thick (crusty) oxides on the weld surface. Use of alternating current or variable polarity also helps in this regard. For gas-metal arc welds made with electrode positive polarity, a thin surface oxide surface layer on the joint may actually be beneficial for arc stability. Hot and cold cracking are not normally a problem, and porosity originating from hydrogen contamination is seldom encountered.

Mg-alloys have typically been used in selected automotive and aerospace applications, primarily in the form of die castings. With the recent development of rolled sheet, however, there exist many new possibilities for welded constructions, with the higher strength wrought alloys feeding the need for weight reduction. In addition, new power supply technology has allowed the gas-metal arc process to operate in the short circuit mode with reduced spatter. This process shows promise for the welding of thin section magnesium, as does the use of laser and friction stir welding processes. Laser beam welding of AZ31 sheets with and without wire additions provides excellent hardness, ductility, fatigue (including crack propagation) and fracture properties for the butt-joints.

Due to the difficulty in forming HCP magnesium, filler wire of good quality is only available from a few suppliers, and is typically limited to one or two sizes (e.g. 1.2 and 1.6 mm dia.) suitable for gas-metal arc welding. To solve this task for gas-tungsten arc or laser welding, finer wires have to be developed in the near future. In addition, there are typically only a few alloys available in wire form: e.g. AZ31 and AZ61. The question then becomes, what is the desired filler composition so as to optimise joint properties in terms of corrosion resistance? Weld metal is often the weak link in magnesium welds, suggesting that improvements are possible with filler alloy development. For use of welded components in automotive applications, fatigue and in particular corrosion fatigue of welds becomes an important design criterion. When dealing with a reactive metal like magnesium, corrosion must always be considered when evaluating lifetime behaviour. While limited data is available for magnesium weld fatigue, little or no information is available for weld

corrosion fatigue. Likewise, stress corrosion cracking may be a problem with some magnesium weldments, with hydrogen (formed in local galvanic cells) and residual stress driving the crack growth. This also opens a research field within the welding of magnesium alloys.

Dissimilar joints

Due to growing fuel costs, there is a strong desire to replace steel parts with light metals (Al, Ti, Mg, and composites) in all segments of the transportation industry. With each component evaluated separately, an alloy replacement is typically made based upon an optimisation of cost, availability, mechanical properties, and ease of fabrication. This has resulted in, particularly for automobiles, the need to join together many different alloy types in a multi-component structure. This presents a formidable technical challenge, because fused alloy mixtures (e.g. Al-Mg, Al-Fe, Mg-Fe) result in intermetallic phases that severely embrittle the joint. In some cases this need has been met using braze-welding techniques whereby a filler material, deposited using a conventional welding technique (e.g. gas-metal arc), is made to wet the joint face with only minimal fusion. FSW appears to work well for some dissimilar metal combinations. Likewise, mechanical fastener-adhesive combinations have been used. A further challenge is to avoid or minimise galvanic corrosion which further complicates this problem, necessitating the use of insulators or coatings.

Metal-matrix-composites (MMC)

Light-weight structures often require high strength and stiffness at minimum weight where MMC materials may provide such property combination. An example can be given from aluminium matrix composites consisting of the matrix AA6061 reinforced with 10 to 20 vol. % aluminium oxide particles. Successful fusion welding of such materials (containing particles, short or long fibres and whiskers of Al_2O_3 or SiC as reinforcement) is essential for development of various novel components. Responses of the MMC materials to the weld thermal cycle can significantly be different than the unreinforced alloys due to changed viscosity of the weld pool. It remains a challenge to weld MMC materials with or without filler wires to obtain optimum weld microstructure (avoidance of porosity and particle clusters etc.) and joint mechanical properties. It is important to improve current understanding of the materials response to various joining processes.

4.1.2 Consumables

Welding consumable developments have not kept pace with developments in steels and other alloy systems. Steels of 900 MPa yield strength and higher are commercially available, but they are without matching filler metals with sufficient ductility and fracture toughness. At the moment, most welding of such steels is with *undermatching* strength filler metal, requiring that this be taken into account in weldment design and flaw assessment. Likewise, high toughness high strength pipeline steels lack consumables of corresponding toughness and strength suitable for field welding. These high strength steels often must be welded in high humidity environments, where hydrogen introduction from the atmosphere, as well as from the consumable, into the weld is difficult to avoid, with consequent concerns about hydrogen induced cracking. This issue poses new opportunities and challenges for the consumable manufacturers. Introduction of flux-cored wire type of consumables opens new technological opportunities in various industrial applications (such as shipbuilding) due to their higher deposition rate and deeper penetration capacities.

The power generation needs of the industrialised countries and especially of the developing countries with growing populations, combined with the need to limit greenhouse gas emissions, require higher thermal efficiency in fossil fuel power plants, that in turn require higher operating temperatures, up to 750°C. Available filler metals do not match the creep performance of the advanced steels and nickel base alloys at such temperatures.

Needs for weight reduction in aircraft and automotive transport to achieve higher vehicle fuel efficiency are only partially being met by metal matrix composites and switching from steel to aluminium and magnesium alloys. Matching filler metals for metal matrix composites are lacking, as are suitable filler metals and welding systems for high production joining of steel to aluminium.

The IIW pioneered both the measurement of diffusible hydrogen in welds and the understanding of the phenomenon of hydrogen induced cracking. Indeed, the international standard for measurement of diffusible hydrogen, ISO 3690, is a direct product of the collaboration of experts within IIW Commission II. Likewise, ISO TR 17844 *Welding – Comparison of standardised methods for the avoidance of cold cracks* provides guidance on selection of pre-heat temperatures for various conditions of restraint and various levels of diffusible hydrogen. This Technical Report was developed by collaboration among the experts in IIW Commission IX. Taken together, these two documents contribute to the solutions of welding of high strength steels. These are only two examples of how the work of the IIW has contributed to the global quality of life over many years.

Ongoing and future work in IIW with welding consumables will continue to focus on hydrogen induced cracking issues in high strength steels. These include differentiating the contributions to diffusible hydrogen from moisture and other hydrogenous compounds in the consumable as-manufactured, from adsorbed moisture in the consumable due to exposure to humid air, and from incursion of the humid air into the arc independent of the consumable employed. As part of this work, modernisation of the ISO standards for diffusible hydrogen (ISO 3690) and electrode exposure (ISO 14372) can be expected to take place, along with updating of the guidance documents for avoiding cold cracking. Hydrogen limits and corresponding preheat requirements for crack free welding with very high strength steels remain to be defined.

Continued sharing of approaches to high strength steel consumable development can be expected. Traditional approaches to consumable design employing acicular ferrite microstructures have advanced the state-of-the-art consumables for low and intermediate strength steels to the point where they can largely match the properties of high quality steels in these strength ranges. Higher strength filler metals apparently cannot be achieved with acicular ferrite microstructure, forcing further development in the direction of low carbon bainite/martensite. Complex roles of traditional macro-alloying elements, along with the even more complex roles of non-traditional micro-alloying elements and tramp elements will continue to be explored.

Many modern high performance alloys, of either body-centred cubic crystal structure or face-centred cubic crystal structure, rely upon extensive controlled precipitation of carbides, carbo-nitrides, nitrides, borides and/or intermetallic compounds to achieve outstanding creep resistance. Optimisation of these precipitates in the base metal alloy can be achieved by controlled mechanical and heat treatment. Possibilities for controlled heat treatment of weld metal and the HAZ are more limited, and possibilities for their mechanical treatment are nearly non-existent. It therefore often becomes necessary to design welding consumables for achieving near-optimum precipitates in the as-welded condition, or after a limited PWHT, which is a much more daunting challenge.

Metal matrix composites, such as the aluminium alloys containing silicon carbide whisker crystals or aluminium oxide dispersions, continue to challenge the filler metal designer. Means of producing weld metal with an appropriate dispersion of strengthening particles remain to be discovered. All of the above concerns, and many more, related to welding consumables, can and are being addressed by the IIW.

4.1.3 Testing

Testing for the evaluation of the weldability in combination with respective joint design and the service behaviour of welded structures needs to be carried out separately. *Weldability tests* are generally targeted at the avoidance of joint defects during the fabrication phase of a component. Since cracks represent the

most critical flaw type during fabrication most of such tests are targeted to define welding and respective heat treatment procedures for crack avoidance. For this, numbers of test procedures have been developed to assess the hot and cold cracking behaviour of welds. Significant progress has been achieved by the IIW to compare the various procedures in Round Robins and to provide respective specifications, guidelines and standards. Hence, numbers of heat treatment procedures for cold crack free welding of structural steels have been specified and standardised. Design aspects have been taken less into account during establishment of the respective test procedures.

As a major design aspect, an evaluation of *shrinkage restraint* of welds is gaining attention among the IIW community now, because this parameter is significantly affecting the local and global stresses and strains in a joint. Through the pioneering IIW work, procedures developed in the seventies have provided quantitative evaluation of the shrinkage restraint. These procedures have been improved in recent years and with the advancements in numerical modelling, more insight has been gained on how the shrinkage restraint affects the stresses and strains as well as respective cracking of joints.

In recent years, significant improvements have been made in the testing procedures of the welds for determination of the tensile properties (local and global). The use of micro-scale specimens, for example, micro-flat tensile specimens (0.5 mm thick and 2.0 mm wide) have been developed to establish the very small weld volumes and HAZ gradients. The use of the micro-indentation technique has also been developed to test extremely small zones of weld joints.

Fracture toughness using Charpy-V or fracture mechanics (CTOD or J-integral) test methods have been well-established for structural weldments. There exists ongoing discussions on the consequence and essence of higher constraint specimens (deeply notched three point SENB specimen) versus weld (single edge notched tension, SENT) specimens tested under tension (lower constraint) particularly for design and qualification of the girth welds in pipes.

Testing under cyclic loading for S-N behaviour is well established to be used in fabrication and design stages as well as for design of welded structures. Furthermore, IIW has developed unique *Fatigue Design Guidelines including improvement techniques* over many years and nowadays used by industry for design of welded components. With respect to fatigue crack propagation (FCP) test procedures, the community still uses testing standards developed for base materials. Here, there exists need for further development of FCP testing procedures taking into account the special features of the welds including narrow EB and laser beam welds, dissimilar joints etc.

Fatigue testing, for instance, has been improved towards a more consistent evaluation of welds in comparison to barely testing of base materials. Also, corrosion testing of welds is meanwhile carried out in more realistic environments.

Significant progress has been made in testing of *component-like welded specimens* and/or *complex welded components* under different loading conditions (uni-axial or multi-axial) as well as under the environmental conditions (e.g corrosive or sub-zero temperatures). These tests (in limited number) are usually accompanied with numerical simulations to predict or verify predictions of service performance. Obviously these tests contain the effects of welding residual stresses, as exist under the testing conditions of interest. Nevertheless, suitable test procedures have to be developed to simulate more complex, but respectively realistic conditions to gain more insight into the service behaviour of welded components in combination with modelling efforts.

As further perspectives, sensorics and micro-electronics will increasingly be applied to both, materials related testing and, in particular, to the testing of welded/joined components. Also on-line monitoring and in-situ investigations (including structural health monitoring, SHM) during fabrication and service of welded structures will gain importance.

Finally, testing of welds will be extended to all periods of the life-cycle of the welded structures. In addition to the fabrication and service phase, they will also significantly contribute to life-cycle extension (repair) procedure of the critical components.

4.2 High energy density welding processes and material response

High energy density (HED) welding simply refers to Laser Beam Welding (LBW) and Electron Beam Welding (EBW) processes. The benefits offered by HED fusion welding are narrow, deep weld penetration, high welding speeds, low heat input (and hence low distortion and heat affect) and precision. EBW is somewhat mature and has various well-accepted applications including packaging (e.g. pressure sensors) and aerospace components. There have been attempts to broaden application to high production (e.g. automotive) manufacturing, but incompatibility of vacuum systems with the demands of large scale production have prevented these applications. In contrast, LBW has benefited from continual development of new laser sources with new capabilities and is somewhat more compatible with the demands of high production and large component manufacturing, so it enjoys a broader range of applications.

Nonetheless, challenges of high equipment cost, lack of system portability, laser safety, lack of robustness to manufacturing environments (particularly, the need for cleanliness of optical surfaces) continue to hamper LBW applications. Smaller, more efficient laser sources or central laser generators with fibre distribution system would help with LBW portability. Practical, robust cost-competitive out-of-vacuum capability would promote EBW applications. Eliminating root defects in partial penetration LBW would assist its application, and laser systems with multiprocess capability (i.e. cut, drill, weld, machine interchangeably on the same system) would be more economical. The general need for off-line process planning for virtual manufacturing are the same as for other joining processes, but the models and needs for HED processes are unique.

The continuously disappearing global resources in metals require and make it economically advantageous to join dissimilar materials according to function. Bi-metal segment saws need wear resistant teeth and a carrier for fastening. With continuous wear the teeth may be sharpened by grinding down to the holes of the rivets *(Figure 4.5)*. High speed steel costs today 10 times more than carbon steel. It is evident, that such a bi-metal design is cost effective and works as well as made from full HSS. The preferred process with minimum energy consumption for joining is electron beam welding.

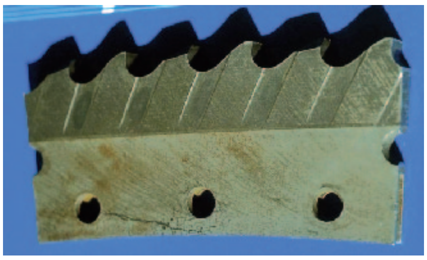


Figure 4.5 *Segment of a cold saw of high speed steel EB-welded to carbon steel in annealed condition. This saves 50% of the expensive high-speed steel (Reproduced courtesy: Probeam)*

A similar application with the same underlying concept is EB welding of worm gears consisting of bronze and steel. The expensive bronze is only used where its lubricating characteristics and wear resistance are required at the outer circumference. There are many such examples already taking place today and with rising material cost, in the future, these applications of joining dissimilar materials will increase.

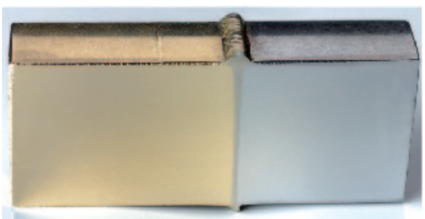


Figure 4.6 *Combination of steel and bronze, 30 mm deep electron beam weld (Reproduced courtesy: Probeam)*

Another area of improvement of efficiency is the increase of temperature of combustion in any kind of gas turbines. The related materials, for example Ti-alloys in aircraft engines, Cr-steels in steam turbines or super alloys in the helium driven turbine for the 2020 pebble bed reactor all require special welding processes. These have to be energy efficient and adaptable to the metallurgical needs of the related materials.

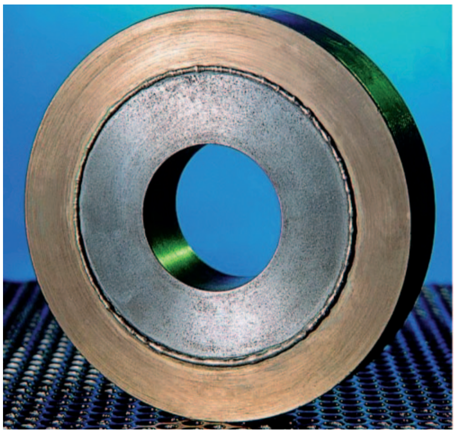


Figure 4.7 *Bronze-steel or bronze-cast iron combinations are an economic method to produce worm gears (Reproduced courtesy: Probeam)*

Welding of heavy gauge sections bears a tremendous potential of materials and energy saving. It should be expected that EB-welding will be the process of choice for such visionary applications, already under development now.

Figure 4.8 *Housing of a gas turbine being prepared for EB welding (Reproduced courtesy: Probeam)*

An education aspect of the EB welding process will be a serious challenge for coming decades. For successful and wider implementation of the EB welding (which involves high degree of application flexibility) there exists a need for more intense communication and transparency to the potential end-users.

4.3 Repair welds and material response

In order to extend service life of aging welded structures, there is need for advanced welding technologies for repair. Most of the repair welding procedures are principally different from welding during fabrication regarding the parameters, the weld sequences as well as the metallurgical conditions and the design features. This means that ideal welding conditions cannot always be achieved during repair welding. Additionally, poor material conditions of the component segments to be repaired might result from previous service operation. Here, advanced welding simulation technologies need to be developed to predict final microstructural conditions and the residual stress state of the repaired area to achieve optimum repair welding procedures and prevent further problems.

As another most important item, the prevailing stiffness (restraint intensity) in the repair area due to surrounding assembly groups and the associated strain constraint are usually much higher than during fabrication welding and have to be assessed before a repair welding procedure is carried out. For crack-resistant repair welding, knowledge of the stresses introduced by welding is of major importance, especially when the repair welding procedure has to be carried out at a high shrinkage restraint. Since the research efforts in welding have been concentrated on the respective materials and the development of new welding procedures, investigation of the design aspects of repair welding probably represents a major target for the near future. This involves correct and quantitative evaluation of shrinkage restraints for repair welds, including the effects of the various joint types and reinforcements. With this respect, it has to be anticipated that the intensity of restraint as a quantitative parameter to evaluate structural stiffness in the near and far field of a joint will gain increasing importance. Additionally, a precise knowledge of the thermo-mechanical effects of the repair welding procedure on the residual lifetime has to be elaborated.

It is also essential to determine the welding sequences with lowest possible likely stress-strain distribution during and after the repair of steel structures. This will allow it to enlarge the available load spectrum for later service. In this context, it has to be mentioned that interaction of concurrent repair welds has not been understood up to the present time.

The failure resistance of a repair weld is also dependent on the applied filler materials and their transformation behaviour depending on metallurgical, welding and heat treatment parameters. With respect to the repair of steel structures and components, high-strength filler materials with correspondingly lowered martensite transformation temperatures have to be developed further to achieve lower residual stresses in the repair welding at respectively higher strength, i.e. service load capacities.

It has also to be mentioned that a series of downstream methods are available for reducing welding-specific loads in repair joints or even for producing compressive residual stresses at the surface. Such technological procedures, like stress relieving, shot peening, peening, ultrasonic treatment etc., are generally very time-consuming and costly and should be developed further regarding better applicability to repair welding.

It can only be emphasised that repair welding requires decent component weld tests, rational residual stress evaluation and respective numerical calculations to achieve an actual increase in the life time of a component or structure and to avoid further failure origins in the repaired parts.

4.4 Advanced design and structural integrity rules

Recent advances in joining technologies together with new materials bring increased attention to the damage tolerance design, long service life and improved structural performance together with the developments in structural integrity assessment rules (e.g. BS 7910, API 579, R6, FITNET FFS) for the load-bearing structures. Recently, IIW Commission X has taken the task to develop IIW recommendations for the assessment of structural integrity of welded structures by taking into account recent developments in this field. IIW FFS Recommendations for Fracture Assessment of Weld Flaws (Doc. X-1637-08/Rev.3, Vol. I Procedure, Vol. II Annex) document is now in its 3rd revision and available as a working document.

For example, in the field of aircraft manufacturing of new welded integral airframe structures, specific “Local Engineering” considerations in design and fabrication have potential for further improvements in local laser weld joint properties. Established damage tolerance assessment rules for conventional (riveted) structures may need to be further developed for welded integral airframe structures. Fatigue and fracture assessments can be over-conservative with current methods and this in turn may act as a limiting factor for successful implementation of advanced joining technologies in airframe manufacturing. Therefore, R&D efforts for better understanding of failure mechanisms of joints, development and validation of testing, structural integrity rules and hence an overall roadmap for LBW and FSW welded integral airframe structures are needed.

4.5 Role and potential of modelling

Advances in the development of welding processes and techniques are only possible with a profound understanding of the mechanisms that underlie the particular processes. In this context, modelling and simulation are indispensable tools with continuously increasing relevance. Modelling and simulation help verify the theoretical perception of a process by checking experimental results qualitatively and quantitatively against corresponding numerical models. With growing computational power, the numerical approaches become increasingly complex and accurate. Currently, numerical simulation is used on a routine basis in many fields of welding research, such as modelling weld pool and arc phenomena, microstructure development during PWHT, simulating residual stresses and hot cracking susceptibility or predicting hydrogen embrittlement. Recent developments in modelling approaches and computer programmes have opened the way to new and improved welding procedures.

Recent approaches to modelling weld pool and arc phenomena as well as metallurgical processes during welding have advanced simultaneously with progress in computer power. The complexity has continuously increased and it is possible now to quantitatively describe the flow of liquid metal in the weld bead, the gas flow and energy input from the arc to the weld bead as well as the microstructural and metallurgical processes during solidification and in the heat affected zone with good accuracy. *Figure 4.9* shows two very successful examples of these modelling activities for the flow pattern of the liquid metal in the weld bead and the solid-state material flow in friction stir welding.

Considerable progress is evident in the fields of computational weld mechanics. The development of powerful computer codes based on Finite Elements or Finite Differences to solve the partial differential equations describing the thermal, mechanical and/or velocity fields in the welding process has opened the way to a quantitative prediction of component residual stresses. Recent developments also focus on the development of entire process models starting with the weld input parameters and finishing with a quantitative prediction of the weld bead shape and the mechanical properties of the final weld.

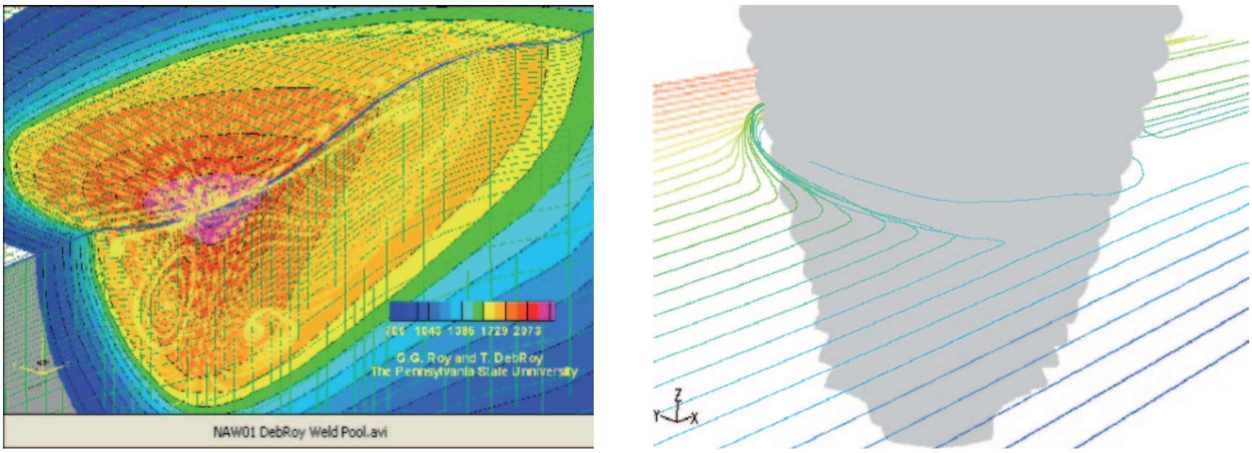


Figure 4.9 *Modelling weld pool dynamics in arc welding (left) and material flow in friction stir welding (right) (Reproduced courtesy: Institute for Materials Science, Graz University of Technology, T. DebRoy)*

In order to make the developments in the field available to practical users as well as the scientific community, a number of software codes have been made available in all fields related to welding. These include the prediction of the weld parameters and the weld properties as well as the simulation of the microstructure evolution in the HAZ. Examples are shown in *Figure 4.10*, where the left image shows a screenshot of the process software WELDSIM and the right image the software MatCalc for simulation of the precipitate evolution in the HAZ.

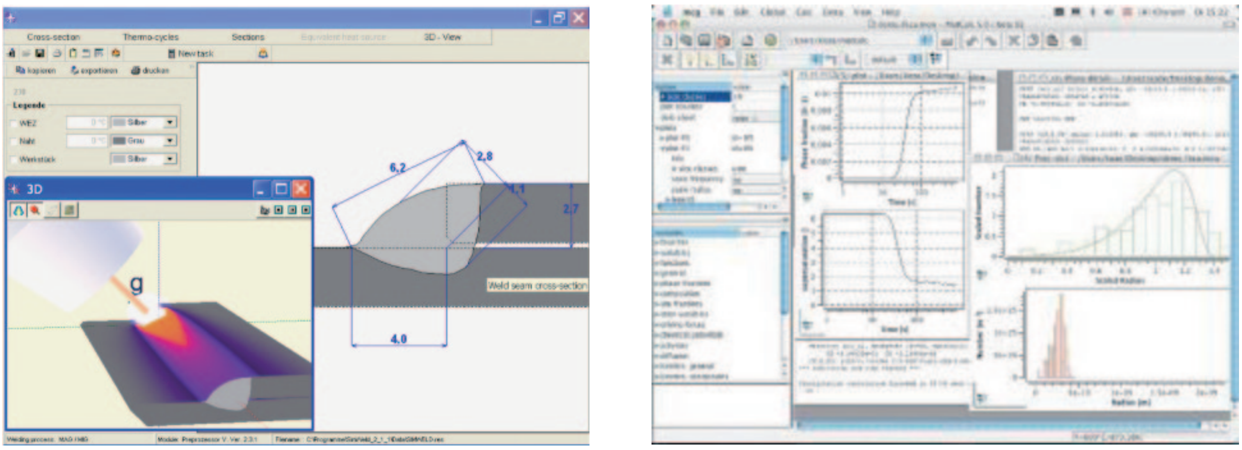


Figure 4.10 *Development of computer software: WELDSIM (left) and MatCalc (right) (Reproduced courtesy: N. Enzinger and E. Kozeschnik, Graz University of Technology)*

If modelling and simulation continues to grow at the present speed, significant progress in the prediction of welding processes and microstructure evolution is to be expected in the future. This will affect the understanding of the mechanisms of welding and will enable increasingly more accurate prediction of the weld and entire component properties. Computer codes will continue to represent major research and engineering tools in research and development of welding procedures and will also help in developing new concepts to open the way for joining materials and components which are not yet accessible by established techniques. The most important impact of modelling and simulation is given by the fact that the development times and costs for welding applications and procedures can be drastically reduced.

4.6 Strategies to meet scientific challenges

One of the major challenges of welding and joining technologies is to improve quality and productivity at the applied side of the community. On the other side, scientific challenges require research efforts (more of a fundamental nature) to generate innovation and better understanding of the complex issues of process, material, inspection and structural performance of welding and joining. The strategy to meet scientific challenges of 2020 should be described both in *fundamental* and *applied* research terms.

Basic research should provide the means to resolve key issues of welding science by transforming the welding and joining technology from “empirical-based” to “physical-based” process to cover the entire life-cycle of the welded product. This requires parallel knowledge building in the physical, chemical, materials sciences, mechanical and mechanics areas to tackle challenges of welding science.

A creation of a knowledge based “virtual factory” requires better understanding of the relationships between “3Ps”, *Process-Property-Performance* of welded products and modelling of these stages as an integral system. To achieve that goal, it is essential to ensure that welding process and welding mechanics specialists are included in product/project design teams and that welding, and joining as well as service performance

aspects of products fully integrate themselves with processes of fabrication excellence. ***Therefore, one of the major scientific challenges is to integrate welding & joining processes with the knowledge of welding mechanics into the design process to ensure high performance welded structures***.

Complex and ever increasing requirements of welded products include energy saving both in material use and fabrication while providing long and safe service life with almost no inspection and repair. This situation will require to use significantly more dissimilar materials (in combination with a multi-material design approach) to make innovative products. Breakthroughs in the technology for joining dissimilar materials could lead to new manufacturing strategies that could reduce costs, improve productivity, and open up new markets for welded structures and components.

The use of high energy density welding processes, such as laser beam with advanced materials and design considerations can tackle various future challenges. Scientific analysis of joint features, properties and predictions of performance will remain, however, as one of the long-term challenges.

Development of methods to expand capabilities of laser beam technology for surface modifications, create “barriers” against crack initiation and growth, property gradient (e.g. to improve fatigue performance via crack growth retardation) and for forming with better understanding of local metallurgical and mechanical evolutions with predictions of weld lifetime and performance.

Tailoring the local properties of the weld joints to meet the quality and performance requirements of the product should integrate design guidelines (including local engineering), materials science and mechanics based modelling and automated testing. Engineers should possess the ability to design a high performance product and its manufacturing process on the computer before production even begins.

Development of intelligent weldments containing embedded sensors combined with real-time defect sensing techniques and laser based seam-tracking systems will provide new opportunities and challenges which need to be tackled within fundamental research activities. Here, real-time defect sensing techniques with their new developments are expected to validate joining processing while determining the fitness-for-service. This requires strong team work and interaction of designer, fabricator and end-user.

Fitness-for-service analysis of welded structures is highly developed; however, they mostly use stress-based approaches. There is a need to develop “strain-based” fitness-for-service analysis procedures particularly for welded pipelines where welded pipe undergoes high plastic straining during the fabrication or service. A strategy for this challenge is to establish a task force of the IIW Working Units of X and XI to generate a Best Practice Document and/or guidelines for better assessment of weld fitness-for-service and life expectancy.

Basic research is needed to develop alloys (base metal and filler wire) for the laser beam welding process to enable high strength aluminum alloys to be welded with minimal material property degradation. This will have a major impact on the quality and performance of welds of aircraft structures while promoting welding as a key engineering process for metallic airframes. Joining of metal to carbon reinforced composite materials of the critical components of aerospace structures with durable and damage tolerant design should also be considered as one of the major challenges of the future. Furthermore, rethinking of the aerospace design and manufacturing processes to incorporate advanced welding processes will depend on the comprehensive scientific understanding of the welding processes and structural performance predictions of welded components.

A better understanding of post-weld heat treatment (PWHT) is needed in terms of property (microstructures, residual stresses etc.) evolution of the weld metal and HAZ of original and repair welds. For this, the development of a capability to simulate thermal, mechanical and metallurgical changes caused by PWHT and the integration of information with overall system models should be considered as a challenge.

Reduction and/or elimination of distortion and residual stresses (near-net welding) will also have a major impact on the quality and structural integrity performance of welds, leading to corresponding savings in production costs. Research should be focusing on the “on-line techniques” (such as mechanical tensioning) to introduce compressive residual stresses while reducing/eliminating distortion. Developing capability to predict distortion of complex weld geometry and understand the effect of residual stresses on fatigue, corrosion and fracture is essential for many applications.

In the longer term, basic research activities will be scientifically challenging to replace Cr and Ni in welding consumables while more alloy development for high performance welded structures will remain as high priority areas. In this context, new filler metals, more weldable alloys and advanced joining techniques must improve productivity while reducing emissions of toxic fumes and other pollutants to contribute to achieve improved environment and safer working conditions.

Finally,

- All of the scientific challenges identified above require attracting globally top-quality personnel, scientists and enhancing their core competency for innovations while developing solutions for the identified high-priority R&D needs and problems.
- IIW with its Working Units should further develop its knowledge management systems and continue to create forums to develop and conduct tasks, and support a high level of global scientific awareness.
- IIW with its global organisation should provide a forum to identify research needs and emerging scientific challenges to help with the establishment of a baseline of knowledge and set clear directions and recommendations for further research in member countries while providing quick dissemination of new findings.

5

Needs and challenges in welding and joining technologies

5. Needs and challenges in welding and joining technologies

The introduction of new or high-cost welding/joining technologies (such as laser beam welding, large scale robotic welding line etc.) into industrial production needs to be justified with economical consideration. New and advanced joining technologies are needed in some regions or nations, while others may need more fundamental developments to support existing technologies and still achieve higher quality and reduced production time. Hence, needs and challenges will be identified from these perspectives.

5.1 Innovations in welding and joining processes

There is fast development of different joining technologies, which is obvious in the automotive industry (*Figure 5.1*).

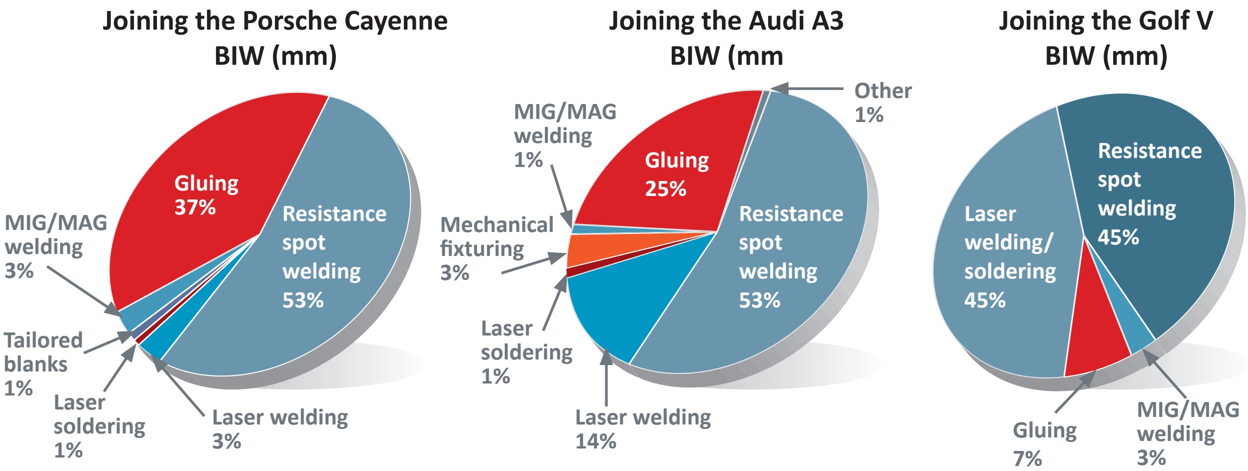


Figure 5.1 *Joining processes used in automobile industry (Reproduced courtesy: TWI Ltd)*

5.1.1 - Robotic welding

Most of the joining operations will of course be made close to the major markets but also moved to the low-labour-cost countries like China. Every country will, however, relentlessly defend its workload by introducing more efficient processes. Robotic welding will continue to increase the productivity and quality to the fabrication industry. In 2006 robot sales increased by 10.3 %. The problem has been that current technology has not allowed for an efficient manner of applying robotic welding to large-scale, low-volume fabrication. In an EU-project NOMAD this restriction has been eliminated by:

- Use of manufacturing simulation for automated process planning and real-time system monitoring
- Autonomous robot transport vehicle (RTV) navigation for high accuracy positioning of a robot arm in an industrial manufacturing environment.
- Design and build of an industrially rugged RTV with the accuracy and stability required for welding tasks.
- Use of specially developed welding consumables, welding procedures and sensor systems designed to allow "all positional" robotic welding with a degree of control and dexterity unmatched by current systems. *Figure 5.2* illustrates the developed system.

Figure 5.2 *Robot with all its equipment mounted on a RTV welding a large structure (Reproduced courtesy: TWI Ltd)*

The system can be equipped with several sensors:

- Torch collision unit, contact sensor for searching start and endpoints for the welds.
- Laser sensor system for joint tracking and through-the-arc system for joint tracking as well as a camera system for monitoring the complete station.

The application also includes a CAD-based system for simulation of the whole process and off-line programming. This solution with the welding system moving to and around the large work piece can become a new concept instead of manipulating the work piece to get the best welding position for the robot. Simulation software are becoming powerful tools. ABB is marketing a programme named VirtualArc® for simulation of the arc welding process. Robot Studio is another simulation package for movement of the robot offered by ABB. The two programmes can easily be justified due to the high savings that can be achieved.

5.1.2 Renaissance for EB welding

Thanks to the great interest in laser beam welding and the increased number of applications, the electron beam (EB) welding process has been rediscovered and considered to be complementary to laser welding. Earlier the EB was judged to have many advantages when considered alongside more conventional multi-pass arc welding processes for fabrication of heavy section structures and components.

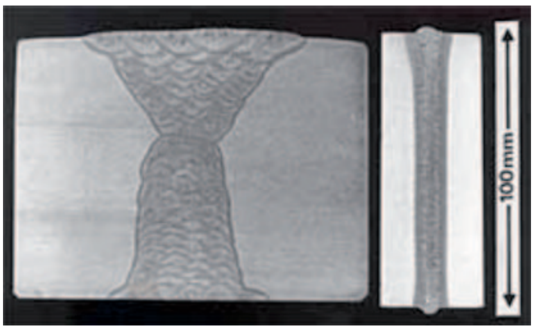


Figure 5.3 *Comparison of single pass EB weld profile with multi pass submerged arc welded joint in 100 mm thickness C-Mn steel (Reproduced courtesy: B. Pekkari)*

The productivity in EB welding has been increased drastically by introducing several chambers for loading and unloading of work pieces from a separate chamber that is evacuated before the work piece is transferred into the welding chamber (*Figure 5.4*).

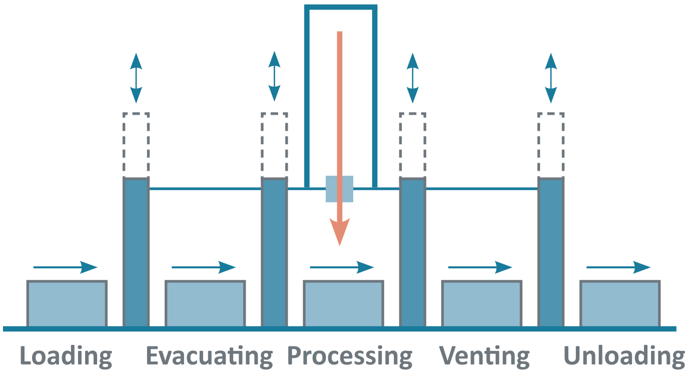


Figure 5.4 *EB welding system with loading and unloading chambers linked to the vacuum chamber for welding (Reproduced courtesy: B. Pekkari)*

Recently, out-of-vacuum and reduced pressure EB welding has been further developed. Not only heavy sections are EB-welded but thin sheet parts for the automotive industry e.g. an aluminium hollow section is welded with 12 m/min in Non-Vacuum EB-system. Such a system is highly recommended when high weld speeds and short cycle time are required from 1 up to 10 mm in thickness. There are test results showing that welding speeds for Al and steel with t=1 mm of 60 m/min and 45 m/min respectively are possible to achieve. EB welding applications will definitely increase thanks to the progress in technology. Currently there are about 3,000 EB-installations in the world. 800 of these are in USA, 1,300 in Asia, 700 in Europe plus 200 in the former Soviet Union and 22 units installed in Sweden.

5.1.3 Laser beam welding

The laser beam welding process has long been used in various industrial sectors, including automobile, ship-building and aerospace applications. These applications are driven by cost and weight efficiencies achieved in the welded structures. Both CO_2 and Nd:YAG welding processes are capable of producing structural welds with narrow weld and HAZ regions having high quality. Due to the rapid cooling, most structural C-Mn steels respond with weld zones of high hardness, while austenitic steels provide welds without any hardness increase.

Recent developments in high-power lasers and robotic control have accelerated the application of the LBW process for car-body fabrication and assembly, for example through so-called “remote welding”. LBW has the advantage of single-sided access, high welding speeds and precision while providing consistent weld integrity and a low heat input which yields reduced distortion. Unlike conventional resistance spot welding, laser spot welding (LSW) is a single-sided, non-contact process and as a result, LSW can be a very attractive joining method for automotive mass production. Various factors need to be considered, however, when replacing one joining method by another.

5.1.4 Laser hybrid welding

The number of laser welding and especially laser hybrid welding applications is growing fast. The laser welding process is already common in the automotive industry. The most impressive installation with 150 YAG lasers on 4 kW each and one 1 kW at Volkswagen are connected to 250 welding and three cutting heads. In this line production for the GOLF V, 70 meters are laser welded and brazed while there are only 7 meters of arc welds per car. With the further development and introduction of the laser hybrid process (*Figure 5.5*), the possible number of applications for construction will increase significantly.

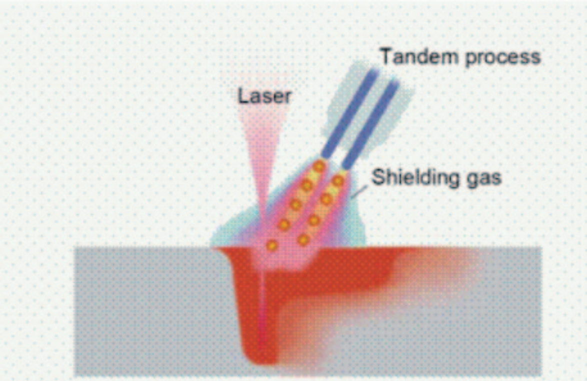


Figure 5.5 *Schematic showing the coupling of the laser beam with the tandem process (Reproduced courtesy: Fronius)*

Meyer Shipyard in Germany is the first in the world to have a panel line with 4 CO_2 lasers each of 12 kW, welding large ship panels with up to 20 stiffeners of 20 meters long. The Laser Hybrid MIG Process produces about 50% of the welding seams. Lately, very promising test results with fibre lasers (*Figure 5.6 and Figure 5.7*) by Precitec KG in Germany have been realised. Currently, the high initial investment is the main obstacle against a laser installation. Additionally there are several types of laser sources CO_2-, YAG-, Direct Diode-, Disc- and Fibre-lasers to choose from. Many experts judge the Fibre laser to have the highest potential. Independent of laser type the market growth will be a two-digit figure during the coming years.

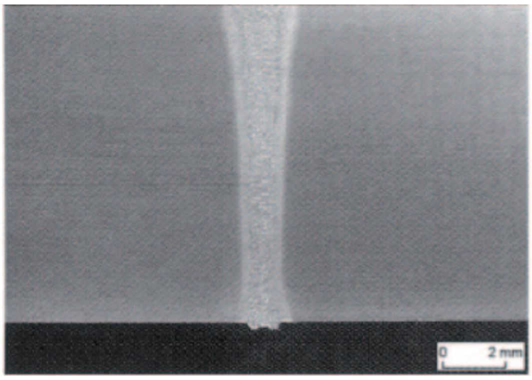
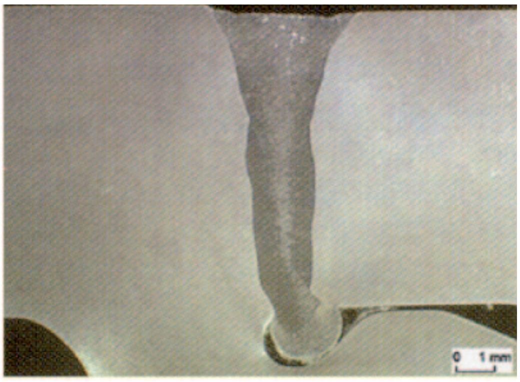


Figure 5.6 *Laser weld, single pass, butt joint pipeline steel X70, t = 12 mm, laser power 10.2 kW, Welding speed 2.2 m/min*



(Reproduced courtesy: B. Pekkari)

Figure 5.7 *Laser hybrid weld, single pass, Al 6008, t = 8 mm extruded profile, laser power 10.5 kW, Welding speed 8 m/min*

5.1.5 Friction Stir Welding (FSW)

FSW process, which was invented in 1991 at TWI, is attracting increasing interest and hence many research institutes are conducting research in FSW with over 60 FSW installations recently installed. About the same number are running in regular production. The Swedish Al-company SAPA has 7 FSW installations. The research area is illustrated in *Figure 5.8*. TWI has invested in the largest FSW machine "POWERSTIR" in the world, in "PRECISION SPINDLE FSW MACHINE" and "ABB-FSW-ROBOT" to develop the process further. So far results achieved are:

- Single sided linear welds up to 75 mm section in 6082 T6
- Pipe girth welding up to 32 mm in Al-7000
- Run-off tab technology
- Steel thickness of 6 mm, 10 meters welded with v=100 mm/min with one tool in USA
- Welded samples of Inconel 600 and Zircalloy 4

The potential applications are for example:

- Single sided linear welds up to 100 mm section and double sided linear welds up to 200 mm section
- Lower heat input/higher productivity double sided welding
- Adjustable pin technology and 3D welding with robots

It will definitely be worthwhile to follow the fast development of the FSW process. Some FSW steel welding has been accomplished with low welding speed and excellent mechanical results. The tool life, is for the time being, far too short to justify the introduction of the process into production It is a challenge to develop tools which can withstand the high temperature.

FSW Capabilities Chart

Material	Sample Thickness						
	Sub 1 mm	1-4 mm	4-8 mm	8-12 mm	Up to 25 mm	Up to 50 mm	Up to 75 mm
Al – Pure		D	D				
Al – 2xxx series		P	P	P	R	R	
Al – 5xxx series	R	P	P	P	P	R	R
Al – 6xxx series	R	P	P	P	P	R	R
Al – 7xxx series		P	P	P	R	R	
Al – Castings		R	R	R	R		
Mg – AM series		R	R	D			
Mg – AZ series		R	R	D			
Cu – Pure	D	D	R	R	D	R	
Cu - Brasses		D	D	D			
Ti – Pure		D	R	D			
Ti - α-β alloys		R	R	D			
Ni - Pure		R	R				
Steels – mild		D	D				
Steels – C-Mn		R	R	R	D		
Steels - Stainless		R	R	R			
Pb - Pure		D	D				
Zn - Pure	D	D					

Figure 5.8 *Applications of friction stir welding (Reproduced courtesy: TWI Ltd)*

Area of Current FSW Production Use

Area of Current FSW Research

Area where FSW has been Demonstrated

5.1.6 The Magnetic Pulse Technology (MPT)

This process can be used for welding, crimping, punching, forming and for calibration (*Figure 5.9*). The welding process attracted very high interest, when it was demonstrated at the Essen Show in 2001 but to many people's surprise the process has never taken off probably due to low marketing efforts and/or due to high investment cost. The process offers, however, many advantages such as; cold process, welding in less than 100 µs, no filler material, no shielding gases, it is a non-contact process and a "green" process.

Welding on conventionally unweldable materials such as Al-7075 MPT is first of all suitable for large batch production to justify the high cost for the electrical coil, which is surrounding the work piece. It is not necessary that the parts are circular. Square parts can also be welded with the purpose designed coil. MPT has such potential applications that it will sooner or later be introduced on a wider scale.

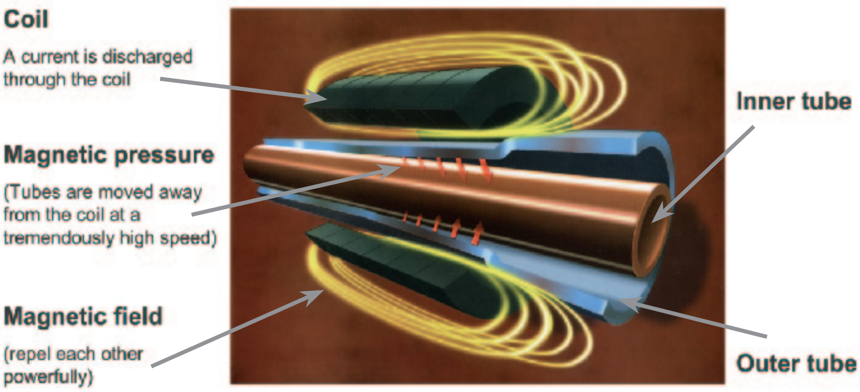


Figure 5.9 *Magnetic pulse technology (Reproduced courtesy: B. Pekkari)*

5.1.7 Structural adhesives

Structural adhesives are not a threat to arc welding but gluing is growing and mainly used in large scale in the automotive industry. One has to keep in mind that there are several types of gluing, such as; adhesive types, structural adhesive, hem-flange adhesive, weld-through sealant and anti-flutter adhesive. The important points for the process when used in cars are:

- improved fatigue properties,
- increased rigidness and,
- improved collision properties.

The previous version of the Volvo S80 had 5.5m of glued joints while the latest one has 26 meter and is 7 kg lighter. These figures can be compared with the length of welds in the BMW 7-series with 150 m, Audi A6 with 122 m and VW Golf V with 30 m.

5.1.8 Composites

Advanced materials such as composites are challenging the supremacy of metals in structural applications due to weight reduction demand in various industrial sectors. In particular the aircraft industries are making drastic changes in the use of materials. The share of aluminium on an aircraft has fallen from 70 % in the Boeing 777, the previous commercial jet launched, to just 20 % on the Boeing 787. The Airbus has made a similar switch from aluminium to composites in the fabrication of A350 aircraft. The main reason for doing this is to make the aircraft more fuel-efficient and cheaper (less inspection) to operate. Representatives from the aerospace and aircraft industries are stating that:

- **Joining** in the commercial aircraft industry will continue to be a technology area that can make a major contribution to the industry.
- **Materials technology** is moving forward quickly and the associated processes must evolve with it.
- **Metal joining** remains a challenge but alternative materials such as composites, ceramics and thermoplastics can offer significant potential.
- **Key technology area** - Joining of dissimilar materials is a growing challenge.

The market for composites including fibre-glass has an annual growth of 5.5% in the world. The Asian market is very vibrant and growing with 9.9% p.a. The total market was forecast to be more than £24 billion year in 2010. The huge market covers applications such as tanks and pipes, which are working in harsh environments for storing and transporting corrosive materials. The total cost of metallic corrosion in the US alone is estimated at $280 billion. China is today number two in this area but it will soon overtake the current market leader USA.

5.2 Higher automation, productivity and quality control

In every country, there is a relentless fight to maintain orders by increasing the productivity and improving the quality and the working environment. One simple means is to change the arc welding process from MMA to MIG/MAG or FCAW, which has been the case for many years in Western Europe, the USA and Japan as illustrated in *Figure 5.10*.

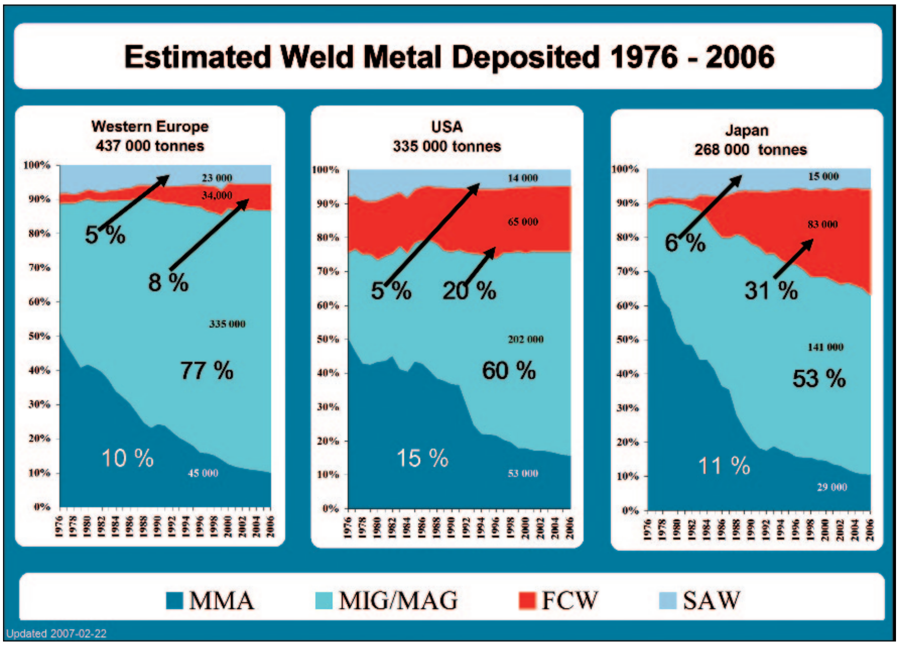


Figure 5.10 *Changes in welding procedures (Reproduced courtesy: ESAB)*

One will certainly see a faster conversion from MMA in the Asian countries (62 % in China) than the ones shown in Figure 5.10. The amount of deposited weld metal in China is about 1.1M tons (*Figure 5.11*) or more than Japan, USA and Europe deposited together. China consumes more than one third of the total for the world, which amounts to 2,923 million tons. China has much more submerged arc welding (13%) than Western Europe (5%) due to the higher amount of plate welding consumed in the construction and shipyard industries.

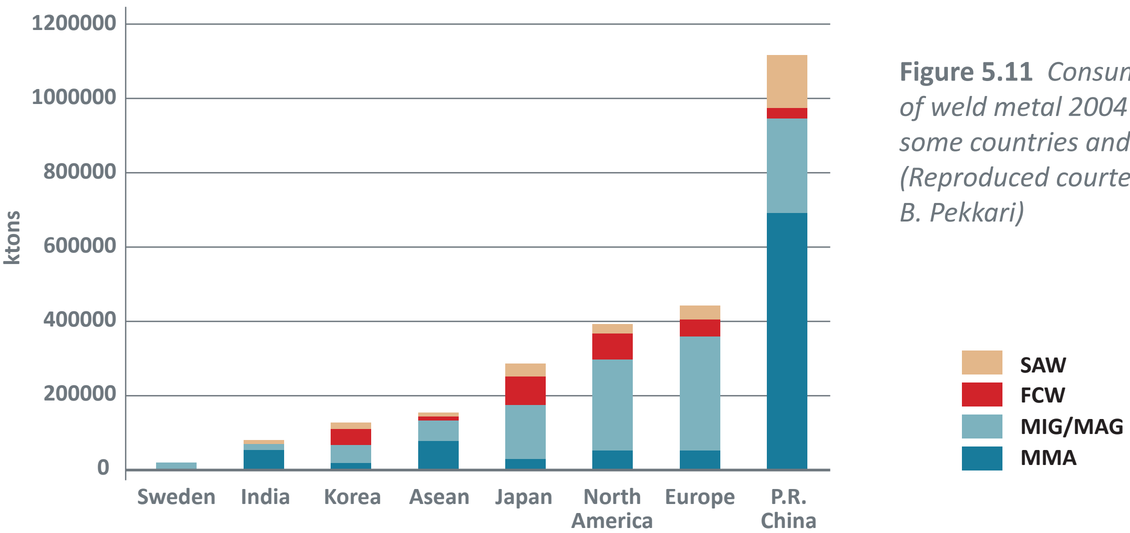
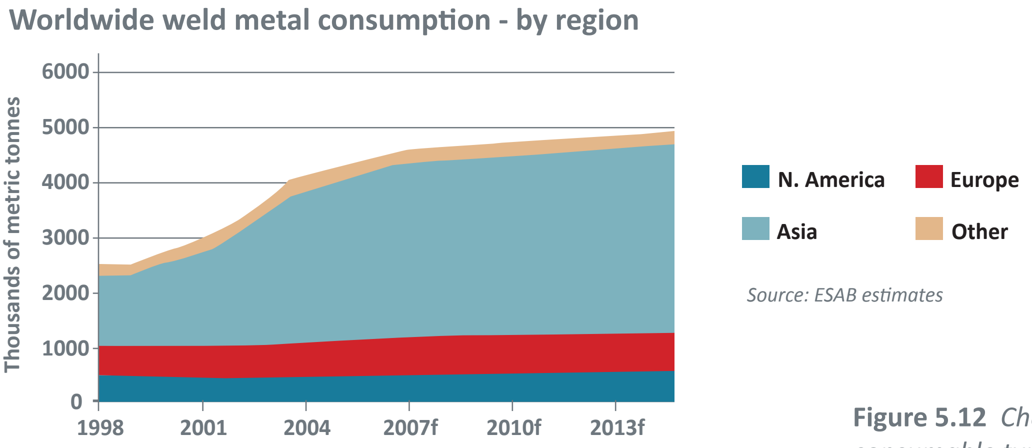


Figure 5.11 *Consumption of weld metal 2004 in some countries and regions (Reproduced courtesy: B. Pekkari)*

Arc welding will remain the most important joining process and its use will continue growing quickly in Asia as forecast in *Figure 5.11*.

The change from electrodes (MMA) to solid (MIG/MAG) and cored wires (FCAW) is estimated to be as shown in *Figure 5.12*. It has been obvious for 30 years to automate the welding operations by introducing robotised stations. The number of stations continues to grow quickly to increase productivity and to improve the working environment and to eliminate monotonous tasks. To design purpose built installations without robots is almost a malpractice due to the price reduction for robots. During the last 15-20 years robot prices have been reduced by 46%.



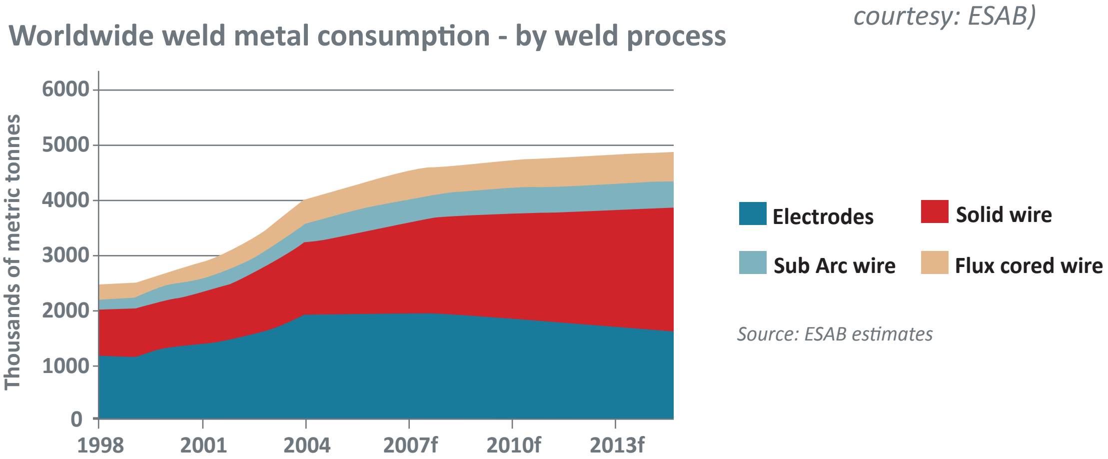


Figure 5.12 *Changes in welding consumable types (Reproduced courtesy: ESAB)*

One should consider the higher capability of the robots today particularly since the prices have dropped by 77% since 1990 (*Figure 5.13*).

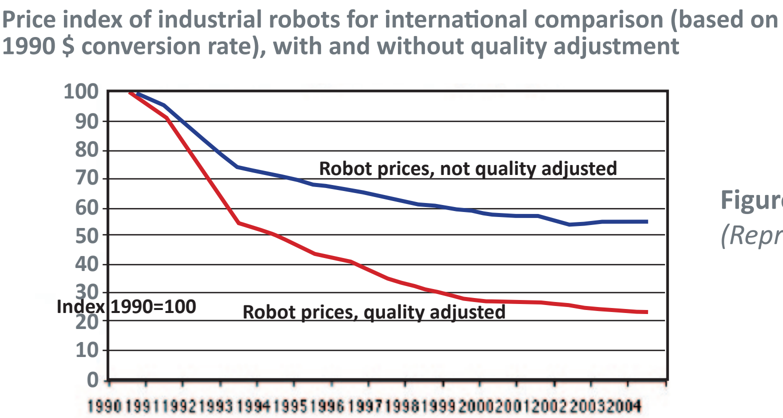


Figure 5.13 *Changes in prices of robots (Reproduced courtesy: B. Pekkari)*

In mechanised applications one can further increase the productivity by using large packaging solutions.

In submerged arc welding one can reach very high deposition rates, 50 kg/h by multiple electrodes (*Figure 5.14*), which is required for heavy welding such as wind power towers.

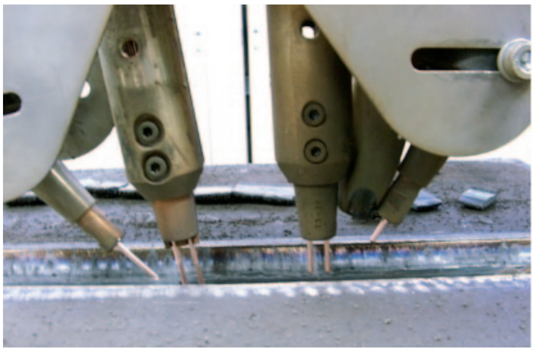


Figure 5.14 *Submerged arc welding with two tandem-wire heads and cold wire added SCWTM (Reproduced courtesy: ESAB)*

Tandem MIG/MAG welding is another process attracting a lot of interest but there are still fairly few in regular production. The automotive industry is increasingly using different forms of brazing such as MIG/MAG, Plasma and Laser brazing for zinc coated sheets to reduce the amount of pores in the weld metal and with acceptable mechanical joint properties.

In accordance with modern quality management strategies (ISO 9004), non-destructive inspection (NDI) and evaluation (NDE) are always embedded as continuous tasks into the quality circle conducted during the lifetime of a product, beginning with the design phase of a component and ending with the recycling phase. NDI includes testing, detection, classification and sizing of imperfections (pores, inclusions, shrinkage cavities, cracks, etc.) in material joints and components. Clearly safety-relevant components require NDE to be regulated by technical rules, standards and/or laws throughout their production and operation lifetime. NDI and NDE contribute to the assurance of the product's integrity by characterising tolerable findings and relevant material degradation (corrosion, fatigue, creep, thermal ageing, and synergies) limiting the lifetime. NDI/NDE techniques developed in the last decade have opened new fields of application.

NDI/NDE techniques are integrated in the early phases of product design in the industrial R&D-laboratories and contribute to the quality strategy, i.e. to design the basic safety of components. During the design phase of the component the NDE procedures for testing after production and in service are also designed. Modelling of NDE is a strong tool for technical inspection justification. In the aviation industry this "*concurrent engineering*" approach absolutely is a must when "damage tolerance" principles are to be fulfilled in design. The use of NDI/NDE gives increases in "intelligent processing" in order to assess quality characteristics which can be estimated often only destructively and which are parameters for process diagnosis, monitoring, and control; for instance mechanical properties like hardness, yield or tensile strength or toughness parameters.

As part of the maintenance strategy and in combination with fracture and fatigue mechanics, NDE contributes to lifetime prediction delivering input parameters for failure assessment by applying "fitness for service" (FFS) approaches. Software based on this state-of-the-art technology taking into account probabilistic features is under development worldwide, mainly for applications in transportation, pipeline servicing, nuclear and aviation industries. The most modern approach in quality management relies however on online monitoring technology of the full structure. Here also, the aviation industry is the front-runner in the technology race of "structural health monitoring" (SHM). The challenge is inspection reliability by developing low-cost but highly durable (40 years in aviation) sensors. Future applications are in civil engineering (bridges, off-shore structures, wind energy mills) and in monitoring of vehicles (air planes, ships, railway, and cars).

NDE like other technologies too can benefit from the mainstream microelectronics and computer-science, which have revolutionised the development speed and have enabled the development of new testing technology, with the support of automation and robotics.

5.3 Advanced technologies for maintenance, repair and life extension

As mentioned in the previous section, the revolutionary developments in microelectronics and computer science are the reasons for advanced NDT technologies becoming available during the last decade. NDT has been developed for maintenance, for better quality inspection after repair and for more reliable lifetime prediction. The main areas of progress in NDT techniques applied in practice and reflecting the work in the sub-commissions of IIW Commission V "NDT and Quality Assurance" are covered below.

5.3.1 NDT of welds by use of radiography, technical radiology & computer tomography

As long as radiography means irradiating a component by X-rays or Gamma rays and sensing the information on a film, developing the film and analysing the developed film by human eye, the technique will suffer high errors due to human factor influences. Some quality standards for instance in nuclear technologies, have asked for film storage to have long-term documentation. Following the example of medical doctors who have changed their standards, adopting the digitisation of the film material has tremendously enhanced the technology. By applying automatic online working pattern recognition software, considerable success in detecting imperfections can be achieved using the best trained NDT inspector as a benchmark.

After online digital radiology gained popularity, the more pixelised solid state flat panel devices became available. Here also, by the use of pattern recognition software, reliability comparable to the best film application can be achieved. The highest achievable capability for inspection is obtained by use of computing tomography because of the multi-angle information taking into account imperfections that can lay with an individual angle to the direction of the incoming energy. Here the synergic combination of digital detectors, optimised reconstruction algorithms test and high-speed computing power is responsible for the progress. A first inspection qualification according to the European Network for Inspection and Qualification (ENIQ) recommendations in Europe for multi-angle radioscopic inspection of primary circuit pipe welds in Nuclear Power Plants in Germany was successfully performed.

5.3.2 NDT of welds by use of ultrasound

5.3.2.1 Advanced UT techniques

In ultrasonic testing (UT) with the development of the so called array transducer the most intelligent and flexible inspection probe was introduced into practice. The piezoelectric sensor membrane is divided into multiple single source elements which individually are controlled in the amplitude and phase of the electric pulses used for transmitting and receiving ultrasound. As micro-electronics becomes more miniaturised and computing power becomes cheaper, systems are now available at reasonable prices. The advantage of the transducer is the quick multi-angle-beam inspection which can detect individually oriented flaws.

Industrial phased arrays have been in development for decades, following medical phased arrays and other areas like radar, sonar and geophysics. In the past, a small market, considerable flexibility demands, data handling, software, and extensive training and experience requirements have hampered the wide use of phased arrays for industrial applications. The first industrial commercial phased array systems appeared in the early 1990s, but were large, expensive, and required good software skills. Most of these units were used in the nuclear industry on specific advanced applications.

Currently, the phased array industry is maturing rapidly and phased arrays are becoming pervasive in inspection markets worldwide. This is true both for industrial field applications as well as for more academic applications in universities and research institutes. From a technical perspective, this is being driven by the flexibility that they bring to an inspection task, with their ability to generate a wide range of ultrasonic beam characteristics with one phased array unit.

From a practical perspective, the new phased array systems are relatively easy to use and are portable, thus allowing easy access to the inspection location. This is in sharp contrast to older phased array systems that were essentially immobile, quite heavy and thus difficult to deploy. Lastly, from the commercial perspective these systems have now come down in price to a level that they can be used by organisations that span many different fields. This has also led to a corresponding lowering of cost that has allowed their usage in many new commercial applications. It is these three factors acting together that have driven the large increase in phased array usage.

Nevertheless, phased array testing remains an ultrasonic testing technique and the fundamentals of physical principles shall be kept in mind by the operators. The application of such a technique needs specific training, verification of the competencies and careful verification of the procedures.

IIW Sub Commission V-C has prepared a “Phased Array Handbook” to be issued soon by DVS media GmBh.

ASME has published separate Code Cases on phased arrays to cover both manual and encoded scanning. These Code Cases specify many of the parameters and requirements for performing phased array inspections.

ASME VIII Div2 and B31.3 defines the use of ultrasonic testing in lieu of RT inspection and the acceptance criteria to apply. Phased array or Time of Flight Diffraction method (TOFD) can comply.

Figure 5.15 *Phased array inspection in lieu of radiographic inspection on welds in piping (according to ASME B31.3)*
(Reproduced courtesy: Institut de Soudure)

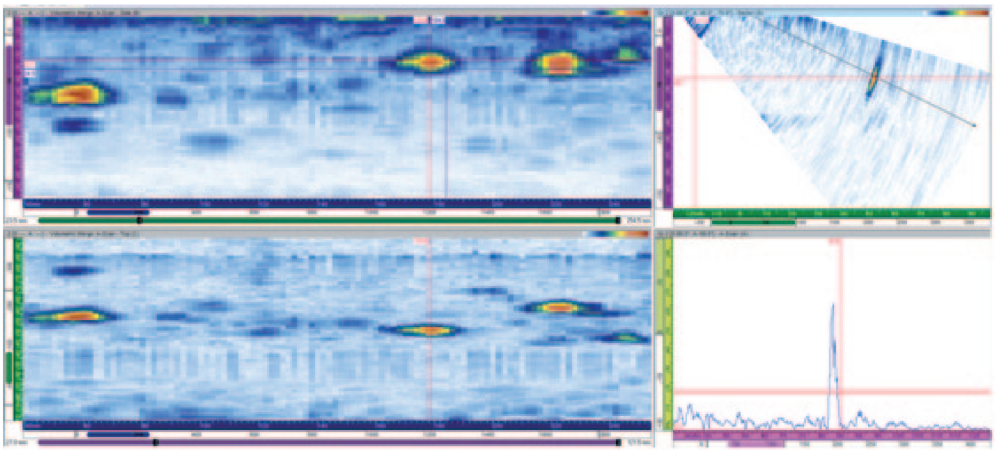


Figure 5.16 *Examples of Phased array inspection results (Reproduced courtesy: Institut de Soudure)*

ISO standardisation now takes into account TOFD and phased array inspection related to the weld quality class defined in ISO 5817 provided the corresponding testing and acceptance levels as defined in ISO 17635 are met.(*see Figure 5.17*).

	TOFD		Phased array	
Quality levels ISO 5817	Testing levels ISO 10863	Acceptance levels ISO 15626	Testing levels	Acceptance levels ISO (not available)
B	C	1	B	/
C	B as a minimum	2	A	/
D	A as a minimum	3	A	/

Figure 5.17 *Example of levels to apply for TOFD or phased array in agreement with ISO 17635*

When the replacement of a NDT technique by another one is not defined within a standard or a construction code, the approach suggested in the IIW V-1502-11 document can be applied. For a specific weld on a given welded construction, the proposed actions are to carry out a systematic analysis called OPC consisting in assessing:

- The Occurrence of flaws liable to appear while welding (in the conventional risk assessing analysis, this represents the probability of the feared event).
- The detection Performance of such flaws for each of the used NDT technique/method.
- The Consequence(s) liable to result from the non detection of these flaws by the NDT technique applied and the alternative one when using construction weld or welded equipment.

After this analysis, risks are assessed combining parameters by means of a set of rules allowing comparison of, at least qualitatively, the NDT techniques. This approach is advantageous since it is global and allows a better assessment of the criticality resulting from a undetected flaw and thus to compare the risk induced by changing the NDT method.

5.3.2.2 Ultrasonic testing of austenitic welds

The need to test austenitic welds by means of ultrasonic testing is growing in various industry sectors such as nuclear, LNG tank storage and oil and chemical industries.

IIW Sub Commission VC has prepared a Handbook published in 2012 by DVS media GmBh (Handbook on the examination of austenitic and dissimilar welds – ISBN 978-3-87155-969-3).
This handbook covers the ultrasonic inspection of austenitic butt welds. The objective of the handbook is to provide all those involved in the volumetric examination of austenitic welds with the background knowledge necessary to perform effective ultrasonic inspections of austenitic welds and to inform them of the limitations caused by the acoustic properties of the material.
The handbook is particularly addressed to technicians, engineers and scientists involved in austenitic weld inspection. It should be of particular value to those responsible for preparing inspection procedures, but it does not provide a detailed inspection procedure for any particular weld.
The handbook deals mainly with butt welds but the theory and practice presented can be applied to welds with more complex geometries providing the additional difficulties of the geometry are taken into account. The handbook also covers dissimilar-metal welds, which are generally more difficult to examine than a straight butt weld due to the buttering layer. The scope of the handbook includes fabrication and in-service inspections.

ISO 22825 was recently revised and issued in May 2012 and specifies the approach for the development of procedures for ultrasonic inspection of welds: stainless and austenitic steel - nickel-based alloys - duplex - dissimilar metals. The objectives of the tests may differ, for example: assessing the level of quality (manufacturing) or detection of specific indications produced during the service.

Acceptance levels are not included in this standard, but can be applied depending on the scope of testing. The requirements are applicable to both manual and mechanised testing.

5.3.2.3 Ultrasonic guided waves

Guided waves are low frequency ultrasonic waves that propagate along the length of a structure, guided by and confined in the geometric boundaries of the structure. Several modes of propagation can be used.

Commercial equipment is available, working either by using piezoelectric elements or magnetostrictive sensors, and this has led to a strong increasing use on site especially for corrosion detection in pipes and piping.

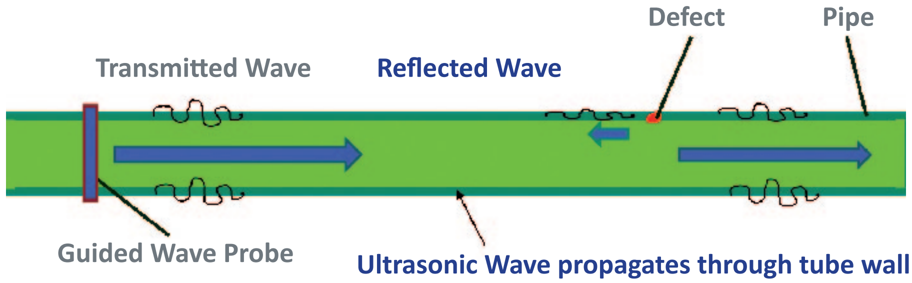


Figure 5.18 *Ultrasonic guided waves propagation principle*

Guided waves are sensitive to changes in cross section (increase or decrease) of the waveguide mainly by reflection. Other interaction modes are possible, such as mode conversion and diffraction, but they are not widely used in field applications. Guided waves are a screening technique and are generally not appropriate to characterise accurately the indications detected. The technique can classify the indications from their amplitude and when calibration can be carried out, the loss of cross section can be assessed. They are generally not appropriate to determine the residual thickness except in special cases. The position where the indication is detected can be assessed at ± 50 cm.
An ISO standard prepared by IIW Sub Commission VC will be issued soon. Several Projects (MOSCO in France, OPCOM in Europe, Buried Pipe Integrity initiative in US) aiming to assess performances of guided waves inspection are being undertaken.

Figure 5.19 *Testing loop built to assess performance of guided waves (Reproduced courtesy: Institut de Soudure)*

5.3.3 NDT of welds by use of electric, magnetic and thermal techniques

Here, on one hand advanced developments have the ability to characterise materials in terms of mechanical hardness, to achieve yield or tensile strength by use of micro-magnetic NDT taking into account the relationships between magnetic and mechanical properties. On the other hand, new types of magnetic sensors such as giant magnetic resistors (GMR) or giant magnet impedance (GMI) became available. By use of them, magnetic testing (MT) can be performed with a high sensitivity of 10^{-8} × the value of the earth magnetic field. Thermography in combination with inductive heating, can revolutionise the inspection for surface-breaking flaws. By superimposing high-powered ultrasound, the contrast can be enhanced significantly and also near-surface- hidden flaws can be detected.

5.4 NDT modelling

NDT modelling plays an increasing role for designing new procedures, demonstrating performance, analysing results and providing help to experts. Modelling tools are now used for ultrasonic, eddy current and radiographic testing. For more than a decade, the CEA (French Atomic Energy Commission) has been contributing to this evolution by developing the CIVA software and integrating the research of universities from various countries.

Modelling tools can be based on semi-analytical calculations or finite element analysis. The first is quicker but the latter one can help to solve more complex situations. The scope of application fields has increased a lot during past years: nuclear industry, aircraft industry, steel industry, petrochemical, railways.

Generally, the user can define the shape, size and material of the part to be inspected as well as the parameters of the inspection. Different types of flaws/defects can be placed in the simulated part, then the inspection results calculated and displayed in a similar manner to what would be obtained experimentally.

The main advantages of using modelling tools are to:

- Reduce the cost (less welded samples with representative defects are necessary to qualify a new procedure).
- Help to understand NDT inspection results.
- Perform parametric studies in order to assess procedures and NDT performance.
- Assess the ability to be inspected of a given part leading to possible design modifications.
- Help to design new sensors optimised to reach the adequate sensitivity.
- Compare the performance of different NDT methods on a given part.

An example of the use of such tools is given in *Figure 5.20* aiming to compare the advantages of a phased array UT inspection compared to a RT one.

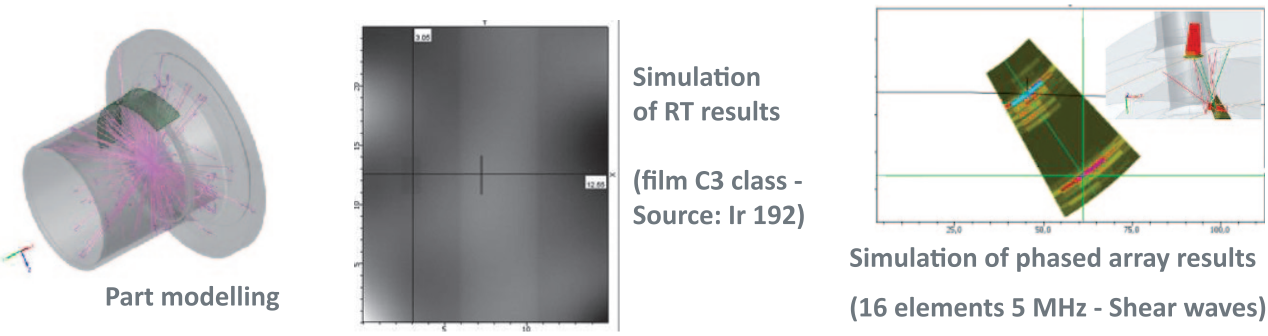


Figure 5.20 *Example of modelling NDT results (reproduced courtesy Institut de Soudure)*

5.5 NDT and structural health monitoring (SHM) of welded and composite structures

The trend of introducing light-weight structures in applications such as aviation, railway cars and the automotive industry has involved new joining technology (Laser welding, friction stir welding, adhesive joints) and new materials (high strength steels, Al-, Mg- and Ti-alloys, fibre reinforced composites). The classical NDT technology for maintenance will be replaced by structural health monitoring where in a short term strategy over the next few years, the aviation industry will monitor the fatigue experience of components such as a wing as a first step.

These experiments have to be performed according to the damage tolerance concept in order to detect the early development of fatigue flaws and the speed of the damage accumulation. Possible sensor types for continuous monitoring will be tested in reliability tests. In a second step, the optimised sensors will be applied in the structure to monitor critical places where according to the design, fatigue damage can occur. The last step of the SHM strategy is the integration into the structure of reliable lifetime online integrity monitoring of 40 years. The added value by SHM is given by an extension of the maintenance intervals or - if these intervals will not be changed – by reducing the weight of the structure.

Some sensors under development are based on fibre technology. Piezoelectric fibres can be embedded in the fibre composites. The fibre is a local transducer which can passively detect acoustic emission propagating from local damage but can also actively emit ultrasound interacting with flaws and producing reflected or scattered waves for detection.

Other sensors under development are based on the use of guided waves and can be set at the surface of the composite structure to be monitored. These new type of sensors could be set on composite pressure vessels aiming to store hydrogen for fuel cell development.

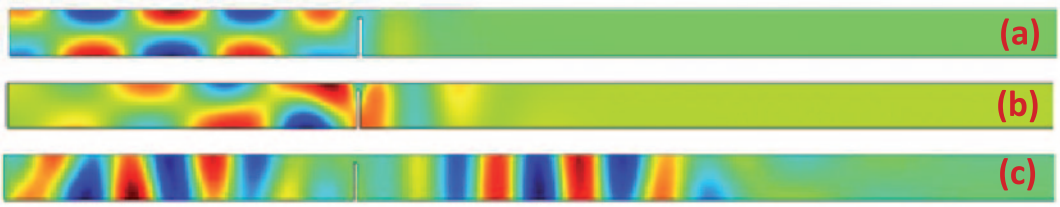


Figure 5.21 *Simulation of propagation and interaction of an ultrasonic guided wave with a defect within a composite medium (reproduced courtesy Institut de Soudure/Georgia Tech university)*

5.6 Developments with "local engineering" & SHM towards "Intelligent welded structures"

Materials engineers have the vision to further develop the SHM concept in combination with adaptive features. One idea is to utilise the SHM sensors to determine the actual state of a component, for instance the local mechanical stress state in an aircraft wing or the local dynamic pressure on the leading edge. By embedding piezoelectric actuators in the structure, the wing profile can be locally adapted in order to enhance the air gliding and to reduce fuel consumption or to damp vibrations. The wing of the plane is becoming intelligent, the structure is smart. In the case of railway cars, development projects in Europe aim for noise reduction by embedding piezoelectric sensors and actuators.

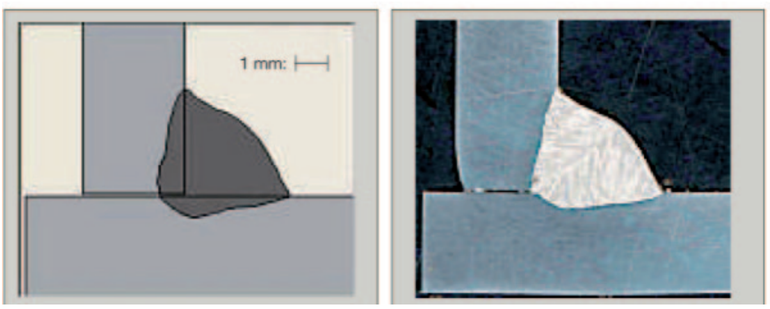
A dream is that materials can be developed with a self-healing or self- repair function. In this case, the SHM sensors give early detection of the beginning of damage and the intelligent processing of the structure, initiates the repair by a local engineer.

5.7 Strategies to face technological challenges in welding and joining technologies

There are numerous IT programmes that have been developed and used for design, simulations and off-line programming and expert systems. These can drastically reduce the testing costs and time in the development of new products and check different design alternatives. There are several numerical programmes in the market for such calculations. With the Schaeffler /Delong programme for the calculation of an appropriate weld metal, it can save a lot of work effort compared to manual calculation. The required Heat Treatment of a welded product can easily be calculated with a computer programme. Welding cost calculation is another application suitable for computer calculation.

Other examples include:

- Major cost savings can be realised e.g. by using the ABB software programmes.
- RobotStudio for simulation and optimising of the movement of the robot arm/wrist for off-line programming and as well welding cycle times.
- VirtualArc® for optimising of the welding parameters for optimising of welding parameters (*Figure 5.15*). These programmes are powerful tools to calculate the economical feasibility of planned investments.



a) Calculated penetration **b) Real penetration**

Figure 5.15 *Comparison between calculated penetration with VirtualArc® and real penetration (Reproduced courtesy: ABB Robotics)*

SMEs have a huge challenge to introduce such IT-means. Many of the technicians in SMEs must be better educated and the programmes easier to use, which a survey in Sweden has shown. Welding companies can only be competitive by having the personnels with the right education and experience. IIW offers training courses and qualification through its members such as:

- IIW IWE – International Welding Engineer
- IIW IWT – International Welding Technologist
- IIW IWS – International Welding Specialist
- IIW IWP – International Welding Practitioner
- IIW IWSD – International Welded Structures Designer
- IIW IWI P – International Welding Inspection Personnel
- IIW IW – International Welder

Competitive companies are likely to need to have certified welding personnel, with which IIW can assist.

Certification of a company's quality system is another way of getting appropriate procedures applied in order to get the right output quality in products, systems and services the company is delivering. Even in this case

IIW can help companies to get their quality systems certified through the IIW Manufacturer Certification Scheme According to ISO 3834 (MCS ISO 3834). The image of welding needs to improve in order to simplify recruitment of young people for the welding profession.

The welding environment needs to be improved continuously to offer safe and sound workplaces, which is one of the major objectives for IIW Commission VIII Health & Safety. The commission has the best knowledge available in the world about risks associated with welding and this knowledge is continuously updated by world experts.

6 Needs and challenges in health, safety, education, training, qualification and certification

6. Needs and challenges in health, safety, education, training, qualification and certification

6.1 Human and material resources

The study of the effects of phenomena occurring during welding fabrication and their effects involves many disciplines, including welding technology, metallurgy, design, industrial hygiene, medicine, ergonomics, epidemiology and many others.

The complete understanding of the effects of human activities on the humans themselves and on the surrounding environment seems to be a never ending process because of ongoing changes in the working environment due to the continuous development of materials, technologies and fabrication techniques.

In addition, the effects seem to be hardly distinguishable as the workplace environment can be only ideally distinguished from the external environment and the relevant interaction always work as confounding factors.

Moreover, despite the fact that the associated hazards are similar all over the world, the precautions taken to control the risks of harm to humans and of the negative effects on the environment which may arise in this work will vary greatly between and within countries.

Ideally, agreement would be reached internationally on the best ways forward and the agreed standards and methods would be adopted and applied with equal vigour all over the world to benefit workers and the industry in general. In reality, however, barriers so often spring up to prevent agreement being reached on exactly what should be done, let alone making progress on actually achieving improvements in the workplace.

A profitable tool to try to solve the situation might be the use of models and criteria for the design of the welding fabrication process through the use of health and safety and environment management schemes. This needs to be fully integrated economically with the fabrication process, leading to better use of human and natural resources in general, while leading to better quality of the products.

6.2 Health, safety and environmental aspects

The health, safety and environment aspects associated with welding and other joining processes can be classified as follows:

- Physical aspects, such as risk of fire, radiation, heat, noise, electrical dangers, work environment conditions, etc.
- Chemical aspects, i.e. gases and particulate matters (fume) produced during welding and other hazardous chemicals and substances used during all phases of the fabrication process.
- Environmental aspects, such as disposal of waste (slags, packaging materials, etc.), natural resources depletion due to ineffective use and contamination of air, land and water.

Lack of skill and knowledge of what action is required to protect health and safety is among the most basic of these barriers. Others include cultural, political and economic pressures which may dilute the strength of well-founded scientific conclusions as national exposure standards are set and health and safety laws are framed by government agencies. When it comes to implementation, in some countries the self-interest of employers and governmental indifference can, from time to time, appear to blind all parties to risks of injury, illness or even death and obstruct the reduction of their incidence.

The IIW seeks to provide a forum which is recognised internationally and throughout the welding and joining industry as a place where a cross-section of well-informed people from that industry and associated academic establishments can meet, free of special interest pressures, to share their knowledge and experience. This is done mainly through IIW Working Units dealing with the matters of health, safety and environment, where members are asked to consider new technological developments, to debate the validity and conclusions of scientific reports on health and safety risks on these and established processes, to seek a consensus view and to advise everyone in the industry on their best assessment of levels of risk and how these might be managed most effectively and efficiently.

While there is still much to be done to achieve the ideal mix of skills in the membership, Commission VIII already offers an opportunity for fair, free, well-informed and balanced debate and can provide a source of soundly based advice to the industry. Moreover, the breadth of expertise is enhanced from time to time by inviting expert contributors from other Commissions and host countries to contribute to discussions or by organising joint meetings with other IIW Commissions or Working Units.

As a result of this process, IIW provides its members with “IIW Statements” as consensus reached among members of its working units which can be considered as an informed point of view within the International welding community. In addition, IIW participates in the standardisation process and has produced several ISO Technical Reports on the matters of health, safety and environment in order to achieve the most widespread contact with the international industrial world.

6.2.1 Health and safety issues of welders

Despite advances in (welding) control technology, welders are still exposed to welding fumes and gases. The chemical composition of the particles in these fumes and gases depends on the welding processes, the chemical composition of the filler metal and the base material, the presence of coatings, time and severity of exposure ventilation.

Although there are many different welding processes, it has been estimated that shielded metal arc welding (SMAW) and gas metal arc welding (GMAW) on mild steel and aluminium are performed by 70 percent of welders. According to the EN ISO 14001 Standard and organisations such as OSHA, possible elements of welding fumes and related hazards include, among others, zinc used in large quantities in the manufacture of brass, galvanised steels and various other alloys. With the welding of stainless steel, protection of the

welder against Cr6 is a very important issue. When exposed to zinc, symptoms rarely last more than 24 hours, but each time a welder suffers from metal fume fever he has 1 or 2 days of sick leave.

The European MAC value [maximum accepted concentration of welding fumes], a legally determined value, is 5 mg/m^3. Scandinavian governments are reducing this value. Since 2003, Dutch companies have to work with MAC = 3.5 mg/m^3; a reduction of welding fumes of 30% according to the European norm. This introduces high investment costs for industrial companies. Regulations in Far East countries are far less stringent, seducing companies in Europe to outsource welding work.

In manual welding the position of the welder (bending towards the welding zone) is stressful, often leading to back injuries and although the welding torch does not seem to be very heavy, holding it in a stable position for some minutes gives one a different view of the meaning of the word “heavy”. It is remarkable that workplaces are often not designed to fit the needs of the workers but most of the time exactly the other way around. Welding introduces many challenges to the field of ergonomics, which are at this moment only just being understood. Europe has to find solutions for the problems such as Repetitive Strain Injury (RSI) among welders and Cumulative Trauma Injury, both resulting in lower productivity, lower quality and workers’ dissatisfaction. There is therefore a very urgent need for guidelines for designing workplaces and tools to improve working conditions of welders, which will also make welding more cost effective and thus industry more competitive.

SMEs have to stay competitive to survive. There is a need on the European level to lower production costs by technological innovations. For a lot of SMEs, welding costs are a substantial part of the production costs. Depending on the welding process, different solutions are being investigated to lower the emission of welding gases and fumes or to reduce physical demands. Solutions can be found by lowering the droplet temperature during GMAW welding, by using green consumables with special coatings in combination with more effective shielding gases, by smart product design, replacing manual welding by mechanised welding and the development of a lightweight torch with reverse fume extraction. Smart protection equipment such as self-positioning exhaust arms and smart helmets with sensors informing the welder about fume concentrations will be developed and tested at SME shop floors, just as well as smart air blowers, forcing fumes away from the welder. A software tool for virtual welding, ViWeld, is being developed in a EU project, enabling design engineers to determine if their products are weldable in an ergonomically responsible manner. ViWeld also estimates welding fume concentrations depending on welding positions, thus making design optimisation possible with regards to costs, throughput time, ergonomics and concentrations of welding fumes.

6.3 Job, skill, career and competence developments

Welding and joining industries are faced with the challenge of declining numbers of people entering welding-related activities. The longer-term impact of this decline in attraction of our young includes loss of talent, lower potential rate of growth and safety to people, assets and the environment. The key challenge is to be able to ensure that whatever one does, one keeps product and whatever raw or intermediate material inside the pressure envelope. Design of one’s processes must be sound, one has to construct our plants in accordance with good quality standards and practices and when operating, one needs to have trained and knowledgeable operators. Personnel maintaining the units need to be well trained and have the required competencies to keep the plant in reliable condition. One way or another, welding and welding related technology do feature in all these needs. So having a steady infusion of talented and trained people entering the field of welding and welding related technology is quite an important and vital element to ensure safe and reliable plant operations.

On Tuesday 15 Aug 2006, the Wall Street Journal published an article:

Where have all the welders gone, as manufacturing and repair boom? Quoting from it; "Welding, a dirty and dangerous job, has fallen out of favour over the past two decades, as young skilled labourers pursue cleaner, safer and less physically demanding work. Now, thanks to global boom in industrial manufacturing, skilled welders are in greater demand than ever. Companies can't find enough of them." and also "The average age of welders, currently 54, keeps climbing. As a wave of retirements loom, welding schools and on-site training programmes aren't pumping out replacements fast enough."

One commentator stated "We need welders like a starving person needs food…"

The American Welding Society had correctly predicted that by 2010 demand for skilled welders would outstrip supply by 200,000 in the US alone.

At first glance this might appear to be totally irrelevant to anybody outside the US, but with a bit of experience of welding operations, one realises that a similar scenario has already unfolded on a worldwide scale. The underlying causes may be different to that of the US, but the potential negative affect is just as devastating. Every single day on construction sites the implications of the declining pool of skilled artisan welders manifests itself. Repair rates on high pressure and high temperature plant completed weldments as high as 50% on some components prove not to be uncommon any more. Repairing unacceptable weld defects is notoriously expensive due to many factors such as negatively impacting on planned schedules, as well as metallurgical issues. Although the manpower to repair the defects is usually for the contractor's account, this can be insignificant when compared for instance to the potential loss in production costs on the client's plant.

One might argue that plant owners should not be concerned with where resources for maintenance and erection projects come from, as long as the required contract work is completed on-time to appropriate quality levels while the market forces in a global economy takes its course. The reality, however, is that top welders will be lured to perform relatively easy welding jobs at a very competitive remuneration, as compared to the demanding weldments required, for instance boiler and pressure vessel work, with respect to skill and quality requirements. Not only will this put tremendous strain on finding enough welders for the ongoing world-wide expansion programme of power generation and petrochemical facilities, but also those available will provide their services at great premium prices. This will inadvertently lead to cheaper replacements brought in from other countries, that is if the booming global utility market will allow it with current large expansions projects that are planned for China, Europe and the USA looming.

The solution seems to be fairly simple and obvious. End-user companies need to realise their obligation to embark on an urgent concerted effort to establish an artisan welder training programme, using a country's own resources and existing facilities. With the necessary funds invested in a bursary scheme coupled to some form of tax relief to the company, groups of fully trained artisan welders can be presented to the industry every two year cycle. Remuneration packages would need to be constituted attractively enough in order to attract promising young students to the welding industry, with sufficient long term job prospects to aspire to, while participating in the effort to steady the ship so to speak. Market forces will dictate and some of the successful candidates will inadvertently leave the employer but one can be sure that a significant proportion will take up permanent positions within organisations.

6.4 Communication and information technologies

6.4.1 Training, education, qualification and certification

Training, education, qualification and certification are issues on which the future of industry is dependent. In fact, a look through the publications and newspapers, which reflect informed opinion, will confirm that there

is considerable national concern for these topics, all over the world. Moreover, the significant investment at national and international levels in programmes related to training and education is indicative of the paramount importance these issues have assumed. In 1992, IIW recognised that industry would be better served as regards training, education, qualification and certification in welding by creating a harmonised system for welding personnel, that could be used all around the world.

IIW has then set a target of developing course syllabus guidelines and quality assurance rules for the implementation for this harmonised system. This was done by taking over and improving the system used in Europe by the EWF- European Federation for Welding Joining and Cutting and continually developing it further to comply with the requirements from countries outside Europe. The International Harmonised System for Welding Personnel was implemented by the IIW Members in 2000 and now, in 2012, is used by 44 countries.

The use of Distance Learning Courses, computer or internet based training was, since the beginning an issue on the table as it was widely recognised that many of the IIW countries, needed to use distance training to reach remote regions. Also many trainees needed flexible training hours as they were taking the course while working normal hours in industry. Examples of the use of computer based technologies for training in welding started to appear soon after the approval of the documents that create the basis for the International System.

Australia, Denmark, Germany, Sweden and Spain used CBT in the training of Engineers and some of these countries have also developed CBT for Technologist and Specialist levels since 2002 by developing CD based course modules. After the first CBT training programme trials, the above mentioned IIW Members, started implementing Distance Learning Courses, internet based, complying with IIW Distance Learning Course Guidelines and Operating Procedures. These first approaches targeted the theoretical part of the courses. Using CBT for practical training in welding is more of a challenge which has been addressed by several countries.

Some EWF Members, led by the Belgium Welding Institute and with the EWF Secretariat support, during the past few years have developed under the Leonardo da Vinci programme two projects which had the goal to develop two interactive tools for the theoretical training of welders according to the IIW guideline content for the TIG and MIG/MAG welding processes. Virtual tools that reproduce the welds for training of welders are other examples.

Demand for training in welding technology is increasing in many of the IIW countries generating a higher need for using IT in training. In this context, there has been an increasing effort in standardising the training principles for welding personnel when using ICT. This new pedagogical solution combines on-site training, e-learning methodologies, video on DVD, Video streaming allowing thousands of simultaneous end-users, and video-conferencing. The inclusion of pedagogical approaches using ICT, therefore, aims at supporting learning activities with video based learning resources, which represents an added-value when comparing these with just textbook approaches.

An important Standard to assist driving the need for skilled personnel at all levels is ISO 14731 “Welding coordination – Tasks and responsibilities”. The need for welding coordination has led to the IIW and national welding societies producing education, training, qualification and certification (ETQ&C) programmes for the different personnel in a Welding Coordination Team (WCT).

An example for Australia is given in *Figure 6.1*, whereby a mixture of IIW programmes and national programmes provide the ETQ&C requirements of all the different welding-related personnel.

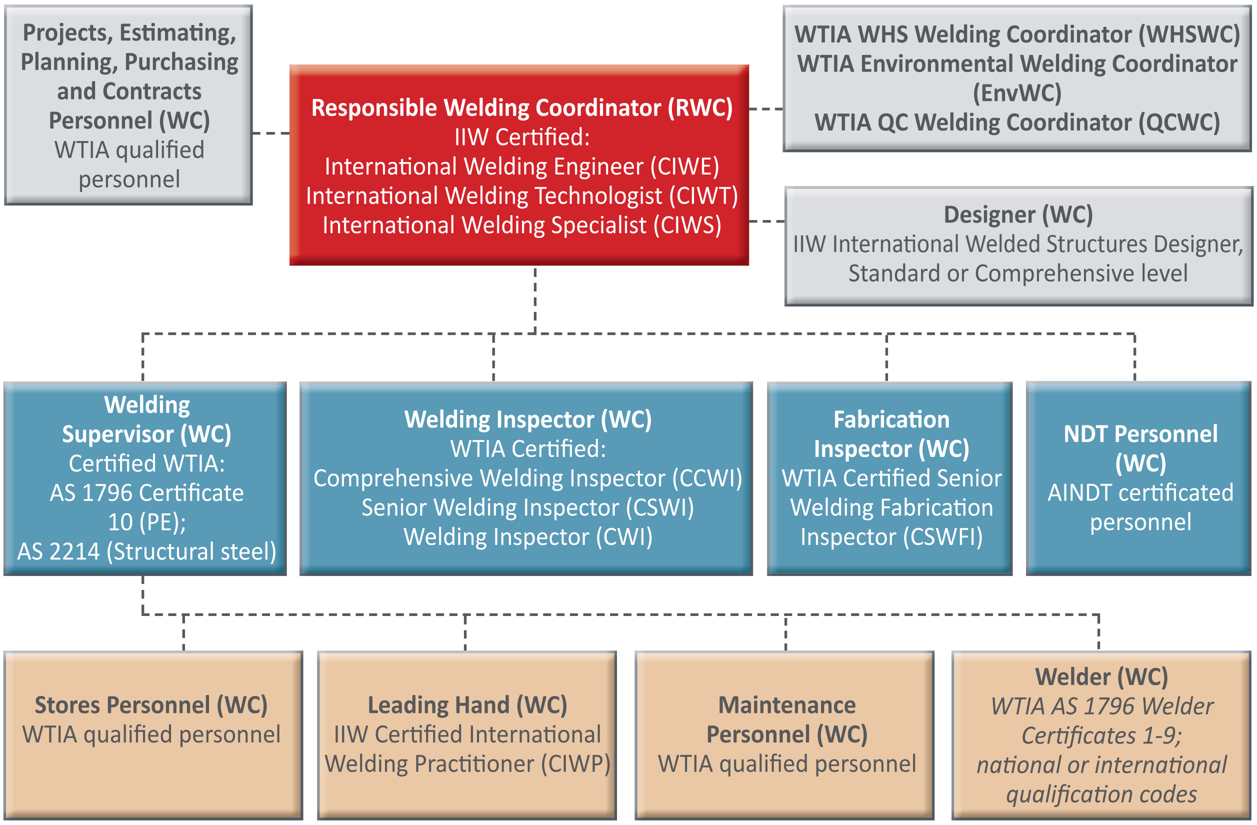


Figure 6.1 *The Welding Coordination Team concept in Australia (Reproduced courtesy: WTIA)*

This could be an excellent model for developing countries to modify for their own use.

6.4.2 Use of IT and Communication technologies

Use of IT and communication technologies has been key to welding and joining industries support and technology transfer activities of IIW member organisations. Of course, with the growth of the internet, electronic communication has assumed greater importance among a mix of methods for transferring technology. These methods may be:

- Through experts (staged sequences of activity: enquiry, product and process review, feasibility study, R&D project).
- Through people (staff transfer, secondments, postgraduate training partnerships).
- Through networks (collaborative projects, virtual enterprise networks).
- Through licences and on-line.
- Structured knowledge base and enquiry service.

Computer based services have a long history at some institutes. For example, at TWI these range chronologically through; Weldasearch literature database from the mid-sixties, technical software for welding engineers from around 1980 and training multimedia from the early eighties, JoinIT on-line information and advice service from the mid-nineties.

Outlined below are some of the stages of development of this key service, which now plays a significant role as a source of information and knowledge across welding, joining and materials engineering. It is thus

important in meeting needs with respect to health and safety, education and training, and qualification and certification among the areas covered.

To structure the development of its JoinIT service, TWI undertook a knowledge audit. The starting point was an exercise to define the scale of the task in terms of the fields of interest. TWI technology specialists were asked to identify the technologies and materials in which they had expertise. They identified 144 technology classes and 30 material classes (steels – plain carbon, alloy and stainless; aluminium alloys; titanium; plastics; ceramics; etc). This produced an initial knowledge matrix 144x30. Much of the knowledge across this matrix, however, has specific sector relevance within the main sectors served by TWI – aerospace, oil &gas, etc. Taking five main sectors therefore produces a knowledge matrix 144x30X5, i.e. initially 21,600 knowledge points.

There are of course a significant number of void points – none of the arc welding technologies applies to plastics for example. Having eliminated these, TWI was then able to assess what useful information and knowledge had already been captured relevant to each knowledge point, and where there were gaps to be addressed. The type of material to be created was also based on an assessment of the likely users, i.e. would it need to cater for a limited specialist audience, or would it have wide relevance in a training context? In the nature of technology, this is a process of continuous evolution. When considering how to package knowledge, TWI attempted to replicate with specially written material, the stages in the process of consulting an expert directly, namely:

- A simple question – these are addressed by answers to frequently asked questions (FAQs). These are generally aimed to provide of the order of a single screen of information in easily understood and ready to use format in say the fabrication shop of a small company.
- A need to know a little more about the technology at issue. This is addressed by knowledge summaries, painting a broader picture than the FAQ, and where relevant highlighting areas of special concern or risk with respect to health and safety.
- A need to understand and evaluate options. This is addressed by best practice guides which take a still broader comparative approach to a body of related knowledge, for example “Joining low cost stainless steel”, “Cutting” or “Brazing”. These are designed to provide the JoinIT user with sufficient knowledge to arrive at a conclusion with respect to a realistic course of action.
- A need to explore the technical or economic feasibility of a proposed solution. Software toolkits have been developed to allow the JoinIT user to explore a range of “what ifs?”.

Alongside this investment in special content creation has been a range of complementary activities, which are again ongoing, to develop the platform and the access, search and ancillary facilities of the web service. Access control has been a particular concern so as to ensure that the rights of members to TWI core information are properly preserved. The JoinIT service has proved extremely popular. It is accessed regularly by many members and non-members, and several hundred new registrations for access are received each month.

6.5 Strategies to meet challenges in human and material resources, demographic developments

IIW seeks to provide a forum which is recognised internationally and throughout the welding and joining industry as a place where a cross-section of well-informed people from that industry and associated academic establishments can meet, free of special interest pressures, to share their knowledge and experience. This is done mainly through the IIW Working Units, for example Commission VIII is dealing with the matters of health, safety and environment, where members are tasked to consider new technological developments to debate the validity and conclusions of scientific reports on health and safety risks on these and established processes, to seek a consensus view and to advise everyone in the industry on their best assessment of levels of risk and how these might be managed most effectively and efficiently.

Legal codes, rules and standardisation

7. Legal codes, rules and standardisation

7.1 Introduction

This section briefly reviews the current needs of, and challenges for, the global welding community including governments, for improving quality of life through optimum laws, standards, codes of practice, and various scientific and technological data and information. It then proposes strategies to meet these challenges by 2020 and beyond. Before doing so it looks back to look forward – "history is the prologue to the future". There has been huge progress in welding.

7.2 Background

The introduction of any new technology creates change and difficulties that are unexpected. This is seen by *Figure 7.1* giving approximate data for boilers and other pressure equipment (PE) and motor vehicles.

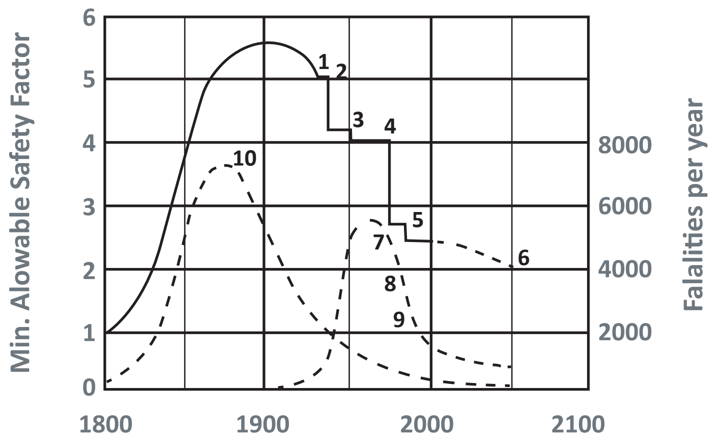


Figure 7.1 *Impact of technology, law and standards (Reproduced courtesy: S. Ambrose)*

Curve 1 = Road fatalities in Australia
2 = USA & UK PE fatalities
3 = PE safety factors

With boilers, the huge number of explosions, death toll and loss of trade and profit in the mid 1800s resulted in many actions to correct this disaster. These included research and development (R&D), training, laws and appointment of public officials (inspectors) with varying requirements, formation of insurance bodies etc. To avoid the many problems caused by different requirements and of different bodies and inspectors, national technical standards were developed in many technologically developed countries.

Overall, this co-operative effort was hugely beneficial to the world. These laws, practices and standards were then used as models or adopted directly by many other countries. The world has gained from this early work

by a few countries – so that today, despite the huge increase in PE numbers, pressure and sizes, the number of failures and fatalities has been greatly reduced. Welding technology has helped this improvement.

Figure 7.1 also shows a similar trend with motor vehicles a 100 years later – where obviously many different strategies including laws, technology and standards have been effective in reducing fatalities. Another example is with welded shipping where a similar trend curve resulted. There were many failures due to brittle fracture in World War II but now these are fairly rare.

In the above examples and in many other areas, improved technology (including improved understanding, design, materials, welding, non-destructive testing, inspection, R&D and technical data) plus standards and laws, coupled with huge improvements in education, training etc., have benefited global quality of life, though regional inequalities still exist. All countries still have serious failures however – much less frequently but often with major multi-billion dollar consequences. Thus the world still needs to do better and IIW is helping.

7.3 Current position with laws, standards and technical knowledge

7.3.1 Laws

In most countries, Acts, Regulations, Directives, and other government orders impact on the "welding industry" in many varying ways. These include workplace health and safety, environment, safety with hazardous plant and materials, piping, pipelines, boilers, pressure vessels, gas cylinders, transport equipment, cranes, lifts, structures, tanks, major hazard facilities, defence, security etc. They also impact on trade within and between countries (free, fair and with minimum protection to suit each country), industrial relations, wages, education and training, taxation, immigration and suitable support for industry, research, education etc.

Laws are needed for us to live reasonably and cooperatively, and have been a major contributor to improved national safety and well-being.

All successes and failure are due almost invariably to human endeavour. Hence actions and functions involving people need to be clearly identified. Laws may go so far without being specific while standards in some cases may not be able to fill the gap. This is where help and guidance may be needed from industry bodies such as welding institutes. The biggest gains can be with improved understanding, use, and performance of people.

The current trend with laws on technical issues is to reduce "prescriptive" requirements which inhibit innovation and prefer "performance" laws which give objectives, matters to be considered, general criteria and performance requirements or outcomes, plus duties of important parties and administrative matters. There is a reluctance to be highly specific in technical issues because of the complexity for politicians and the wide and changing nature of technology. To help apply the law, competent bodies within or outside government are sometimes identified – a good example is the European Union Pressure Equipment Directive. Technical guidance and support is often given by reference to acceptable national or international standards.

7.3.2 Standards

There are thousands of international, regional, national, industry and company standards which are often far from harmonised. They are the distillation and repository of best thinking and consensus aimed to help all parties; industry, law and society, and assist in fair economic manufacture and use of, and trade in quality equipment. Sometimes they are used as trade barriers, but overall have greatly benefited the world. All leading countries have a variety of standards relating to the welding industry with a general trend to harmonised ISO Standards for global use. IIW and its members have contributed significantly in this process.

In national or regional legal codes, e. g. European Directives, mostly general requirements for the function and safety of products are stated. As an example in Annex I of the European Construction Directive (CPD) “Essential Requirements” asks for: mechanical resistance and stability, safety in case of fire, safety in use, hygiene, health and the environment, protection against noise, energy economy and heat retention. Details to those requirements given in legal codes are stated in national or regional rules and standards.

USA and Australia and others vary – all for beneficial outcomes for the nation – some very prescriptive, others less so. EU PED is good.

Standards are the result of deliberate actions by all stakeholders to achieve consensus. They are outside legal requirements and take the form of recommendations that are used voluntarily. Standards are used in practice because they satisfy the needs and expectations of stakeholders and support them in their activities. Moreover, used in combination with more generally worded legal provisions, they make it easier for a manufacturer of a product to prove its conformity with such legal provisions by complying with the requirements specified in the appropriate standards.

Regional standards, like European Standards (EN), take over the task of national standards and unify good practice within the region. European standardisation has already largely taken the place of national standardisation. It may be followed by other regional standardisation. In no respect is regional standardisation a rival to international standardisation. Regional standards should support free world trade and reduce trade barriers. They acknowledge that both technical directives and voluntary European or other Regional Standards need to be harmonised if technical barriers to trade are to be dismantled. This is the cornerstone of cooperation between state and voluntary technical standardisation. Therefore European or other regional standards are important for the function of the Regional Internal Market best for the world.

National and regional standards should be only the first and second step on the way to globally relevant standards.

7.3.3 IIW source of technical knowledge

In 1984, as a result of a change in policy at the International Organization for Standardization (ISO), IIW applied, and was accepted, as an International Standardizing Body to produce ISO standards directly. It was the first such organisation accepted by ISO and is one of three such bodies today. IIW is permitted to issue ISO International Standards, ISO Technical Specifications, and ISO Technical Reports under dual ISO/IIW logos. Approximately 30 such documents have been published to date, and another 15 are in development. This activity has been increasing on an annual basis.

In 2006, it was recognised that further recognition of the technical work of IIW could be achieved if the IIW Journal – Welding in the World – could be registered in the Science Citation Index. A concerted effort was launched, and by the end of 2008, all of the requirements for registration had been completed, and registration was completed in 2010.

IIW, through its 16 Technical Commissions, Working Group Standardization and other Working Units, develops and publishes technical information in the form of reports and peer-reviewed papers, ISO standards, and ISO Technical Reports to address the needs of its members and the general public. There is a significant need in the world today to make this information available in an easy and implementable form for the lesser developed countries. IIW is attempting to meet this challenge by increasing its efforts in technology transfer workshops, International Congresses, and its standardisation efforts.

A guide for the welding industry is needed on up-to-date fair realistic practice on copying anything and fair use of intellectual property.

7.3.4 IIW help for developing nations

IIW began primarily with developed industrial nations as the member countries, due to the fact that the knowledge and understanding of welding was with these members. Over the years it became obvious that technology transfer of this knowledge needed to occur to the less developed countries if world trade was to occur effectively and efficiently.

There is also an ongoing need for simple, practical means for improving water, food, fuel, shelter, health and education especially for children and youth. Developed nations must help on humanitarian grounds alone; and the spinoff for the world should be reduced tensions and gain for all.

One of the greatest needs for IIW was to find a sustainable method to provide technical knowledge to the emerging economies and economies in transition so that they could improve their quality of life and contribute to their economic future. This challenge has been partially addressed by technology transfer workshops and providing mechanisms for these countries to become members of IIW and access to welding knowledge and experts.

Many of the technical reports that are issued annually by IIW are of use and value to the emerging countries, but many are above the basic needs of these countries. There is a great need to develop and provide appropriate welding information in a manner that can be implemented directly at the particular user level. This challenge is currently being addressed through the mechanism of International Congresses that are held in specific regions where the countries in those regions can gather and share information through a conference, an exhibition, personal contacts or other means.

The development of ISO standards through IIW has also contributed to the need for better understanding of various government regulations and trade policies. Through collaboration with ISO TC 44 (the ISO Technical Committee on Welding) and CEN TC 121 (the European Committee on Welding) practical welding standards have been, and are being, developed that are globally relevant, to assist the manufacturing industry in world trade. While the need is still beyond what is currently being delivered, this challenge is being addressed by an increasing number of IIW Working Units developing ISO Technical Reports.

7.4 Needs in laws, standards and technical information

7.4.1 Welding Industry involvement

All welding personnel need to help as far as reasonably practicable to help ensure laws and standards of their country are optimum at least for the immediate future, keeping in mind we are all part of a world where interdependency is increasing. Both are important documents which influence the use of welding technology and proactive, progressive input from industry can improve both.

These documents should where practicable be computerised and be available to industry – easily and if possible freely unless a fee is needed to cover costs. IIW and industry need to assist in the feed-back of successes and failures. This is a powerful way to learn from others and inspire innovation for improvement. A guide for the welding industry is needed on up-to-date fair realistic practice on copying anything and fair use of intellectual property.

Our biggest need in 2012 is help to overcome the global economic and other disasters which will hurt all of us – some much more than others. We need also to learn from these disasters how to behave and to have suitable controls or watchdogs to avoid repetition of failure. We want as much freedom as possible and the right balance of essential controls. IIW and member countries need to continue to give best information and advice to their members and general industry on how to tackle these and other problems.

7.4.2 Optimum laws

Laws applying in some way to the welding industry, ideally need to be simple for those who must comply, in easily understood language, transparent and addressing principles and outcomes required, and provide controls, powers for corrective actions and any penalties. They also need to be readily and freely accessible, transparent and supported by a suitable explanation of essential themes and an impact statement.

Technology should be covered by performance requirements rather than detailed prescriptive technical requirements wherever appropriate, though this is not always possible. Reference to codes of practice and standards may give guidance on technology which is deemed to comply with the law, but changing technology must be accommodated to avoid inhibiting innovation and to assist both parliamentarians and industry.

Society, governments and industry are, for the reasons shown in *Figure 7.1* wary of new or changed technology. The welding industry will need in future to respond by improving the development stage with suitable proving tests and trials.

There is also a need for suitable support for governments to administer the laws and understand the relevant technology to ensure success and help industry optimally implement law.

Law, standards and welding technology come together in the changing area of workplace health and safety, with greater interest being shown by governments and industry. The need for the continuation of the work of IIW Commission VIII in this subject area is clear.

It should be recognised that laws will differ between countries to suit each special need and cater for its history, political system, social and religious system and citizens. With respect to welding technology, IIW and others should continue to consolidate innovations and solutions and transfer knowledge making optimum use of new information technology tools. All of this should contribute towards achieving global peace, healthy security, economy and trade.

There are still significant differences between technical standards in different jurisdictions which need to be minimised e.g. currently there is up to 34% difference in pressure vessel shell thickness for identical conditions, formulae, material, workmanship and safety factors. Such differences need minimising and resolution. Fortunately the above is being tackled and differences are gradually being resolved on scientific grounds as standards gradually harmonise. The international cooperative effort to minimise the differences with design of welded joints against fatigue is an excellent example.

7.4.3 Conformity assessment

All countries have experienced and reported evidence of defective imported and locally produced new or second-hand welded structures and products, and the materials and services required for the above, including heat treatment, NDT and painting. In 2012 there are many notable examples.

Hence, there is growing concern regarding the need to avoid defective products due to the increased risk to all (manufacturers to end-users and operators), increased cost of re-work or recall, loss in confidence in national products and welding technology, and impairment of national essential services, trade and economy.

To reduce these problems, Conformity Assessment (CA) provisions are being required by specifiers and/or law, and cover a combination of:

- Third party inspection.
- Quality systems.
- Design verification.
- Regulatory requirements.
- Good sound engineering and economic practice.

Examples of current CA systems are the:

- European Directives covering 11 modules including type approvals etc.
- ASME VIII quality systems covering assurance, third party inspection, declaration of conformity (MDR).
- Quality Mark Systems for mass produced products.
- Regulatory requirements such as verification and registration of designs and registration of hazardous plant via commissioning inspection. They may include compliance with referenced standards and identification of competent inspection bodies and inspectors.
- ISO work on global supporting Standards.

A minimum level of CA is needed to cover the general safety and interests of each country, its industry, workers and public. Additional CA may be necessary for particular cases to suit the interests of the owner where consequences of failure are high. The level of CA increases and applies to the whole life cycle of welded equipment, from original concept to disposal, especially at commissioning and in-service inspection for conformity.

The success of CA primarily depends on the competency of the parties concerned and the particular people involved. This raises the biggest need and challenge: how to have sufficient confidence in the reliability of the people or bodies responsible for CA. To help in this respect, each country has its various systems of recognition of bodies and personnel for high hazard equipment e.g. State regulatory authorities, ASME, EU Directives for notified bodies, global systems for Non-destructive Testing Personnel and Testing laboratories, and of course IIW with its various qualification and certification systems for personnel and welding companies. International systems facilitate equity and help reduce barriers to trade.

What is needed is an authoritative guide preferably from IIW on the principles, practices and examples of optimum CA at least for the purchase of important welded structures, including reference and relevance of key standards such as ISO 3834 *Quality requirements for fusion welding of metallic materials and ISO 14731 Welding coordination – Tasks and responsibilities*. Also needed is advice on how the CA bridges the gap between law and standards; some laws specify CA required while others reference standards or are silent.

Where legislation is to address CA, industry should make major contribution to law development and revision making full use of the above guide which should promote fair trade and help "caveat emptor" – buyer beware.

7.4.4 Material standards and grouping

Weldments today can use materials from many counties to a variety of standards. There a need for each standard to give guidance, directly or by reference, on properties, material grouping and effects of welding, forming, heat treatments, etc to guide designers and users.

IIW needs to help ISO and others classify weldable materials in standards and specifications at least according to the main grouping systems now used; and also aim for an internationally agreed preferred standard system We are almost there at least with non-ferrous materials. A solution similar to that reached internationally with flanges should be practical.

7.4.5 Welding industry roles

There is a continuing need for the welding industry to help:

- More efficient production of power and use of energy, nuclear, wind, wave solar, hot rock, geothermal, hydro systems and so move to a more sustainable world despite a growing demand for power.
- Reduction of pollution, control of environment and climate change which is impacting on all.
- Conservation of essential resources and including materials, food and water.
- Optimum maintenance and life extension of critical infrastructure i.e. water, energy and food supply, bridges, transport systems of all types, and security.
- Each country needs to get it right and play its role in protecting the world.

For a better world the welding industry in each country needs to encourage competition but not without essential constraints, needed to avoid events like the global economic disaster. The art is to get the right balance as both are needed to facilitate innovation and avoid failure. A brief guidance document could help industry get this right to suit each individual country.

7.4.6 Up-to-date consistent laws, regulations, codes of practice and standards

Laws, regulations and codes of practice need to be up-to-date to avoid losses or increased risks in not using latest technology wisely. Cost and effort in maintaining with advances in technology and social changed attitudes.

Standards are the repository of collective wisdom and consensus. Thus they also need to be up-to-date with the latest R & D and ideas and experience. They need transparency because of increasing global use, and ideally need to be supported by a basis commentary, report or technical paper to help users understand and assist future changes. A comparison with other benchmark standards of critical issues would help users and reduce misunderstanding. With increasing trade between all countries, the harmonising of Standards is desirable and hence ISO and ISO Standardisation needs support.

Uniformity in terms is an ideal aim between various laws and standards within one country let alone 200 countries. As there is so much international trade and communication, however, the need for clear understanding between parties is important. ISO standards need to set an example and not be afraid to include alternatives. The IIW thesaurus has helped but is a big task with so many languages.

7.4.7 Management systems

Modern laws for occupational health and safety, environment, major hazard facilities, dangerous goods, transport etc often give performance requirements in terms of risk management i.e. identification of hazards and their assessment and control to a very low level as far as reasonably practicable. They can identify duties which need to be complied with.

There are many papers on the subject, but a brief review paper, preferably via IIW to give a global view is needed to guide the welding industry. The recent ISO standard on this subject provides an excellent basis.

Great experience has been gained since the early introduction of quality assurance and control systems and standards over 50 years ago. Many errors resulted in their introduction into the welding industry, many gains were made and today quality systems recognised by authoritative bodies are proving valuable. Naturally global, technology, economic and people changes raise new challenges.

There is a need to identify the more important changes, with a suitable review document, and the improvements which can assist all countries, individual companies, etc to make for more efficient, economic, globally acceptable conformity assessment of weldments traded within and between countries.

It is natural to resist change especially these days when there usually are many reasons for and against and when the people concerned are not adequately aware of the pros and cons of any proposal. Thus all players in the welding industry need to properly manage change properly to achieve the best outcomes. Remember change takes time and the quicker the greater the upheaval. Hence national cost benefit should help to determine the pace of change.

7.4.8 Non-conformances

With reference to weld acceptance standards for low stressed welded equipment, guidance is needed here because the workmanship standards for highly stressed welds are excessive and result in non-conformances, excessive unnecessary NDT, dilemmas and costs for users and inspectors e.g. small bore (below 75DN) piping for pressures less than 0.5 Mpa with wall thickness 20 times that needed for the pressure.

Similarly guidance is needed with regard to uncertainty and variability in measurements. For example, in hardness testing on site in difficult conditions, what should be done if a reading is Rc 22.5 in place of the maximum specified of 22 and the unstated “uncertainty” of the only available testing equipment is say ± 3? Appropriate standards should address this to avoid cheating or misuse.

Other examples include uncertainty in material identification which can lead to unwarranted assumptions and worsening of a situation during a site repair. This is not likely to be avoided by a high level fitness for service assessment using FEA and fracture mechanics though this response is becoming more frequent as new personnel enter the industry and others do risk assessment for themselves and their professional indemnity insurance.

Some countries resolve these issues through national recognition and empowerment of competent bodies and personnel, though reciprocal international acceptance is an on going challenge particularly for economic and fair purchase and trade in goods and services.

There is a need for IIW to:

- Recognise these programs serve a very useful purpose for each country concerned as well as globally.
- Issue a guidance report summarising the essential features and scope of each, using the input provided by each country and IIW giving approximate costs and numbers.
- Issue a guidance note for industry explaining the value of these programs, certification and qualification, how they work, the options available and the long term aim of IIW to simplify and improve globally.

7.4.9 Strategies for unified standards

From a global trading position, it is desirable to have international product standards for fabricated items such as pressure vessels, bridges, ships, transmission pipelines, boilers, railway vehicles, and probably

structures. It is unlikely in the short term that such international standards will be developed and universally adopted. Rather, it is expected that a small number of product standards will be applied internationally for each industrial sector.

Whilst this may be the case for the product standards, such standards rely on fabrication standards that may be stand-alone documents or a group of supporting standards that cover the essential areas where fabrication control is needed. These areas include, welding procedure development and qualification, the verification of welder skill, inspection requirements, dimensional and imperfection acceptance criteria, NDT techniques and requirements for the qualification of NDT operators amongst a range of supporting criteria. They also embrace the specification of base materials and welding consumables and the documentation of knowledge to provide guidance on the avoidance of welding defects and the application of good practice in the fabrication activities carried out.

IIW has already played an important role in the development of ISO standards for welding filler metals and ISO standards for testing of filler metals. A unique partnership has grown among IIW Commission II, ISO TC44 SC3 and CEN TC121 SC3 that has, in a few short years, produced a now nearly complete set of ISO filler metal standards. This partnership will continue to fill in the missing pieces to round out the portfolio of these standards, and momentum for adoption of these standards as national standards in major parts of the world is building.

IIW can play a pivotal role in developing certain of these supporting standards as well as promoting their adoption in regional and national standards that find global application. In developing this aim, the following strategies are identified:

- Developing in association with ISO/TC44, globally relevant, supporting welding standards where IIW has technical competence and is able to incorporate the development in its working programme.
- Preparation of technical, welding-related guides to enable users avoid making unsatisfactory welds where IIW has the competence to develop such guides and can include such projects in its working programme.
- Promotion of international supporting welding standards through the publication of articles in the technical literature, the submission of proposals to technical committees preparing product standards and the personal involvement of IIW member societies and working units with product standardising bodies.
- The preparation of IIW briefing documents giving explanations about international standards and encouraging their adoption by standardisation organisations in developing countries.

7.4.10 Challenges in laws, standards and technical information

All of the needs listed above require tackling appropriately. Some can be done quickly while others may take some time. All will be subject to evolution. At present we live in globally challenging times which will require our best thinking and endeavours to resolve with minimum harm to all.

The challenges the world and the global welding industry face are:

A) How are we to meet these needs which will vary from country to country? We all will need patience, tolerance, fair play and follow the rules, and need to recognise in making progress there:

a) are usually many ways of tackling and solving problems;
b) is rarely one universal optimum solution because of varying conditions;
c) is usually a need for a proper balance and flexibility to achieve practical solutions and optimum compromises necessary for agreement;
d) is the need for good leadership and management.

B) Who should undertake this work in times of economic pressures?
C) What are the **priorities and timing** of work to satisfy the above needs?

7.4.11 Strategies to meet needs & challenges in laws, standards & technical information

These are:

- IIW should set an example by gradually addressing each of the identified needs, using one member country to do the initial work review on one listed need and propose a suitable priority solution and action, keeping in mind the challenges identified above.
- IIW should be a focal point for coordination of this effort and outcome. It should strengthen cooperation and its important role of voluntary technology transfer globally with support from member countries.
- All parties involved should consider what action they should take to meet the objectives of the White Paper, and if appropriate utilise IIW.
- We should all, where practical, help improve the quality of and access to laws, standards and technology data.
- IIW, technical societies and institutes should continue and improve as appropriate with increased use of computerisation.
- Copies of this paper should be given with a suitable covering note to those major organisations involved in some way with the optimum use of welding technology. There is something of value to most e.g. UN, ISO, WHO, WTO, ILO, welding societies and institutes, standards bodies, regulatory authorities, and research, education and training bodies.

Needs and challenges for global communication

8. Needs and challenges for global communication

8.1 International networks and IIW

IIW undertook a major review of its business plan in 2007 involving all of its working and administrative units. This plan (2008-2012) is reviewed each year holistically and by each administrative and working unit.

Some key IIW objectives, amongst others are:

- Identify, create, develop and transfer world's best practices.
- Identify, develop and implement the IIW Education, Training, Qualification and Certification (ETQ&C) Programmes on a global basis.
- Promote IIW, its Member Societies and services in various regions of the world to the mutual benefit of all.
- Implement the IIW's outcomes.
- Provide quality services to IIW members and other organisations.

To achieve these objectives in practice, experts from around the world are voluntarily working in 16 Commissions, 5 Select Committees, 2 Study Groups and a host of Working Groups or other units on a permanent basis to stimulate and co-ordinate research and technology diffusion, and to diffuse information on welding technology, its application in terms of materials, processes, design and inspection and other associated subjects such as health and safety, education, training, qualification and certification, terminology and documentation.

The policies of IIW are decided by the General Assembly at which are represented all the national member societies. The General Assembly elects the President of IIW and the members of the Board of Directors which directs the affairs of the IIW. The day-to-day work is ensured by a five staff member permanent Secretariat based in Paris. Under the responsibility of a Chief Executive, the Secretariat includes a Scientific and Technical Officer, a Standardization Officer a Communications Manager and Secretarial Assistant.

The Secretariat also maintains contact between IIW and other international bodies such as the International Organisation for Standardisation, United Nations agencies and others.

The Board of Directors has a Technical Management Board (to which over 20 working units report), as well as three other Working Groups; Communications and Marketing, Regional Activities and Liaison with Developing Countries and Standardization reporting to it.

By far the greatest contribution from Member Societies comes in the form of the input of their delegates to the working programmes of the Commissions. The cost of delegate's attendance at Annual Assemblies and

any intermediate meetings of Commissions and Sub-Commissions are borne by their Member Societies or the delegates' employers.
The Institute, in July 2007, finalised its new Business Plan involving all administrative and working units to ensure ownership by all participants over the 2007-2012 period.

8.2 Technology diffusion strategies to meet challenges to be "world centre" of knowledge, innovation and best practise in welding and joining

The economies of many countries often depend on the performance of the small to medium enterprises (SMEs). For example, the Australian economy now depends on 97% of Australian Industry being classified as SMEs and 60% of these have less that 20 employees. Anecdotal evidence suggests that probably 10% seek to improve themselves through the adoption of proven technology and only 1% are probably prepared to invest time and money in new technology.

The sources for such technologies include the 2-3% of research outcomes generated in Australia (through universities, Cooperative Research Centres (CRCs), Commonwealth Scientific and Industrial Research Organisation (CSIRO) and industry laboratories), as well as the 97-98% of research outcomes generated in the rest of the world.

Through IIW Member Societies (often not-for-profit industry institutes/associations) and their technology/diffusion/innovation cooperative programmes, thousands of SMEs in each country are assisted each year with the support of a wide range of industry sectors and governments. This helps create and implement highly successful innovative outcomes, giving tremendous value and return-on-investment to the country.

These national industry institutes/associations/organisations have painstakingly built up basic infrastructure of nationally sourced expertise and capability and developed international technology linkages. This has increased their capacity and legitimacy to provide a broad range of technology diffusion and collaboration services, and have established a sound industry support structure both within themselves and with other players in the innovation system such as other industry associations.

A unique example is the OzWeld Technology Support Centres Network established in 1998 by the Welding Technology Institute of Australia (WTIA), which is still today successfully helping Australian Industry become locally and globally competitive. These Technology Support Centres (TSCs) both within Australia and overseas, including the research providers noted above, with the support of Federal, State and Territory Governments and industry, provide significant technology support to the industry as a whole, and innovation at all levels.

8.2.1 IIW Member Societies

The IIW Members are often the national welding institutes/industry associations which recognise the need for innovation. These organisations are focusing on the diffusion of latest technology into industry. They have a non-sectoral approach i.e. across all industries and industry sectors utilising a variety of enabling technologies covering manufacturing, fabrication, construction, repair, maintenance and other services such as inspection and testing and related training.

Their programmes often give a strategic, national dimension encouraging industry collaboration and technology diffusion on a large scale as well as identifying new global sectors of industry activity where their industries can develop both "niche", world-class competitive edges as well as implement the appropriate technologies to the country's needs.

They also accelerate the take up of new technology, so firms can access the best ideas from around their country and the rest of the world. They also strengthen publicly funded innovation and research

infrastructure to develop multiple pathways for industry to access the knowledge and expertise in universities and research agencies.

Such organisations therefore help to deliver sustainable development and economic growth of industry through:

- Supporting strategic manufacturing (and allied) industries and their enabling technology sectors.
- Giving greater access and direct exposure of SME firms to new and emerging technologies.
- Providing skilled technological assistance to a range of companies, particularly SMEs, who need and want varying degrees of such assistance i.e. extend the range of SMEs assisted.
- Facilitating collaboration and cooperation between new product development contributors.
- Stimulating and implementing collaborative activities between Multi-National Corporations (MNCs), SMEs and micro-enterprises and industry Associations.
- Establishing key mechanisms to enhance university and graduates and industry interaction.
- Disseminating industry best practices to companies on a coordinated national basis.
- Improving the capacity of national non-profit industry support organisations and centres of expertise to support the objectives of the IIW and its members working together.

These outcomes can be delivered in the technology diffusion processes that occur within and also across "*industry verticals*", and involve the application of technologies and skills which are pervasive and transforming in nature.

8.2.2 Key Actions and Activities in Technology Diffusion

***Technology Diffusion* is a vital element of the total innovation process with the key activities being as follows:**

- Initially identifying and analysing the needs of industry.
- Sourcing solutions to meet these needs including R&D.
- Diffusing the technology and information into companies, particularly SMEs and micro-enterprises.
- Adopting, adapting and implementing new technology/information by technology receptors.
- Improving performance of the companies through innovation.
- Providing feedback for further national improvement at each stage of this technology and information process.

Many IIW Members have strategic plans containing a number of the key actions shown below, as well as conducting many of the key activities listed against each key action.

Table 8.1 – *Key actions and key activities of IIW Members*

Key actions	Key activities
A. Analyse the needs of industry	• Industry and Technology road-mapping • Workshops • Industry Mapping/Surveys • Industry Groups (clusters, alliances, etc) • Individual companies • Product and process reviews • Technology audits • Feasibility studies • Feedback from SMEs and Key action C below
B. Source solutions to meet the identified needs	• Industry Clusters • Cooperative, collaborative, pre-competitive R&D • Network of technology support centres • Centres of expertise • International collaborative arrangements • New group projects/demonstration initiatives • Research outcomes and personnel • Universities, Cooperative Research Centres, Colleges • Global bodies of information and experience • MOUs with international technology centres
C. Diffuse through technology mechanisms the technology and information into companies	• Prototype testing and trialling • Conferences • Exhibitions • Cluster events • Technology awareness forums • Technology demonstrations • “Expert Technology Tools”, specific technical notes, etc. • Technical help desk/hotline • Information website • Libraries • Industry study missions • Visits by overseas experts • Publications and journals • Training courses • Skill competitions • On-site face-to-face visits • Problem solving • Industry expert/specialist advisers
D. Ensure optimum technology receptors	• Alliancing with training providers (universities, colleges, RTOs) • Up-skilling including greater use of university and college graduates • Training of new entrants • Careers promotion • Image improvement • Education and training courses at all levels • Qualification and certification of personnel and bodies • Training aids • Train the trainer

Table 8.1 *Key actions and key activities of IIW Members (cont.)*

Key actions	Key activities
E. Adopt, adapt and implement technology diffusion activities	• Support, back-up and guidance to technology receptors • Expert Technology Tools • Product and process improvement support • Commercialisation
F. Measure improved performance and benefits	• Assess the value • Benchmark – SME performance • National statistics – collate and use (including benchmarking)
G. Feedback	• Create additional research projects • Improve national and international Standards • Improve local technology support centres • Improve local training facilities • Improve technology diffusion activities • Reporting successes (globally) • Reporting failures (globally)

8.2.3 IIW WeldCare Programme

Through the IIW Board of Directors Working Group Regional Activities and Liaison with Developing Countries, IIW is endeavouring to assist countries throughout the world, utilise many of these communication and technology diffusion strategies. This is done through the IIW WeldCare Programme.

IIW has tremendous strength in its member countries. Its member societies have resources to assist in establishing within a particular country or region:

- An organisation that would be responsible for the promotion of welding technology and related disciplines.
- The required welding education and training infrastructures.
- The appropriate technologies to assist the different industries being established and able to be self sustaining.

A proper business plan for each country would, however, need to be devised, financially supported and implemented with appropriate milestones and key performance indicators.

Depending upon the geographic size of the country, its industrial size and distribution an appropriate master plan should be possible.

Such a plan would consider assistance to companies through:

- Provision of Technical Information and Advice.
- Technical Problem Solving.
- Applied Research and Development.
- Transfer of Technology.
- Related Training.

The WeldCare Programme is based on a model of Technology Innovation, initially implemented in Australia, and now promoted throughout the world.

Major strategies of WeldCare include:

- Development of mechanisms to introduce the model to different countries and regions of the world.
- To establish, implement and sustain national and regional networks of Technology Support Centres and Educational Support Centres.
- Identification of “champions” around the world to help promote WeldCare.
- Liaison with aid agencies to support the model.
- Assisting in the establishment of national welding institutes and associations.
- Liaison with industry and government.
- Implementation of campaigns to help raise the “image of welding“.
- Establishment of recognition awards for organisations and individuals involved in education and training around the world.

Over the past 20 years, many examples can be given of projects where IIW member countries have assisted both member and non-member countries to improve their welding technology and hence quality of life. The main emphasis is on education, training, qualification and certification.

IIW is actively cooperating with Aid Agencies to expand these types of projects through its IIW Weldcare Programme.

Needs and challenges of major industry sectors for future applications

9. Needs and challenges of major industry sectors for future applications

To become more competitive globally, all industrial sectors will continue to strive for more innovative, integrated, efficient and safe ways of doing business. At the same time, the need to protect Mother Earth also means that design, manufacturing, construction, operational and repair processes must give sustainable development in a sustainable environment. The challenge to upgrade existing products, manufacturing methods and plants has to be in place to meet environmental friendly standards. This means that, in supporting these demands in all industrial sectors, technological advances in material and welding processes have to keep pace. The needs of, and challenges for, major industrial sectors are reviewed and briefly outlined in the following sections.

The pie chart of welding market per industrial sector is shown in *Figure 9.1*. The main driving factors behind the development of joining technologies for sheet and plate, are the automotive and shipyard industries.

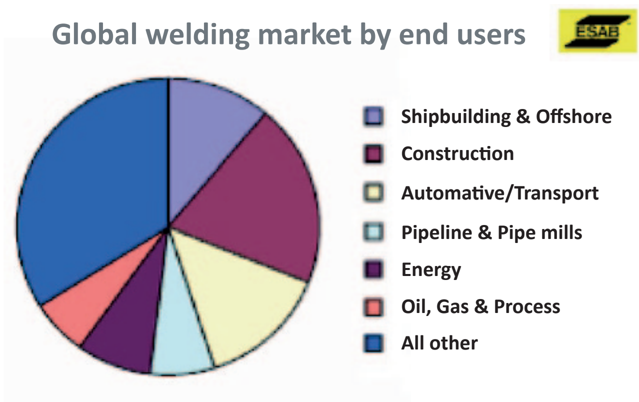


Figure 9.1 *The welding market for consumables, equipment and services is estimated to be about US$15 billion (Reproduced courtesy: ESAB)*

9.1 Energy sector

The European Community Framework Programme (FP7) describes the overall objective for the 21st century with the following statement; "*Adapting the current energy system into a more sustainable one, less dependent on imported fuels and based on a diverse mix of energy sources, in particular renewables, energy carriers and non polluting sources; enhancing energy efficiency, including by rationalising use and storage of energy; addressing the pressing challenges of security of supply and climate change, …*"

Such world-wide strategic objectives for sustainable, competitive and secure energy sources creates new technological challenges to materials scientists and welding technologies to create new infrastructure and to maintain safe structural performance during operation.

New discoveries tend to be in deepwater (>300 m) harsh environments (both climate and product-wise) Transportation of fuels will become of increasing strategic importance. These challenges for exploitation necessitate the wide-spread use of new materials, both in terms of strength to weight ratio and corrosion resistance. With novel materials, or materials combinations, comes the requirement for reliable, enduring and *cost-effective joining methods* as the key enabling technologies for their successful introduction.

IIW's position as a worldwide expert network contributes significantly to the dissemination of relevant know-how and experience. Of particular relevance are: new developments in high-productivity arc welding, especially for pipelines; repair technologies; advanced manufacturing concepts; power beam and hybrid processes; and dissimilar materials joining. In addition to the needs and challenges for joining processes, there is the requirement for the safe through-life performance of offshore structures. Hence, in this sector, improved weldability and life-long structural integrity of new high strength materials and welded advanced structures operating in extreme service conditions will continue to be key issues in future applications.

9.1.1 Energy consumption and power generation

The Exxon forecasts of the energy consumption per energy source (*Figure 9.2*) and region (*Figure 9.3*) and as well the development of light vehicle fleet (*Figure 9.4*) show a very high growth in Asia and specially in China. The economic drivers such as gross domestic product and population are the main ones.

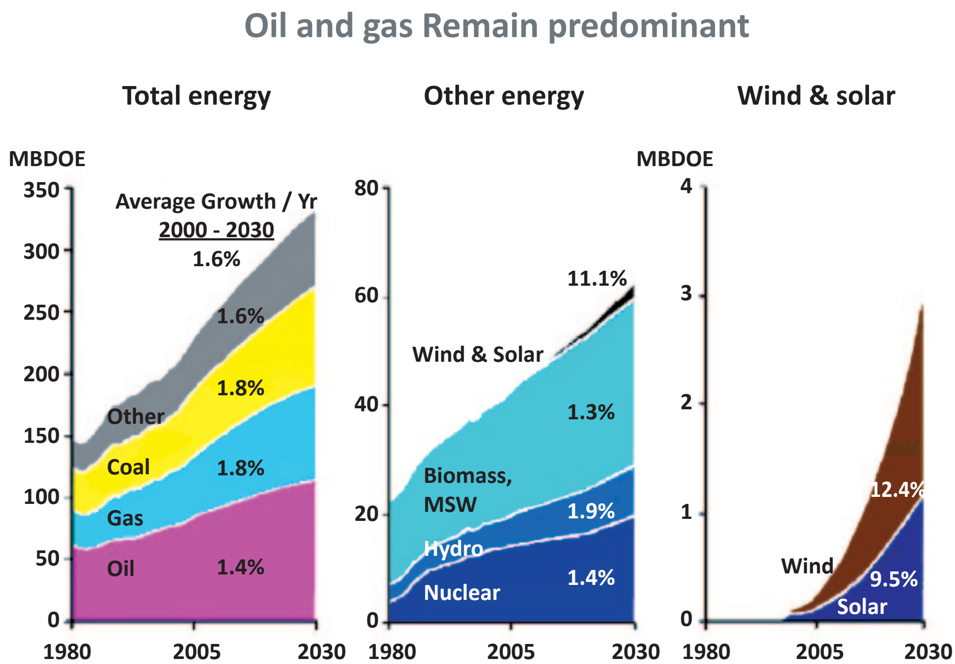


Figure 9.2 *Forecast of the energy consumption per energy source*
(Note: MBDOE stands for million barrels per day of oil equivalents)
(Reproduced courtesy: ExxonMobil)

The energy demand will increase 50% by 2030. 80% of energy demand growth is forecast to be in non-OECD countries. Oil, gas and coal will remain predominant energy sources with roughly an 80% share of total energy. Wind power has a high annual growth 11.1% and it is attracting a lot of interest and very ambitious investments plans are set. There are experts, however, judging these as unrealistic. Instead, there are beliefs that investment in nuclear power will be more acceptable even with the recent problems in Japan. This will definitely result in increased demand for R&D in materials and processes to meet the stricter requirements for quality and safety.

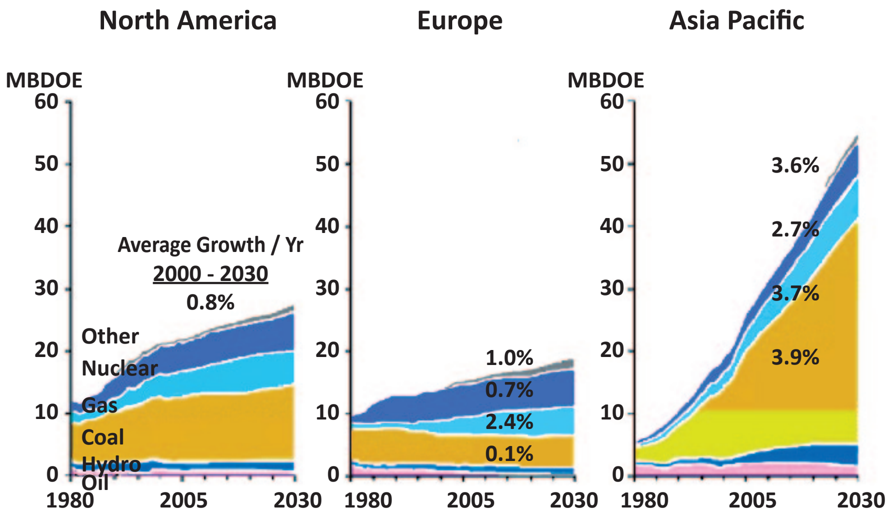


Figure 9.3 *Power generation regional split - Coal will be the dominating energy source in Asia Pacific (Reproduced courtesy: ExxonMobil)*

In Asia Pacific, coal demand continues to grow rapidly, as with other energy types, at just over 3 % per year. This growth will be reinforced by Asia Pacific's massive coal resources. In Asia Pacific, however, the fleet is expected to nearly quadruple up to 2030. The energy demand in Asia Pacific and India will force the extraction of gas and oil, which must be increased. *Figure 9.5* is showing the distribution of reserves.

The energy sector and especially wind power generation is growing in importance depending on the firm commitment by governments to reduce the negative environmental impacts. Wind power grew with 19% year 2006 but corresponds only to 3% of the total electrical power generation. The capacity for nuclear power is also expanded and there are 45 plants under construction worldwide. One of the major concerns is the storage of the radioactive waste. Detailed investigations on how to solve this task is ongoing in many countries. Which joining process is most suitable; FSW, EB or TIG to close the canisters for the waste?

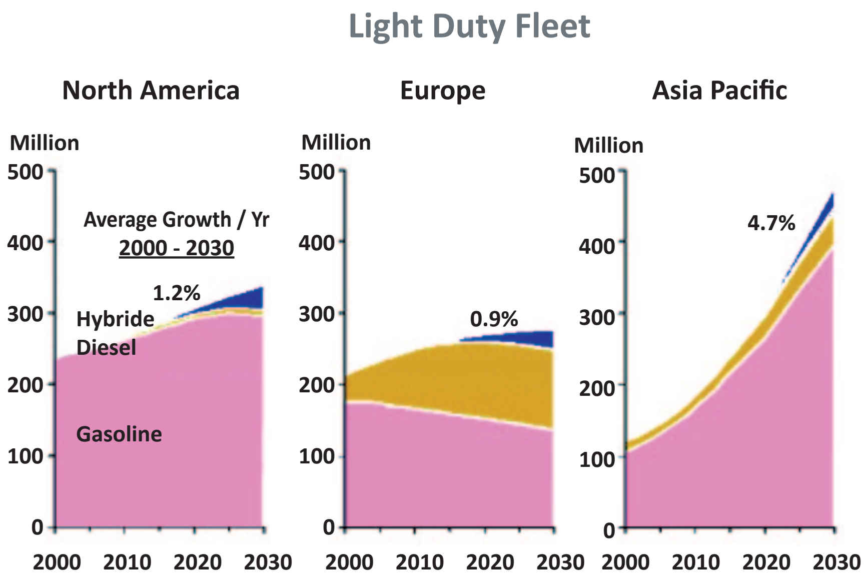


Figure 9.4 *An impressing growth of the vehicle fleet in Asia Pacific (Reproduced courtesy: ExxonMobil)*

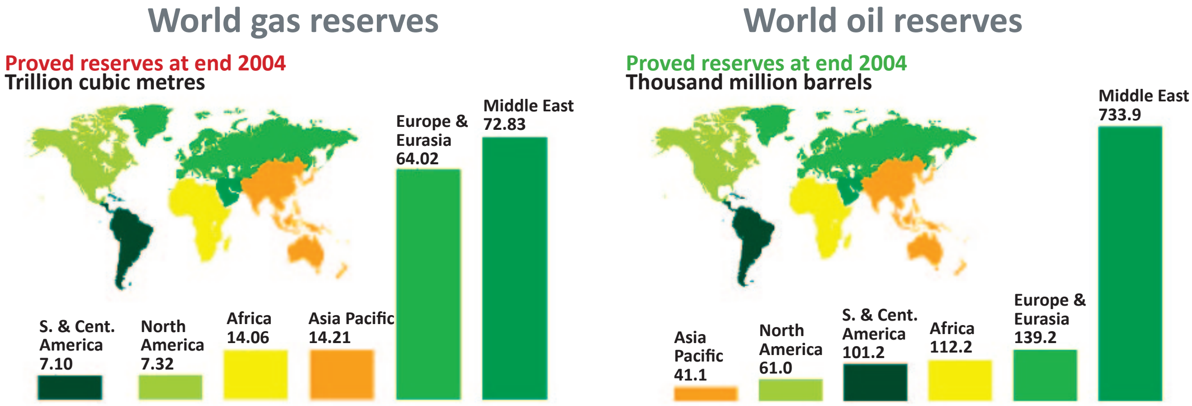


Figure 9.5 *Distributions of oil and gas reserves (Reproduced courtesy: TWI Ltd)*

9.1.2 Power - Fossil

Every country, industrialised or not, has the obligation and is responsible for its own effort in improving the quality of life of its citizens without negatively impacting on the condition of the environment. Any successful developed or developing country relies on a steady and stable supply of electric power. Historically, the global power generation industry has been a notoriously bad performer with regard to preservation of the good health of the environment. Paradoxically, it's also this sector of industry that can achieve large improvements to negative side effects through perceived modest adjustments to the way the business is conducted. Some of these include the introduction of gas conditioning plant to curb emissions of harmful species, changing to cleaner burning fuels, and more recently, by building new plant with increased efficiency by opting for supercritical or even ultra supercritical steam generating plant. Unfortunately, these adjustments usually come at a great increase in the cost of generated electricity, especially when erecting new power stations that includes recent advances in power generation technology.

For the power generation industry moving forward to 2020 and beyond, aligning welding activity strategies will require careful evaluation and investigation of many factors that could play a major role. Promotion of techniques with reduced negative impact on the environment, efficient utilisation of refurbished existing assets and an intensive skills development programme are but a few of these.

It is often alleged by both pessimists and realists that most of the engineering problems of the day have been solved already, and that from results for the majority of research projects more and more is reported on less and less. Notwithstanding this view, history has shown that there will always be room for improvement on finer details which if these improvements are promoted correctly and introduced in a cost effective way can make a difference to the bigger scheme of events.

Technology Trends

The power generation industry is no exception and potentially many improvements to current designs and technology can still be achieved through the introduction of novel welding and joining techniques. One such field were this industry appears to be a laggard is the use of solid state welding processes for the fabrication of power plant components. Benefits associated with this welding process are:

- Superior weldment quality compared to traditional arc welding techniques.
- Simple equipment requiring relatively low levels of operator training.
- Reproducibility of welding parameters.
- Refurbishment of component damage previously considered not viable for weld repairs.
- Low impact on the environment with regard to generation of gases.

The FSW process has been considered by the aerospace industry in recent years, mainly because the fabrication process of high value components can support the use of relatively new and expensive friction welding equipment. Also, the use of relatively soft materials such as aluminium alloys perceived to be ideal for the utilisation of the solid state processes further provided impetus to the development of tool materials and equipment requiring reasonable levels of input power. Rapid developments on tool materials has however opened the door for investigation on the application of the FSW process to higher strength materials such as carbon steel and stainless steel which in effect now opened the door to investigate the feasibility of the wider application of solid state welding in the industry.

Improvement to efficiencies by extending the economical life of existing plant with the aim of also reducing the burden on the environment involves elaborate studies to determine accurately the condition of the plant critical components. The life extension of plant operating up to mid and advanced percentage of the design life requires detailed evaluation of the high pressure and temperature components with special emphasis on:

- Fraction of creep life consumed.
- Fatigue damage (combination of environmental, mechanical and thermal).
- Material wastage due to flow induced mechanisms.
- Corrosion damage effects.

Once the leading components with respect to life consumption are identified, refurbishment involves a combination of repairs of some of the components and replacement of components beyond economic repair status. Philosophies around the economics of weld repairs typically rely on an intricate balance between:

- Their required extension of life.
- Introducing state of the art new technology into dated infrastructure.
- Available investment.
- Refurbishment technology to be used.
- Replacement materials available.

From this point onwards in the refurbishment process, the welding function features prominently in a company's strive to contribute to the effort in slowing the deterioration of the environment by:

- Refurbish rather than replacing components where possible.
- Optimal use of scarce resources including raw materials and energy.
- Recycling of discarded material and consumables.
- Utilisation of procedures and techniques that put a lower burden on the environment.

Legislation for mandatory minimum responsibilities of the suppliers of power plant towards the design of components with minimised 'carbon footprints' is another aspect that require urgent attention. In the same way as electronic companies and car manufacturers in certain countries are required by law to take full responsibility to supply products to consumers, that can be fully recycled in an environmentally friendly way after expiry of the product's useful life, the same should apply to suppliers of heavy power plant equipment. For example, components such as turbine casings and large valves manufactured from heavy wall castings, should lend themselves to easy refurbishment by welding through careful selection of more weldable alloys and a modular type of design, that is designs where areas prone to wear and/or material exhaustion can be readily replaced by new material through weld joints at non-critical areas. Cast iron is popular for its good casting characteristics while being relative cheap as well, but is notoriously difficult to refurbish successfully through welding processes. By rather opting for a slightly more expensive basic good steel casting that is easily weldable, the life expectancy in theory could be infinite through periodic weld repairs in critical areas. One less scrapped casting effectively can in effect reduce several tons less of harmful gases emitted into the atmosphere by an inefficient foundry.

A major challenge for the refurbishment of aged plant is that welding specifications are firmly biased towards the requirements for building of new plant. Significant engineering intervention is often required to support weld repair procedures that sometimes appear to be outside or in conflict with established welding specifications. Of particular significance are:

- The non-availability of original construction material-advances in CrMoV type creep resistant alloys implies that aged material needs to be joined to a new generation alloy.
- The long term operating performance of new to old material joints is often based on extrapolation of limited laboratory test data.
- Welding personnel are not always familiar with the weldability of the latest alloys.
- Inspection techniques accurate and sensitive enough to isolate exhausted components from relatively undamaged components still good enough for extended operating life.

The refinement and modernisation of traditional welding processes and techniques has contributed to significant improvements in efficiency of the welding activities. The introduction of more energy efficient inverter power sources has the potential to contribute towards reduced production costs, while the improved controls of the latest equipment proves to be more forgiving to inexperienced coded welders and in effect lightens the burden on the fast shrinking pool of highly skilled artisan welders. In a way, this might be in contradiction to the drive for skills development but in reality should rather be seen a saving grace situation while the welding industry struggles to reduce the acute shortage of skilled welders by luring young people towards the industry through rationalisation of training curriculum and efforts to introduce a universal qualification system acknowledged on a world-wide basis.

The underground Coal Gasification (UCG) process is considered as one of the new emerging energy sources, which converts unworked coal into a combustible product gas. The gas is suitable for industrial heating, power generation or hydrogen and natural gas production while CO_2 can be readily removed from the product stream thus producing a source of clean energy with minimal greenhouse gas emissions. Future design, fabrication and safe operation of highly steerable and controllable down hole assembly for drilling in coal up to 450 m depth, will certainly require high performance structural steels and weld joints. This will be one of the highly complex technological challenges of the future applications of the welded structures.

Figure 9.6 shows material grades which are currently used for high temperature components in fossil power plants. For all components exposed to high temperatures during service, the 100,000 hour creep rupture strength of base material (BM), weld metal (WM) and cross-welds is the major design criteria.

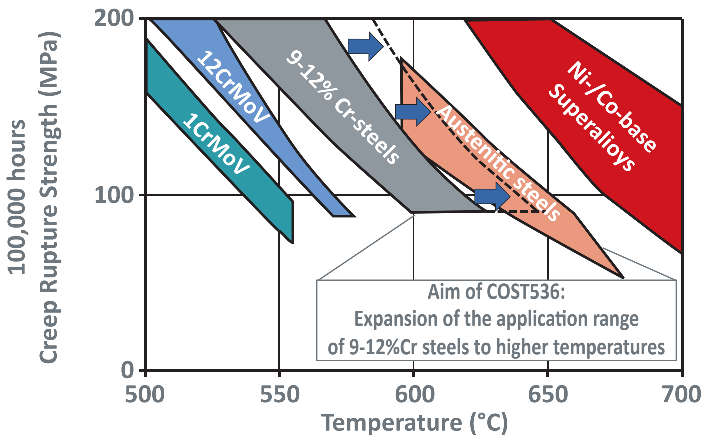


Figure 9.6 *Materials used for high temperature applications in thermal power generation (Reproduced courtesy P. Mayr, based on data from T.U. Kern, Siemens, Germany)*

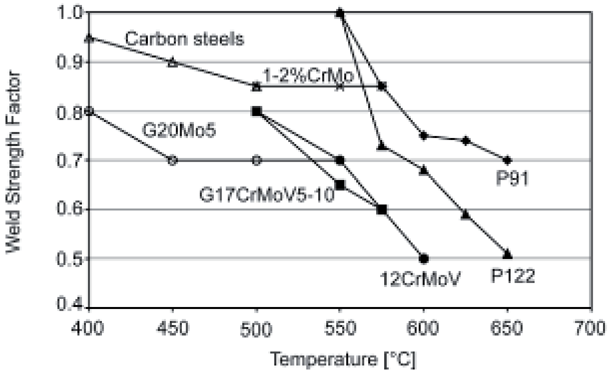


Figure 9.7 *Weld strength factors (WSF) for the 100,000 hours creep rupture strength of different steel grades (Reproduced courtesy P. Mayr, based on data from M. Tabuchi and Y. Takahashi [2006 ASME Pressure Vessels and Piping Division Conference], and J. Schubert, A. Klenk and K. Maile [2005 International Conference Creep and Fracture in High Temperature Components – Design and Life Assessment issues])*

Long lasting experience with creep exposed welded structures has shown, that the HAZ is, because of the mechanism of "Type IV Cracking", often regarded as the weakest link, in respect of creep strength, in welded constructions.

Type IV cracking is defined as the formation and propagation of failures in the fine-grained HAZ and the intercritically heated region of the HAZ. Type IV cracking has been reported in low alloyed ferritic/bainitic steels (½Cr½Mo¼V, 1CrMo, 1CrMoV, 1¼ Cr½Mo, 2CrMo, T/P22, T/P23, T/P24), as well as in ferritic/martensitic 9-12%Cr steels (P91, X20CrMoV121, P92, P122, E911). Type IV cracking is considered as the major "*end of life*" failure mechanism for ferritic creep resistant steel weldments in the power generating industry. *Figure 9.8* shows the appearance of Type IV cracking in an E911 cross-weld.

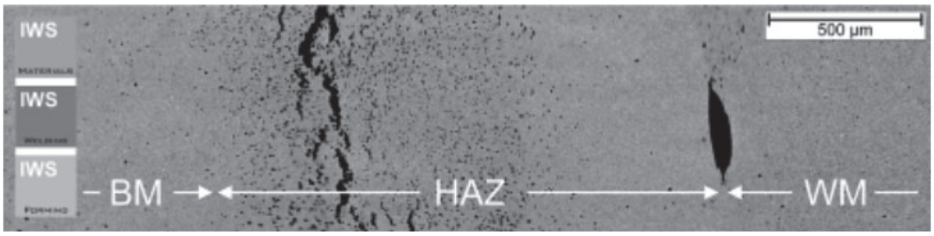


Figure 9.8 *Cross-weld sample prepared from E911 pipe welded with matching filler and creep tested at 600°C for 14,000 hours. Very localised formation of voids and their coalescence to macro cracks at the outer region of the HAZ observed by SEM led to final fracture [Reproduced courtesy: P. Mayr]*

General acceptance of the necessity for long term creep testing data of cross-welds, weld metal and base metal for reliable material selection is inevitable. The awareness of designers, engineers and operators of the risk of extrapolating results of short term creep tests to longer times has already contributed to an increase in safety. In Japan and Europe a 9Cr-3W-3Co steel with controlled addition of boron has been investigated. Contrary to the creep resistant steels recently used, this steel does not show the formation of a fine-grained region within the HAZ. By the elimination of fine grains in the HAZ the formation of creep damage by Type IV mechanism, which is strictly limited to fine-grained regions, should be avoided. Although the mechanisms active in this steel are still under investigation, this might be a possible approach for the prevention of Type IV cracking in advanced creep resistant 9-12% Cr steels. This will help to increase the efficiency of advanced fossil power plants for sustainable energy supply and to contribute effectively to the reduction of CO_2 emissions.

9.1.3 Hot topics

- Reducing negative impact on the environment e.g. by introducing gas conditioning plants.
- Efficient utilisation of refurbished existing assets and life extension of existing plant including appropriate welding repair specifications, technologies and inspection.
- Building new plant with increased efficiency e.g. supercritical or ultra supercritical steam generating plant.
- Changing to cleaner burning fuels, with accompanying asset modification.
- Refurbishment rather than replacement of worn components.
- Recycling of discarded materials and consumables.
- Utilisation of procedures and techniques which put a lower burden on the environment e.g. uptake of solid state welding processes for fabrication of power plant components.
- Improved plant condition monitoring e.g. creep testing.
- Retention of skills, and development of personnel to support technologies and welding management.

9.1.4 Power – Nuclear

The challenges in the development of robust welding technology for nuclear reactor materials hold the key for sustainable development of economic, safe and environmentally friendly nuclear energy. The development of new as well as improved variants of nuclear reactor materials needs adaptation of the latest advances in welding technology to ensure cost-competitiveness of nuclear power. The present maturity in understanding of the science of welding has to be utilised for developing suitable welding consumables for the advanced/ improved materials as also for evolving appropriate repair welding technologies for existing nuclear power plants. The innovative welding technologies, like activated TIG welding, friction stir welding, hybrid welding, have to be harnessed to enable their industrial application for fabrication of nuclear reactor components. Tools like artificial neural networks would find increasing application in ensuring high quality welds. Computational, experimental and theoretical are the three pillars to meet the demands of desired performance and regulatory requirements. On the long-term, development of fusion technology will be crucially dependent on the development of appropriate welding technologies for materials like low/reduced activation ferritic-martensitic steels and oxide dispersion strengthened alloys.

Multi-disciplinary intelligent welding approaches are being increasingly adopted for realising high performance welding technology through synergistic use of sensors, evaluation, modelling and automation. An intelligent welding system, equipped with sensors, artificial intelligence and actuators to sense and control welding operations in real time would reduce the occurrence of defects in welds and would also guide the welder to eliminate errors while providing the adaptability needed to accommodate the variability found in the welding process. Online monitoring of welding processes is feasible through synergistic use of sensors and modelling for evaluation of narrow gap welds and resistance welds in high performance components. The application of artificial intelligence methods in the field of welding is exemplified through the development of quantitative models using artificial neural networks for predicting ferrite content, solidification mode and weld-bead geometry in austenitic stainless steel welds. The models for ferrite content and solidification mode can be effectively used for designing the welding consumables having chemical compositions that minimise hot-cracking susceptibility in austenitic stainless steel welds, while the models for weld-bead geometry can be used for optimising welding process parameters for obtaining high quality welds. Research efforts are continuing worldwide for increasingly applying artificial intelligence methods in automated welding.

Nuclear power is expected to play a key role in the global energy scenario in the coming years, especially in the context of the rapid depletion of fossil fuel resources and increasing concerns about climatic changes

both globally and for specific countries. A nuclear reactor is far more environmentally friendly as compared to fossil power generating station, as it does not emit any potentially hazardous, green house gases such as CO_2, SO_2 and oxides of nitrogen. Nuclear power can be generated using both the fusion and fission reactions, of which the fission based nuclear technology is well established. On the other hand, fusion which offers limitless power resources, needs to overcome several challenges related to materials and associated technologies, in order to become commercially viable.

For the sustained growth of nuclear energy, it is important to ensure that the cost of nuclear energy production is economical, as compared to other energy resources. For this purpose, research in welding technology is vital for the sustainable development of nuclear energy.

Welding is a manufacturing process that is critical for the successful construction and safe operation of nuclear power plants. With the prevalence of fabricated metallic components, such as pressure vessels, pipe work, liners and cable trays, the scale of the welding task is very large for both onsite and offsite fabrication. For example, on the Olkiluoto EPR (French Nuclear reactor of 3d generation) build project there are approximately 200 km of piping and about 30,000 welds within the nuclear island alone. Industry and other stakeholders must be confident of the quality and integrity of welded joints, particularly as the next generation of nuclear power plants is expected to have a design life of at least 60 years.
Ensuring welding quality is challenging and can be costly. Most often it is examined in the finished product and, in instances where quality criteria are not met, costly and time-consuming repair and rework can result. Approaches used in other industries that address quality assurance in the welding process may be applicable to the nuclear sector.

Two sets of rules are in use worldwide which apply to nuclear pressurised components. In the nuclear industry these rules are published by American Society of Mechanical Engineers (ASME) and French Association for the rules governing the Design, Construction and Operating Supervision of the Equipment Items for Electro Nuclear Boilers (AFCEN).

Both codes have significant implications for welding quality and integrity.

✦ ASME

The fabrication and the installation of structures must meet the ASME Boiler and Pressure Vessel Code section III, and then once completed, the continuous in-service inspection and repair activities must meet Section X1 of the same code. The ASME standard for Quality Assurance Requirements for Nuclear Facility Applications (QA) - NQA-1 (2004) provides supplemental information and contract requirements.
This standard provides guidance and methods for defining a quality system that would meet the US legislative requirements. It is also a globally recognised quality standard that organisations planning construction to the ASME code may want to adopt. This standard reflects industry experience and current understanding of the quality assurance requirements.

✦ The RCC and ETC approach

The Rules for Design and Construction (RCC) family and EPR Technical Code (ETCs) are design and construction or technical codes and standards corresponding to industrial practice implemented in the design, construction and commissioning of the 3^{rd} generation EPR reactor.

The last upgrade of RCC-M takes into account the EU standards referenced in all chapters to ensure consistency with EU requirements, and to meet recognised international standards. RCC-M requires product and shop qualification and also prototype qualifications.
As with ASME, NQA-1 RCC-M Section 1 specifies broad quality assurance and quality management requirements based on the ISO 9001 requirements.

Following these codes assures initial high quality construction and appropriate ongoing inspections, with repairs performed to maintain the structural integrity of the systems necessary to assure a safe shutdown of the plant once it has started operation.
One can refer to Nuclear Construction Lessons Learned Guidance on best practice: welding – The Royal Academy - ISBN: 1-903496-82-9.

Contractors that build these facilities mainly employ welders that are skilled in manual techniques using the GTAW and SMAW processes. Typically, piping butt welds are performed with GTAW for the root pass and followed by a second pass of GTAW, then the welds are completed using SMAW. This combination is meant to assure that the higher quality GTAW process is used to seal the inside diameter and the higher production process SMAW is used to fill the balance of the joint volume. This method has been in use since the early 1970s and is still the predominant method to date. Since 2005, there has been a desire to use new highly developed GMAW power sources such as Miller Electric's RMD and Lincoln Electric's STT to replace the GTAW/SMAW method. These two methods are starting to be placed into the hands of welders. It should be noted that many welders do not transition well to this change without adequate training.

Equipment manufacturers' employ SAW for typical construction. This process is well established with both high production and high quality benefits. In a factory environment where the vessels can be manipulated, SAW is a nearly perfect process. SAW can easily be incorporated into an automated production line. When more portable welding is necessary or for certain smaller production assembly, FCAW is typically employed with gas shielding.

The various issues relating to welding technology for nuclear power plants must keep pace with the advances and innovations in welding technology. While materials pose exciting challenges and thus opportunities to materials scientists, development of welding technology for joining these materials pose further exciting challenges for technologists, to enable realisation of the objectives of sustainable development of the nuclear energy option. Development of welding technology for nuclear energy systems involves exploitation of the full potential of the latest welding processes, and also the harnessing the benefits through developing of knowledge-based expert systems for failure analysis and suggesting repair and refurbishing strategies and weld process modeling and control, weld-bead profile analysis for quality control, microstructure prediction and mechanical property estimation.

Alloys that were used in the first generation of nuclear plants have been improved on since the service conditions are now better understood. Examples include the use of unstabilised 304 stainless steel in Boiling Water Reactor Recirculating Coolant Systems and the use of Inconel 600 fillers and base metals in the vessel nozzles which are both attacked by Inter Granular Stress Corrosion Cracking. Other corrosion mechanisms and fatigue will be addressed by material improvements using new alloys and by cladding existing alloys with exotic materials by Explosion Welding. New welding processes and techniques will also be used to address fatigue damage (chamfered fittings or 2 to 1 profile socket welding) and lower residual stress from GMAW versus GTAW/SMAW.

In the future, large equipment manufacturers' will continue to use SAW but high quality Hot Wire GTAW will find a place in attaching smaller bore nozzles such as the numerous Control Rod Drive Mechanism housings. The introduction of the new highly automated process will require new equipment which is now just beginning to be developed. Welding Operators for this specialised fabrication will be in high demand. Currently the training for such equipment is offered by the equipment suppliers.

Due to the heightened safety requirements of nuclear power all welding will require certification testing of individuals and full documentation of welding consumables used and recording of the welding procedure variables that are used. This is carried out by the Welding Engineering professional and/or Quality Control personnel. Presently the collegiate system is not prepared to train which is attributed to a lack of focused foresight by national leadership. Costs for teaching welding professionals is considerably higher than other

engineering disciplines due to the need for high priced welding and testing equipment and laboratories that must keep up with industry.

Machine GTAW and Semi-Automatic GMAW will become important in the coming years and this will require specially trained Welding Technicians to keep the equipment working properly and dialed in for optimal performance. These positions require training found in 2 year associate degree programmes.

Certified Senior Welding Inspectors and Non Destructive Testing (NDT) technicians are needed to assure the necessary examinations are performed to provide evidence that welds meet the requisite high quality standards. New phased array ultrasonic techniques and radiography using digital media will be employed. Presently individuals competent in these techniques are as difficult to locate and train as welders. Typically their training is commensurate with an associate degree in engineering technology. The experience levels needed to work independently are of the order of several years.

A programmatic method for recording welding data will depend heavily on software designed for the task. The information gathered will provide the utility operators cradle-to-grave traceability. Such data is a great asset for plant engineering staff when they find deficiencies or degradation in the plant equipment once it is placed in operation. The engineering and quality control staff will assure this is accomplished and made available for owner and regulatory review.

Generally speaking, GTAW can be applied for the austenitic stainless steel and Ni base alloys against corrosion, heat and extremely low temperature. Since the reactors have the large scale structure, it is necessary to make progress on the welding process with the higher efficiency, the lower heat distortion and the higher quality. This will mean adopting much higher efficiency welding with high deposition rates, such as narrow gap Welding, hot-wire TIG welding, multi-electrode welding and laser-arc hybrid welding at the factory and the local nuclear reactor site. In the case of an International Thermonuclear Energy Reactor (ITER) with large structure and large wall thickness, high power laser and laser arc hybrid welding can be applied for high accuracy and high velocity. *Figure 9.9* shows the trend of welding processes for the application to the nuclear equipment.

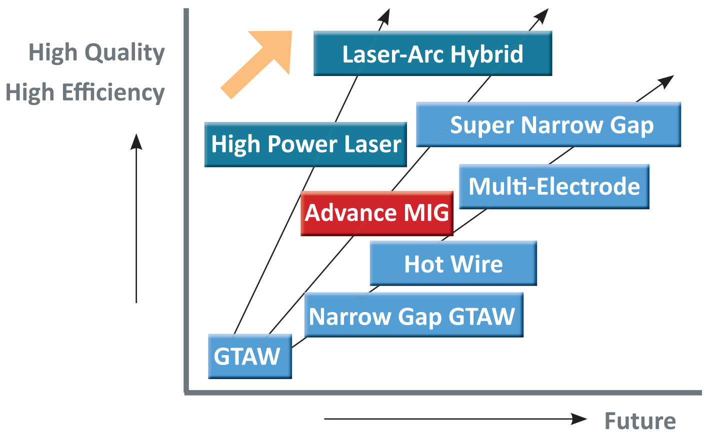


Figure 9.9 *Trends of welding processes for nuclear power plant (Reproduced courtesy: Satoru Asai)*

Finally, as there are many light-water reactors operating for over 60 years, there will be the need to start the decommissioning of the used reactors. The cutting and recycling technologies of the metal, such as RPV and Core Shroud is utilised for the decrease of the waste volume. Moreover, the waste processing system of used fuel rods, are in operation, and so the components are added to the systems and repaired by remote maintenance technologies of laser welding.

9.1.5 Hot topics

- Development and uptake of welding technologies for fabrication of high quality nuclear reactor components and specialised materials, including multi-disciplinary intelligent welding.
- Development of, and adherence to design, fabrication and maintenance codes and regulations on a global level.
- Training, qualification and certification for design, engineering, welding and inspection personnel to international standards.
- Utilisation of latest information technologies to record and analyse data on an ongoing basis.
- Development of environmentally sound procedures for decommissioning and waste disposal.

9.1.6 Power - Hydro

Hydroelectric power plays an important role in the overall power generation mix. The overall installed power of hydropower plants increases steadily and covers approximately two thirds of the world wide renewable and around 3% of the total energy produced. For the application of welding in hydropower engineering the welding of penstocks and linings plays an important role. A special feature of hydropower plants is the long service period of 50+ years which is a challenge for engineers. The selection of materials and welding processes plays an important role to assure the reliability of the sustainable technique.

The Hydroelectric turbine (runner) is the very core and most vital equipment in the plant, which requires a very good emphasis on materials selection and engineering criteria and very good welding practices for proper component integrity. The following highlights the various challenges associated with turbine runner fabrication. Modern hydroelectric turbine runners are made of high strength stainless steels alloys, with reduced weight and high resistance to water induced cavitations. Proper selection of welding technique and welding consumables which match or exceed the base metal properties are absolutely essential towards successful fabrication of hydroelectric turbines. Hydroelectric turbines are often designed to the original equipment manufacturers design standard and recommended codes of practice.

Welding has a very important role in the design and construction of major equipment for hydroelectric generating stations especially turbine runners and other allied components. The following highlight the role of welding in the fabrication of hydroelectric turbines.

Materials of construction

Turbine runners are fabricated often from "Martensitic Stainless Steels" conforming to ASTM A-743. Alternatively EN-10283 is the common standard followed for these alloys if fabricated in Europe. Cast martensitic stainless steels conforming to the above specifications have the following chemical composition and mechanical properties:

- Heat Treatment -QT- Heat to 1850°F [1010°C] minimum, air cool to 200°F [95°C] or lower prior to any optional intermediate temper and prior to the final temper. The final temper shall be between 1050°F [565°C] and 1150°F [620°C].
- Specification: ASTM-A743 Grade CA-6NM or GX4CrNi13-4(DIN-1.4317) as per EN-10283.
- Nominal Chemical Analyses: C≤0.05%, Si- ≤ 1.00%, Mn ≤ 1.00%, P+ S≤ 0.035%.
- Cr-12.00-14.00%, Ni-3.50-4.50%, Mo-0.40-0.70%.
- Mechanical Properties: UTS-760-960 MPa, YS-≥ 550 MPa, %EL-≥ 15, % Reduction of Area-35, Hardness-240-300 HB, Charpy-V Impact at 20^0C ≥ 90 Joule.

Welding Challenges

CA-6NM/GX4CrNi13-4 castings are commonly used for turbine runners and wicket gates. It is a 13Cr-4Ni martensitic stainless steel developed in the early 1960s. An improved version "Super Martensitic S.S" is very popular these days in the off-shore oil & gas industry due to vastly improved resistance to Stress Corrosion Cracking (SCC). CA6-NM is a material of relatively high strength, and has a good cavitation resistance. Due to the relatively low chromium and nickel content, this material is subject to pitting in salt water or a similarly corrosive environment.

While welding CA-6NM, relatively higher preheat and post weld heat treatment (stress relief) is required to prevent cracking when welded with matching martensitic welding consumables. Field repairs with austenitic weld materials are feasible with minimal preheat and no post weld heat treatment. The deposited weld material does not have the same strength as the CA-6NM base metal, however.

Tragic failures in different engineering disciplines in history were one of the main driving forces for accurate investigations of failure mechanisms and the development of improved techniques. In the field of hydropower plants the recent case, Cleuson-Dixence, was a significant failure, which clearly showed the necessity of understanding the mechanisms and the consequences of not doing things correctly. To avoid such accidents in future, new materials and their processing have to be understood in advance. Therefore accurate scientific investigations have to be performed with respect to the basic understanding of the weldability of the materials selected and their service behaviour such as:

- Fracture mechanics and fatigue properties.
- Quantitative description of the relation between materials properties, namely strength, fracture toughness and fatigue and NDT procedures and the evaluation of its results.
- Influence of modern welding processes (including filler material) and parameters on the microstructure and their properties. Definition of significant parameters for the characterisation of welding processes and their influence on possible failure mechanisms.
- Corrosion in weld metal and heat affected zone under service conditions.
- Reliable QA measures in production and during service.

All these efforts should result in modern standards and recommendations for the selected materials and welding processes which enable welding engineers to contribute to effective renewable energy production for a better future of the world.

Future Developments

Materials selection, welding and fabrication technology are very mature for hydroelectric turbines. As the demand increases for hydroelectric plants, turbines with higher capacity may be required in future. Development of steels with high strength and extremely good resistance to cavitations are of paramount importance, accordingly the welding challenges required to be dealt with. With the present day available resources such challenges are very often met by the Original Equipment Manufacturer (OEM) and the end users/utilities.

9.1.7 Hot topics

- Research and development of light weight high strength water resistant materials for turbine runners and associated welding processes and procedures.

9.1.8 Power - Renewable

Rising fuel costs, environmental concerns and financial incentives have expanded development and growth in clean energy alternatives. This includes investment and growth in solar photovoltaics, wind power, fuel cells, and supporting battery technologies. R&D organisations are assisting global growth in these industries through design, material selection, welding/joining technologies, numerical modelling, and structural analysis engineering assistance.

Solar: The solar photovoltaics industry revenue is expected to rise from $15.6 billion in 2006 to over $69 billion by 2016. One of the barriers to growth in this sector is the decline in silicon and high cost to process the material. Advanced manufacturing techniques and alternative materials are now driving down the cost of silicon. Flexible substrates and other design features are also driving changes in the manufacturing of solar panels. Thermal conductive adhesives, coatings, and structural joints are among the joining processes used for solar photovoltaic panels.

Wind: Although wind power currently only accounts for 1% of energy generation in North America, significant growth indicates it will continue to expand and mirror European wind initiatives. Similar to aircraft engines, wind turbines, nacelles, and towers are material and weld intensive and subject to extreme structural fatigue due to operational conditions.

An increase of the efficiency of the onshore and offshore wind towers is principally possible due to an increase in the heights (to 100-160 m) with the development of low-cost structures, new solutions for offshore foundations and improvement of corrosion & fatigue properties of welds. Obviously, new generation large steel towers will require new design, fabrication and welding technologies for steels up to 500 MPa yield strength. Advanced structural health monitoring (SHM) techniques in combination with engineering structural integrity assessment rules will be needed for economic and safe operation of these structures in remote areas.

Batteries: Growth in the battery market has occurred due to new materials technology and chemical compounds being introduced. New applications, including the miniaturisation of electronic communication and entertainment devices, are also placing demands on battery performance which drives technology improvements. The most rapid growth is in large scale batteries for backup power and transportation. These cells use pouch style construction which is relatively new to the industry although it is similar to existing technology used in the food packaging industry. Performance drivers for batteries include shelf life, durability-cycling, higher output, increased recharge cycles, and lower cost of production. Manufacturing challenges include material selection, thermal heat management, glass-to-metal seals, polymer joints/seals, and high production rates.

Fuel Cells: As energy prices rise and sources of energy become more questionable, greater emphasis is being placed on improved energy conversion efficiency. This is the case for all forms of energy usage, including residential, consumer, industrial, transportation, and military areas of application. Government and industry's long range energy analysis and planning call for greater emphasis on hydrogen as an efficient means of converting fuel to electricity for all these application areas. While a great many technical, economic, and political challenges along the road to a "hydrogen economy" remain, fuel cells are widely considered to be an essential component in this vision of future energy utilisation. Fuel cells have been used successfully for decades, one of the most notable examples of which is electric power for space exploration. Hydrogen and oxygen on board the spacecraft are combined to produce electricity with pure water as the waste product. While this solution is light-weight, efficient, and clean, it is far from economical in a terrestrial environment. In fact, current fuel cell systems costs are at least an order of magnitude higher than the cost targets for commercial viability. Many fuel cell designs call for components that consist of multiple, thin, stainless steel, sheet assemblies. These thin sheets are required to be joined in a manner that will provide a leak-tight seal for the life of the product. High-speed (up to 1 meter per second) laser lap seam welding is emerging as a strong candidate to address this joining challenge.

9.1.9 Hot topics

- Research and development of solar panel materials and associated joining technologies.
- Research and development of corrosion and fatigue properties of welds associated with increasing height of wind towers, and development of new design, fabrication and welding technologies.
- Development of new welding technologies and procedures to support innovation in battery and fuel cell design and fabrication.

9.2 Manufacturing sector

The use of advanced technology is a precondition to guarantee economic, safe and high quality manufacturing. Lately, manufacturing has decreased in Europe, America and Japan with the focus moving to Asia. PR China in particular is becoming an increasingly potent force in the global market place particularly in heavy machinery and manufacturing other industrial parts. China's manufacturing production value is growing in line with the world's number one manufacturer, the USA. In recent years, China's wage rates are rising, and with rising transportation costs due to high oil prices this will further affect the situation.

Resource-intensive manufacturing industries will not return to Europe but will move to lower-paying countries. Traditionally, these countries have sought to optimise the use of cheap available labour with minimal capital expenditure. It is now being seen that utilising a higher capital expenditure to labour ratio will not automatically lead to higher unemployment rates, as predicted by the traditional view. Instead, greater employment opportunities can be generated as a result of higher output growth brought about by technological progress embodied in new capital investments.

For example, the production of construction machinery is almost evenly shared by Europe, America and Asia. In the near future, the manufacturers of construction machinery will be forced to reduce environmental impact with energy-saving measures and improved safety measures. The adoption of new technologies for more efficient products will be required.

9.2.1 Joining technology in the production process - Actual status and trends

In the past, processes using joining technology, particularly using welding technology, were carried out separately from the other manufacturing processes for a product because of their special attendant circumstances in fabrication, particularly because of dust, heat and noise emissions as well as often complicated tests. This is connected with an extra scope of work and extra costs for transport and intermediate storage. Moreover, the results of the welding and joining processes frequently cannot be proven on the finished product at justifiable expense. Apart from the product testing, other quality-assuring measures must be applied for this reason. Another factor relates to the wide diversity of the available welding and joining processes from which the optimum process for product manufacture must be selected depending on the material, the stresses, the accessibility, the experience, the availability and the costs.

To an increasing extent, the ever greater diversity of materials and their combined utilisation depending on the specific weight in question and on the respective stresses in a product are leading to a material mix in technical products. Therefore, these materials must not only be joined with each other ever more often but also in ever more complex joining processes. Conventional welding and joining processes with further development are available for this purpose.

9.2.2 Production using joining technology and economic viability

General

The costs of manufacturing technical products depend on the material and fabrication costs. The personnel costs (wages and salaries, including incidental costs, of the people concerned with fabrication) and the energy and operating material costs, including the depreciations, are parts of the fabrication costs.

In particular, the personnel costs are very different all over the world and can be influenced by the manufacturers to a limited degree only unless they relocate the manufacture to other countries. The incurred transport costs which will also rise with rising fuel prices however, must be borne in mind in the case of such relocation as well.

Due to mechanisation and automation, the productivity in fabrication can be raised in such a way that the fabrication costs are lower than without these measures. The operating material costs then become the decisive factor amongst the manufacturing costs. Wages and salaries then rank in second place only.

The question to be asked however, is what location is sensible for such mechanised or automated fabrication. The qualification of the operating personnel and the available infrastructure for energy and input material supply as well as for the elimination of unplanned installation shutdowns then play a very essential role in order to decrease downtimes. Therefore, the choice of a location for highly mechanised or automated fabrication frequently leads to locations in the industrialised countries in North America, Europe or East Asia (Japan and South Korea). Fabrication close to the customer plays an additional role in some sectors (amongst others, manufacture of motor vehicles, energy generation installations, microelectronics).

If customer-specific deviations from standard products are to be allowed, high flexibility is required in fabrication planning and fabrication control. This necessitates more stringent requirements on the component supplies, the personnel and the installations and these cannot be satisfied everywhere. Environmental regulations may be an additional cost factor.

These general deliberations also apply to welding plants and to other manufacturers using joining technology. The economic significance of joining technology is dealt with in Chapter 3.4.

Production using welding and joining technology

In welding and joining technology, there are a few peculiarities in comparison with other fabrication processes. For example, it is particularly difficult to establish and prove, on the finished product, the quality of the results of the manufacturing processes using welding or joining. Therefore, special quality-assuring measures accompanying the production and manufacture of the products are required in close coordination with the design. **These are:**

- Procedure qualification tests to be performed before the beginning of the fabrication.
- Fabrication-accompanying tests on test specimens (destructive and non-destructive tests on work specimens) and on the product (non-destructive intermediate tests).
- Personnel qualification and recurring qualification tests for the executing and testing personnel.
- Qualified personnel supervision.
- Monitoring of the manufacturing plants (plant monitoring).
- Recurring testing of the products during the utilisation depending on the stresses.

This is a scope of work connected with additional costs compared with the manufacture of non-joined components or products. This must be compensated for by advantages:

- Material savings
- Weight saving
- More suitable design
- Great flexibility in the fabrication
- Conservation of resources

In spite of the described peculiarities, development is heading towards the integration of the joining processes into the fabrication chains in such a way that they do not impair the fabrication sequences. This not only leads to shorter throughput times but also sets stringent requirements on the reliability and cleanliness of the joining processes and of the tests connected with them.

Production using joining technology and safety at work

Joining technology utilises materials from which very specific hazards to the employees and the environment may originate if safety at work and appropriate health protection measures are not observed (*see Chapter 6.2*). When gas torches, arcs and laser and electron beams are used, provision must be made for corresponding radiation, eye and heat protection. Extraction and room venting units with suitable filters must be utilised against any arising fumes, dusts and gases and vapours harmful to health. In some cases, new knowledge also leads to the prohibition of the utilisation of certain filler materials, such as the use of solders containing lead. If welding technology is used for the processing of materials with alloying elements harmful to health, provision may have to be made for particular protective measures for the welders and the operators in order to comply with the recommended limiting values, e.g. of certain manganese, nickel or chromium compounds in fumes and dusts. Suitable devices, facilities and protective clothing must be not only available but also used. Moreover, the hazard potential of a few joining processes themselves is occasionally underestimated and this results in fires.

It must be borne in mind that safety measures apply to building sites as well and not just to the fabrication in factory workshops.

At IIW, Commission VIII is not only intensively concerned with the complex range of subjects but is also ensuring that demands or complaints are not exaggerated.

Production using joining technology and simulation

In order to be able to integrate joining processes into fabrication chains quickly and reliably, their complete simulation is desirable. There is still a considerable need for development here. For this purpose, particular interest centres not only on the simulation of the processes but also on their results because cost-intensive and time-consuming tests can be saved in this way. To this end however, significance is attached to the exact physical knowledge of the processes as well as to the behaviour of the materials during their processing.

When simulation tools are considered, the results portrayed can frequently be optimised even further because boundary conditions are taken into account to an insufficient extent. In the simulation and modelling fields, the representation of reality using digital tools today, sometimes still necessitates hardware requirements which are not available to a lot of users.

For joining technology, non-optimum models and a lack of model parameters today sometimes still result in inaccuracies in the modelling and these cannot be tolerated. In part, these are multiplied in such a way that generated modelling operations cannot be utilised for joining technology. Moreover, data exchange is

still sometimes an unanswered question. The transfer and use of power source parameters represents one example of this.

In general, it may be stated that, for digital joining technology, the reduction in its complexity is a decisive factor for the applicability of these tools. The models must be improved further and must become plausible. The results of a real portrayal using digital joining technology are being introduced into the virtual factory.

Production using joining technology and sustainability

With the scarcity of raw materials and with rising energy costs, ever more attention will have to be paid to the sustainability of the production using joining technology.

The demand for sustainability is connected with great market opportunities. These market opportunities however, can only be exploited by innovative production technology and by innovative joining technology. In this respect, joining technology in particular will prove to be the pivotal element because only technical development, continuous research and the quick implementation of new educational concepts in joining technology can guarantee that, for example, renewable energies can be used in a technically and, at the same time, economically profitable way, that power stations can be constructed and operated in an efficient, economically viable and environmentally friendly form and that new mobility concepts can already be put into effect in the very near future.

Therefore, what challenges does joining technology have to face up to against the background of sustainability? How can it contribute to safeguarding production characterised by sustainability, especially for everything to do with the renewable energies, in an enduring and long-term manner and thus to guaranteeing a sustainable national economy? These questions are making an impression on the further developments of joining technology.

For the joining technology perspective, significance is primarily attached to sustainable production because a total of three mechanisms of fabrication are influenced by the imperative of sustainability - with distinct effects on joining technology. These three mechanisms are:

- New materials and fabrication technologies for sustainable energy generation (in the sense and interests of a new energy infrastructure and an economically stable energy mix).
- New materials and fabrication technologies for the manufacture of sustainable products (e.g. fully recyclable products, lightweight construction in transport, design concepts for the mobility of the future etc.).
- Sustainability in production and in joining technology itself, i.e. ever higher energy efficiency with even lower pollutant emissions in production at the same time.

Demographic development and qualification of joining technology personnel

The very different demographic development in the countries around the globe is demanding the quick implementation of strategies for promoting to young people and for developing personnel. Amongst other consequences, the demographic change in quite a lot of industrialised states is producing a considerable need for the development of machines and systems for such strategies. These may contribute to employees being able to achieve optimum working results in complex working environments in the long term and thus to fulfil requirements on productivity with quality. Reducing burdens at the (joining technology) workplace must be linked with this.

Joining technology is planned by the human being. In addition to modern mechanisation and automation concepts, joining technology will still be directly utilised by human beings in future as well. In the wake of the demographic development, there will be globally different requirement profiles for the deployment

of welders. In particular, joining technology designed in a way appropriate for certain ages and, in future, training and advanced training concepts adapted to this will accompany the utilisation of joining technology to an even greater extent than now (*see Chapters 6.3 to 6.5*).

Against the background of longer working life times, concepts for permanent further qualification must be developed for all employees at an early stage and allow them to be qualified for a longer period and to be successfully active in the company.

In this respect, production technology and joining technology must react to different interests from industry and the skilled trades. The skilled trades necessitate a fundamental understanding of application-oriented fabrication concepts using joining technology. Manual joining with an assured quality is essential for many fields of the skilled trades. In this case, cost-favourable training concepts are constantly being discussed as a challenge. Here, modern welding trainer concepts (virtual systems) offer solutions in order to also implement product-related demands from sets of rules in joining technology.

Production using joining technology and international interweaving

Devices and facilities as well as filler materials and auxiliary materials for joining are utilised all over the world but must meet the respective regionally different conditions and statutory requirements.

One peculiarity of welding and joining technology is that these global systems for quality assurance are being carried out and refined with the corresponding qualification and certification systems in explicitly European and international structures and organisations. Global communication standards and Web-based procedures and, to an increasing extent, Web-based training systems are being utilised in this respect.

In the wake of advancing cross-border fabrication, joining technology should be applied with uniform regulation all over the world if at all possible, without restraining competition (*see Chapter 7*).

To this end, standardisation encompassing the following fields is very advantageous and worth striving for:

- Devices, facilities, filler materials and auxiliary materials for welding and joining.
- Requirements on plants (ISO 3834) and their personnel (e.g. ISO 9606, ISO 14731 and ISO 14732) performing welding and joining work.
- Requirements on products which have been welded or have been joined in any other way.
- Tests and proof of compliance (e.g. ISO 15607 to ISO 15614).

For many years, ISO (International Organisation for Standardization) and IIW as the ISO-recognised organisation for the development of ISO standards relating to welding technology have been very successfully drawing up such standards with experts from all the member countries on the expert committees and have regularly adapted them to the changing requirements and conditions. If international harmonisation is not possible, such standards are harmonised in a regional or sectorally specific form, e.g. in Europe in EN standards or in the aerospace or automobile industry.

Consequences

Particularly for welding technology, the above statements result in two consequences:

1. The manufacture of high-quality welding machines and installations requires extremely highly qualified personnel and, with great fabrication depth, is often carried out in medium-sized enterprises. Attempts to relocate such fabrication to low-wage countries have failed time and again particularly because of quality imperfections. With regard to the manufacture of welding filler materials (especially of covered or flux-cored wire electrodes), additional factors are that a constant quality of the input materials must be absolutely safeguarded and that the production takes place on very complex installations in highly automated processes.

2. To an increasing extent, joining processes are being integrated into fabrication lines. With regard to the application of welding, cutting and coating technology in these complex, highly mechanised or automated fabrication lines, it is necessary to ensure the reliable availability also of the relevant joining technology installations. This requires a reliable infrastructure for coping with disturbances of these installations too, i.e. quick presence of experts in the event of perturbations on the cutting, welding, brazing, soldering and coating machines and high availability of spare parts and substitute devices. Examples are automobile production and the fabrication of electronic components.

9.2.3 Visions for joining technology optimised for processes

Joining technology optimised for processes permits the flexible application of joining processes. Joining processes (i.e. installations and systems) are integrated into the production chain as production processes.

Thus, joining processes can quickly react to the product development. There is a direct link between design, production planning and production / joining technology in order to be able to achieve a rapid production start and stable production.

Joining processes can be quickly and flexibly adapted to altered fabrication conditions and also to altered raw material conditions and material conditions.

Joining technology is an integrated part of virtual production.

Joining processes permit maximum productivity with minimum preparation and their joining results (material, joining process and properties of the joint) are reproducible and calculable and can be subjected to a complete simulation.

The physical effects and interactions of joining processes are totally known, reconstructable and able to be modelled and controlled. Therefore, the joining processes of the future can be carried out with resource, energy and cost efficiency and thus in a sustainable way. In concrete applications, joining processes can be performed without any emissions and with a minimum heat input.

Examples of joining technology optimised for processes:

- Joining processes using nanotechnological processes such as nanofoils, nanoparticles and nanopastes.
- Intelligently combined joining processes (hybrid joining processes) and joining processes with the coupling of different energy types.
- High-speed joining of thick-walled structures, components and piping.
- Joining processes for modularised fabrication in vehicle construction using components and subassemblies with final paintwork.
- Joining processes with integrated quality and materials testing and documentation.
- Optimised automated joining processes.
- Optimised hand-guided joining processes.

9.2.4 Production using joining technology and research

The visions mentioned are resulting in the need for research. As in other fields, research and development in joining technology can often no longer be financed solely by one company or by companies in one country; internationally coordinated research and development, e.g. in astronautics, is often the solution. For this purpose, promotional programmes are being offered by international and regional establishments, e.g. by the World Bank or the European Union. With its 16 Commissions and other Working Units, IIW could be a platform for the harmonisation of projects promoted in such a way.

There are promotional programmes particularly in the fields of sustainability (conservation of the environment and resources), nanotechnologies as well as safety at work and health protection. Converted to subjects relating to joining technology, these could be projects such as are specified in Chapters 9.1.1 to 9.1.9 above. From the viewpoint of fabrication, general interest across different sectors centres on subjects relating to saving energy, to raising productivity as a result of further mechanisation or automation and to improving safety at work and health protection.

9.2.5 Hot topics

- In future, joining technology in the fabrication field will still have particular requirements on quality assurance because of the high safety relevance of the joints and their restricted testability on the end products.
- The mechanisation and automation of joining processes will still have a high development potential and still be required in order to maintain production in high-wage countries too.
- With the increasing demand for sustainability and for the conservation of energy and resources, joining technology will become ever more significant as a manufacturing process.
- Particular significance will continue to be attached to the qualification of the required personnel and to the international standardisation in all the fields of joining and welding technology.
- Joining technology must be directly geared to product development, utilisation and exploitation and must therefore be developed and applied in an optimised way for materials, structures and processes. In this respect, robust joining technology processes must be made available and usable all over the world. In order to attain these objectives, research, technology and education in joining technology must be interlinked consistently on the national and international levels.

9.3 Oil and gas sector

Welded structures operating in onshore and offshore regions must have high reliability because of the high risk to life and environment associated with structural failure in harsh operating conditions. In North America and Europe, there is legislation that dictates the need for some welding or welding related activities in an organisation to be staffed by suitably trained and qualified personnel; e.g. API, ASNT, CSWIP, CWB, IIW, etc. whilst in the East, the practices are varied and dependent on the historical trade influences, it could be the European, British or American Standards or other national standards that are being followed.

The better organised refining and petrochemical companies may have periodic assessment performed to determine gaps in their functional competencies to adequately address weaknesses in managing equipment integrity and process safety of their operations. Notwithstanding the above, it is generally true that training of such personnel to be suitably competent is left to external organisations. Also, as welding and welding related technology are not core operations of the refining and petrochemicals organisation, personnel entrusted to perform such related tasks are generally left to their own devices to determine the most appropriate training required for developing adequate competencies. Also the training content is general in nature and not specifically related to the oil and petrochemicals environment. It is therefore important for bodies like IIW to provide the assurance that refining and petrochemicals companies can look toward for guidance on appropriate training, qualification and certification for their personnel.

International Bodies such as the IIW, therefore, do have an important role to play in assisting industries to ensure that the standard of training providers is up to international requirements, that training syllabi are reviewed periodically to reflect advances in the science and technology of welding and that it has relevance to the refining and petrochemical environment. There is also the need to provide training to a wider spectrum of the refining and petrochemical operations such as the plant technologists, process technologists and operations personnel as well, and not just targeting the training effort on personnel that have the direct functional roles and responsibilities on welding related matters e.g. welding engineers, specialists, practitioners. In addition, supporting service organisations such as pressure equipment fabricators would also need to be given assistance to be updated on handling of new material, fabrication techniques, welding processes, etc.

9.3.1 Offshore and onshore – Oil and gas

The offshore oil and gas industry is moving into deeper waters. Several issues arise:

- The pipe wall thickness needs to be increased to resist hydrostatic collapse.
- The pipelines may have to be laid by J-lay, instead of the more conventional S-lay method to reduce the weight supported by the lay barge.
- The hydrocarbons are higher pressure and temperature and often containing a higher concentration of acid gases making the fluids more corrosive. In J-lay it is generally only possible to have a single welding station. Presently automatic gas welding is used but this has limitations.

Possible welding techniques for thicker wall pipe and alternative materials to carbon manganese steels include friction welding, flash butt welding, homopolar welding and friction stir welding. Stolt Comex Seaway is developing friction welding for pipeline and risers of 150-320 mm diameter. The weld is effected by rotating a profiled ring between two static pieces of pipe and radially compressing the rings so that it is welded onto both pipe sections simultaneously. It has been found that sound welds are possible in carbon manganese steels and also in the 13% super-martensite steels (cheaper but less weldable by fusion welding than the super-duplex steels). The welds can be made in about 15 seconds and the ring allows the possibility of introducing a non-matching material if the joint properties require it.

Flash-butt welding (FBW) has been known for many years and is routinely used for welding chain and railroad rails, high-stress applications where quality welds are essential. The pipeline application was developed by the E.O. Paton Institute in Kiev, and was applied to some 30,000 km of large-diameter pipelines in the FSU. McDermott invested substantial resources (reportedly some $10m) in the development of FBW for offshore pipelines and piles, and produced some extremely positive publications, concluding that “on 36-inch pipe, flash butt welding is expected to be 50% more productive than semi-automatic GMAW welding. Conservative estimates for this size pipe indicate that production rates as great as 400 joints per day are possible in the double-joint mode….”. There have been some quality problems with the welds however, and work is continuing in this area through a special group established through a resolution at the IIW International Congress on pipelines in Sofia, Bulgaria in October 2010. This group is making good progress.

Homopolar welding has some similarities with FBW. It butts the pipe ends together and connects a homopolar generator (Faraday disc) across them. The kinetic energy of the generator is suddenly converted into an intense pulse of electrical energy, typically 10 MW, for a few seconds. Resistance at the butt converts the energy into heat. The heated ends are then pushed together.

Normalisation of the narrow welding will be required as for FBW and ERW pipe fabrication but this is not a major drawback. In the McDermott trials, the Vickers hardness was less than 200 DPN after normalisation in a PWHT that raised the temperature to 900˚C for 3 minutes, followed by air cooling; hardness values are acceptable for sour service.

The University of Texas investigated the procedure and economics of homopolar welding for installation of offshore pipelines and concluded that the procedure could reduce both cost and installation time. The second phase of studies to develop homopolar welding for J-lay application began in February 1993 funded by a consortium which now includes oil companies, welding contractors and government.

In friction stir welding the pipe ends are butted together and a ceramic tool is rotated at high speed in the butt, heating and shredding the steel as it progresses. The shredded steel then reforms behind the tool. The technique appears suitable for duplex stainless steels that are complex and slow to weld by conventional techniques.

Many new offshore fields must handle high temperature and corrosive fluids and the need to use corrosive resistant materials has increased. Of the solid Corrosion Resistant Alloys (CRAs), the duplex stainless steels and weldable 13% chrome alloys present the major materials for topside welding. Welding of these materials is difficult and slow, and alternative welding techniques are attractive. Of these, friction stir welding shows the most promise; the method largely overcomes the shift in the ratio of ferrite to austenite, and the lower temperature reduces the risk of formation of sigma phase.

The on-shore gas industry is developing fields in remote areas and economical transport of gas to market requires long distance large diameter, high pressure pipelines. The use of API 5LX100 and X120 steels is favoured. To date, some 500 km of the high grade steel pipelines have been installed. Welding procedures have been developed but require very careful control. The alternative one shot welding technique for the relatively modest wall thickness high grade pipeline materials is friction stir welding.

Mechanical failures in the offshore sector do occur. The BP failure in the Gulf of Mexico and the Montara Oil Spill in the Timor Sea are two dramatic examples. If they do occur, their ecological and economic consequences can be most severe. With increasing understanding of the mechanical behaviour of structures and improving material properties, this industry sector is therefore striving for the continued reduction in failure rates through the application of better predictive material and process models. At the same time, increased competitiveness and cost awareness and the ageing of infrastructures have led the industry to invest in R&D developments to justify reduced safety margins, more cost-effective design methods and extensions to design life.

IIW has contributed for many decades to achieve these goals and many of its member organisations have extensive experience in the development of structural integrity-related issues faced by this industry. Relevant activities include applied research into the material property, performance and inspection of offshore structures and components. The work is based on capabilities and experience relating to metallurgical behaviour; fracture; fatigue; design; residual stresses; failure investigations; advanced NDT; plant assessment; and materials testing. The application of this whole spectrum of technologies is often referred to as fitness-for-service (FFS) or engineering critical assessment (ECA).

9.3.2 Hot Topics

The following issues and technical areas are considered to be the key topics for future technical developments of welding, joining and allied technologies:

Deepwater exploration and production

- Whole-life performance of steel risers.
- New materials for risers, both ferrous and non-ferrous.
- Inspection of risers.
- Dissimilar materials joint performance.
- Pipeline wall thickness, laying and welding.

Materials challenges for exploration in arctic region and transportation of fuels

- High-productivity welding of pipelines.
- Manufacturing technologies for tankers and gas carriers.
- On-line repair techniques of pipelines.
- New design concepts for high-productivity pipe-lay.
- Advanced inspection techniques of transportation structures (pipelines; liquid natural gas carriers and tankers).
- Corrosion mitigation technique developments (coatings etc).
- Life extension of ageing assets.
- Training, qualification and certification of joining and allied human resources in emerging markets.

9.3.3 Hyperbaric welding

Hyperbaric welding is the process of welding at elevated pressures, normally underwater. It can either take place *wet* in the water itself or *dry* inside a specially constructed positive pressure enclosure and hence a dry environment. It is predominantly referred to as“hyperbaric welding” when used in a dry environment, and «underwater welding» when in a wet environment. The applications of hyperbaric welding are diverse – it is often used to repair ships, offshore oil platforms, and pipelines. Steel is the most common material welded.

The demand for highly sophisticated underwater procedures and technologies is increasing, driven by deep sea oil and gas development and by marine infrastructure development and repair around the world.

Dry hyperbaric welding is used in preference to wet underwater welding when high quality welds are required because of the increased control over conditions which can be exerted, such as through application of prior and post weld heat treatments. This improved environmental control leads directly to improved process performance and a generally much higher quality weld than a comparative wet weld. Thus, when a very high quality weld is required, dry hyperbaric welding is normally utilised. Research into using dry hyperbaric welding at depths of up to 1,000 metres (3,300 ft) is ongoing. In general, assuring the integrity of underwater welds can be difficult (but is possible using various nondestructive testing applications), especially for wet underwater welds, because defects are difficult to detect if the defects are beneath the surface of the weld.

The majority of work performed by an average welder-diver does not involve the welding operation itself, but rather executing the tasks that lead up to and follow the actual welding activities. Except under special circumstances, a welder-diver in most cases must possess both certified welder skills and commercial diving skills.

9.3.4 Hot topics

The E.O. Paton Electric Welding Institute of the Ukraine is planning to perform the following work in the field of underwater welding from 2008 to 2030:

- Development and optimisation of processes of wet welding and welding under super high pressures at depths of down to 2,000 m or more: arc welding processes, resistance welding, friction welding, brazing.
- Systems for automatic control of the welding process and quality of the joints: neuron networks, visualisation of the welding process, non-destructive testing.
- Analysis of properties and performance of welded joints by the results of testing and welding process.
- Building of specialised automated deep-water systems for performing welding, construction and repair operations.
- Investigation of conditions for stabilisation of welding processes and interaction of metal with water under hyperbaric pressures. Manufacture of electrode and filler materials for underwater welding.

9.4 Pipeline sector

Pipelines are a vital means of delivery for the world's energy supply. The pipeline sector relies heavily on welding and joining technologies for construction and maintenance activities. Brief summaries of background, technology trends, needs and challenges for future applications of welding and joining technologies in the pipeline sector are provided below. The natural gas and CO_2 transmission pipelines and the topic of testing of pipelines are addressed in separate sub-sections.

9.4.1 Background

The need for energy is stimulating sizable pipelines construction projects. The business driver for these projects, in the Arctic and in other parts of the world, is the retrieval of otherwise "stranded" resources in remote regions. The primary need in the pipeline sector in this regard is cost reduction for new construction. Cost reduction, combined with increasing energy prices, tends to make these projects feasible. Major components of cost reduction include the use of higher strength line pipe steel (e.g. X100 and X120), more productive/less labour-intensive welding processes, and advanced non-destructive testing (NDT) methods. Another need in this regard is design guidance for pipelines hostile environments (e.g. permafrost, deeper water depths, etc.). While many new long-distance transmission pipelines are constructed today using high-strength line pipe materials and high-productivity mechanised welding equipment, many pipelines are still constructed using lower-strength material and conventional "stove-pipe" welding practices. These conventional practices have not changed much in the past 40 years or so and require considerable skill on the part of the welder. There is currently a shortage of skilled manual pipeline welders and this situation is expected to worsen in the future.

A major concern for pipeline operating companies is continued operation of existing facilities. The primary reason for pipeline repair is corrosion-caused loss of wall thickness. Since corrosion is a time dependent process, as pipeline systems become older, more and more repairs are required. The most predominant method of reinforcing corrosion damage in cross-country pipelines is to install a welded full-encirclement repair sleeve. There are significant economic and environmental incentives for performing pipeline repair and maintenance without removing the pipeline from service. From an economic viewpoint, a shutdown involves revenue loss from the loss of pipeline throughput, in addition to that from the gas lost to the atmosphere. Since methane is a so called "greenhouse gas", there are also environmental incentives for avoiding the venting of large quantities of gas into the atmosphere. Changes in the structure of the pipeline

industry have resulted in the need for operators to provide an increasing number of branch connections for new suppliers and new customers, many of which are made by hot tapping. Deregulation in some countries has also made the industry more competitive than ever, so in-service repairs and modifications are more attractive than ever.

9.4.2 Technology trends

There is a unique dichotomy that tempers the technology development of the oil and gas pipeline industry. One is the idea that new technology is the means to reduced cost and increased quality. The other is the idea that the risk lies in the unknown and untested. This divergence in thought is present in every industry. As such, the pipeline industry tends to be driven as much by perception and opinion as discovery and scientific facts.

In the mid 1980s, several organisations (PRCI, US-DOT, TWI, EWI, etc.) developed reports predicting where the pipeline industry was headed. The common thread of these reports was that they were all accurate at the time of their release yet none were completely accurate in their predictions. Unforeseeable changes and technology advancements altered where industry progressed. The thought process and available information at the time of their authorship, suggested that solid state welding technologies were going to be the dominant practice for pipeline fabrications.

The unknown of time was that weld inspection was going to be critically tied to the fitness-for-service (FFS) and engineering critical assessments (ECA). FFS and ECA tended to drive down the acceptable flaw sizes for welded pipelines. The reality became apparent that the fundamental limit of the NDE equipment became the underpinning limitation that controlled a pipelines life prediction and safety factor. Thus, work was underway to improve and optimise the accuracy and limits of NDE technologies. Field NDE companies began to adopt techniques (under the direction of the pipeline owner companies) like automated ultrasonic testing (AUT). This technology had historically been utilised in the nuclear industry and enabled a tremendous leap in pipeline fabrication understanding and life assessments.

Current pipelines construction methods for all but major pipelines projects have not changed much in the past 40 years or so. Many medium to small diameter pipeline are still welded using shielded-metal arc welding (SMAW) and cellulosic-coated electrodes, and inspected using radiography. There is a need to develop or assist companies in implementing some of the emerging pipelines construction technologies for medium to small diameter pipeline projects. For pipeline operations, there is a need to develop innovative pipeline repair technologies. Fibre-reinforced composite repairs are becoming widely used as an alternative to welded full-encirclement steel sleeves, although there are concerns about the long-term performance of these systems. As pipelines become older, the need for repair will only increase as the result of the deterioration of protective coating materials over time and the time-dependant nature of corrosion.

Major pipelines in the near future will certainly be constructed using mechanised welding equipment and the completed welds will be inspected using automated ultrasonic testing (AUT) equipment. Future development in pipeline technology include the use of even more productive welding processes that go beyond the optimisation of the GMAW process (e.g. dual torch, tandem torch, dual tandem, etc.) and further development of the AUT process (e.g. phased array transducers). These developments may include the use of hybrid laser/GMAW for all or a portion of the weld or the use of 'single shot' welding processes such as friction stir welding. Control of weld quality may be accomplished in the future by advanced process control methods instead of non-destructive examination of completed welds.

Now one sees many new welding automation techniques being deployed to fabricate pipelines. Unfortunately, the predictions of a world where pipeline welds take a few seconds to produce using technologies like flash butt welding, dc butt welding or magnetically impelled arc butt welding has not yet come to pass. New solid-

state welding technologies are being developed, however, that may begin to displace arc welding. Some emerging opportunities include field deployable techniques like friction stir welding, spinduction welding or magnetic pulse welding. This prediction is not made lightly; it is based on the fact that AUT has continued to develop since its industrial deployment in the late 80s and early 90s. In 2007, technology advancements have been made which enable AUT technology to be utilised for solid state welding techniques. Combine the fact that solid state welding has continued to become a more controllable process and that it is now inspectable using techniques accepted by industry and one can begin to envision what the future might look like.

The reality that cannot be overlooked is that pipelines will continue to be fabricated using SMAW ("stick") welding. Manual welding will remain a key component of the pipeline infrastructure for the foreseeable future. As long as manual welding exists in the pipeline industry, there will always be applications that require automation of the manual process. Thus, the expansion into GMAW (MIG) and orbital GMAW is normal.

The potential use of hydrogen as an energy source presents an opportunity for the pipeline sector. The use of hydrogen will require the development of a hydrogen distribution network, of which pipelines will play a significant part. Although there are currently several hydrogen pipelines in service in the US, there are technological challenges associated with the transportation of hydrogen by pipeline. Hydrogen pipelines of the future will either be 'new builds' or conversions from existing pipelines.

The pipeline industry is fighting the same labour constraints as every industry and constantly trying to develop welding techniques that overcome these constraints. So as inspection tools continue to be developed and optimised and new welding techniques are discovered, they will be deployed. Since it will take time to overcome the prevailing perception and opinions of these processes, the time for this deployment is unknown. Until then we will continue to see manual SMAW and Orbital GMAW predominate.

9.4.3 Natural and CO_2 gas pipelines

There is an increasing need to replace coal and oil as the primary energy sources world-wide. This has resulted in an increase of the exploitation of the natural gas resources, often located in remote and difficult to reach fields. It has a strategic value to transfer these sources to the market in a cost-effective and safe manner. These large gas reservoirs around the world could provide global economic growth if industry could deliver the gas in an efficient and economic way. The long distance pipeline transportation of natural gas can be more economical than the LNG (liquidified natural gas) and compressed natural gas (CNG) transportation methods. This, however, require significant developments in high strength steels (HSS), advanced welding technologies, higher strength and toughness welding consumables and in fitness-for-service (FFS) methodologies for safe operation.

Development of these technologies to use higher strength (beyond X80: up to X100 and X120 grade steels with minimum yield strength of 825 MPa (120 ksi)) linepipe steels to reduce the cost of gas transmission pipeline is considered to be a strategic target for industries. Significant amounts of research and development work are still needed in the fields of HS steels and consumables as well as in pipeline design and fitness-for-service assessment. It is obvious that the challenge will be to use increased yield strength (of 827 Mpa for X120 steel) with sufficient fracture toughness, adequate weldability, weldment (longitudinal and girth) integrity in terms of dynamic (running) ductile fracture and crack arrest while maintaining cost effectiveness. Here, a particular need will be focused on the improvements of weld joint properties, setting the design requirements and structural integrity assessment rules including crack arrest for these new generation line pipe systems.

Transmission of dense, high pressure (liquid or supercritical) CO_2 in onshore and offshore pipelines is a new and challenging area for various industrial sectors. There is a need to develop new welded pipeline

technology based on the existing pipeline materials, welding technology and standards on transmission of hydrocarbons.

9.4.4 Testing of pipes

Although a very small number of pipeline failures is caused each year by stress-corrosion cracking (SCC), it remains a concern to pipeline operators and regulators. The primary methods for managing the problem include periodic hydrostatic testing, in-line inspection (ILI), or SCC direct assessment (DA). The choice of methods depends on many factors unique to each pipeline. No single method is appropriate for every case. Since all three methods are very costly, especially compared to the relatively low risk of failures, it would be of considerable benefit to the industry if more-cost-effective ways to manage SCC were available.

Hydrostatic Testing: Hydrostatic testing is the most common method for locating SCC. It is well accepted by the industry and by regulatory agencies, and it is certain to find every crack that is larger than a critical size, which depends upon the test pressure. There are a number of limitations to hydrostatic testing, however. It requires that flow of the product through the pipeline be interrupted, which may not be practical if the line is not looped. In areas with large elevation differences, it might not be possible to achieve sufficient pressure at the high points without excessive segmentation of the line. Furthermore, water might not be available, or, if it is, the cost of disposing of it, due to environmental concerns, might be prohibitive. In situations such as those, ILI or SCC DA may be preferable.

In-Line Inspection: ILI has certain advantages over hydrostatic testing in that it can find cracks that are smaller than those that would fail at the hydrostatic-test pressure, thus potentially providing greater margins of safety, and, in many cases, it can be conducted in the fluid that the pipeline is meant to carry, thus not requiring interruption of service. Ultrasonic techniques have been most successful at locating and sizing stress-corrosion cracks in liquid pipelines where the liquid petroleum product serves as the couplant for energy flow between the transducers and the pipe. Achieving satisfactory coupling in gas pipelines has been a serious problem. A recently developed technology involving electromagnetic acoustic transducers shows promise for overcoming this problem, but it has not yet been validated through field trials. Another serious limitation of current ultrasonic ILI tools is their inability to find cracks in dents. This is because the geometry of the dent throws off the angles of transmitted and reflected waves.

SCC Direct Assessment: SCC DA is an important method of integrity assurance, especially for portions of the pipeline where it is impractical or even impossible to do ILI or hydrostatic testing. The SCC DA process was formalised with the publication of an NACE Recommended Practice. Essentially, SCC DA involves making intelligent choices about where to excavate the pipeline and then directly examining the pipe to determine the severity of cracking as a basis for deciding what actions should be taken and how soon. The foundation to SCC DA is proper site selection, which remains a major challenge.

Internal SCC in Ethanol Pipelines: With the increasing use of ethanol as an additive to gasoline, consideration is being given to transport of denatured ethanol by pipeline. Currently, denatured fuel grade ethanol is transported primarily by railroad tanker cars and tanker trucks. The discovery of SCC in user terminals, storage tanks, and loading/unloading racks in contact with denatured fuel-grade ethanol has raised concern about potential effects in pipelines. Research is needed to develop a better understanding of the causes of SCC in ethanol and, based upon that understanding, to suggest and evaluate possible ways to prevent it.

Crack Arrest: When a crack in a welded structure propagates under the action of a load, it can extend in principally two different manners, stably by ductile tearing, or unstably by either brittle fracture or disruptive ductile fracture. Crack growing stably will arrest unless the stress intensity applied to the crack tip continues to increase at a greater rate than the crack resistance curve. Analysis and prediction of an arrest event of a dynamically running unstable crack, however, is a major challenge for higher grade pipeline steels (X 80 and beyond) and welds.

9.4.5 Hot topics

Pipeline construction:

- High-strength steel line pipe - Weldability, consumable development (weld metals), full-scale performance.
- More productive/less labour intensive welding processes – Advanced power supplies (advanced waveforms, etc.), hybrid welding process (laser/GMAW), robotics, vision sensors, adaptive control, single-shot welding processes, etc.
- Advanced methods for pipeline tie-ins – Mechanised single-sided welding, advanced alignment systems, etc.
- Advanced NDT methods – Phased array UT.
- Design guidance for pipelines hostile environments – Strain-based design.
- Shortage of skilled manual pipeline welders – Incentives for young people to pursue welding as a career.

Pipeline operations:

- Pipeline repair and branch connections – In-service welding, new innovative pipeline repair technologies (composites and other non-welded repair methods).
- Mitigation of greenhouse gases – In-service repairs and modifications.

Emerging pipeline issues:

- Transportation of hydrogen by pipeline – Hydrogen embrittlement.
- Transportation of CO_2 by pipeline.

9.4.6 Emerging technologies

High-strength steel line Pipe: The use of higher strength steel requires less wall thickness for a given pipeline design or higher operating pressures for a pipeline design of a given wall thickness.

Hybrid welding process: High efficiency lasers, which are becoming increasingly available, may make the use of hybrid welding processes feasible in the field. These processes are much more productive/less labour intensive than even the most advanced mechanised welding systems. Seam tracking will be an integral part of this technology since the welding speeds are high.

Phased array UT: Phased array ultrasonic testing (UT) equipment is much more compact, reliable, and efficient than conventional multi-probe systems. Higher efficiency inspection systems are required to keep up with high efficiency welding systems.

Innovative pipeline repair technologies: Composites and other non-welded repair methods will continue to be an attractive alternative to conventional repair methods in the future. The primary advantage of these is that the need for in-service welding is precluded.

9.5 Pressure equipment sector

The pressure equipment industry (PEI) was an integral part of the advent of modern industrialisation, and is still one of the core industries. Its products, most of them of welded construction, are essential components of many other branches of industry. Its future, therefore, is very much dependant upon the

general investment climate, including that created by economic and ecological pressures. A listing of the types of pressure equipment (PE) in PE technology terms does not convey much more information to the non-expert than the encompassing term PE itself: “pressure vessels, piping, accessories and assemblies thereof operating where pressure creates a decisive hazard, with an allowable pressure above some specific value, typically 0.5 bar”.

A listing of PE types in process engineering terms does give a better picture: accumulator (hydraulic, pneumatic, steam), air cooler, air heater, air receiver, autoclave, bioreactor, boiler (biomass, black liquor, hot water, power, recovery, steam, warm water, waste heat), chiller, column (absorption, air separation, distillation, extraction, reaction), condenser, converter, cooler (back, inter, quench), cowper, deaerator, dehumidifier, dephlegmator, desalinater, drier, economiser, evaporator, extractor, fermenter, flash vessel, gasifier, heater (feedwater, immersion, super), liquifier, preheater, reboiler, recuperator, refluxer, refrigerator, regenerator, separator, silencer, steam reformer, sterilizer, stirring vessel, storage vessel, stripper, superheater, valve (blowdown, check, safety, shutoff, stop, vent), vaporiser, to list just the more important ones. Piping may also be taken to include pressure pipelines. Gas cylinders are further examples – they may be static, transportable, fired or unfired. The picture this listing conveys is that of an old industry, with a high degree of specialisation and standardisation.

This picture is correct. PEI is an old industry, albeit a substantial component of industry as a whole – in the European Union alone the annual turnover exceeds 86 billion Euro. It is a successful industry, with a good safety record. Failures do occur, but most of them are caused by human errors, and/or result from “money saving” issues, like reduced inspection frequency or saving shut-down times. Operator error and poor maintenance account for 30 - 50% of incident causes, faulty design or fabrication for only a few percent. The success was made possible by successful achievements in welding technology, and of testing methods and equipment.

The success of the PEI is, at the same time, the cause of some of its present problems. For each frequently occurring problem, at least one solution has been developed and embedded in codes and standards. These solutions which are quite good and correct, are frequently overly conservative. Too often, however, incorrect solutions have been “calibrated”, to achieve a usable recipe, often by usage of another inconsistent and confusing “adaptation factor”. The success of the PEI is also the cause of its inherent resistance to change, especially in the relevant codes and standards. Everyone in the industry is used to their local codes and standards and knows that they lead to reasonable results. Equally, however, the background knowledge is often vague, buried in records, or lost altogether.

9.5.1 Future of the industry

There are signs for concern:

- The casting in stone of present national rules by creating lists of codes and standards which conform to a common international standard with (only) requirements of what a standard should look like.
- The reported pressure by inspection bodies on users to specify national rules, in order to be allowed more economic in-service inspection intervals.
- The noticeable resistance by manufacturers to using new design methods, because of “good experience” with the old ones. This argument is seriously flawed, neglects the fact that equipment is hardly ever used at its design limits and neglects the statistical nature of failures.

Advancements in the Pressure Equipment Industry towards global unified rules of technology are likely, even in the near future, but they will require a common effort, and, especially, well-trained personnel and continuing professional development, a possible cause of problems in countries with long established industries and traditional attitudes.

The 21st Century for pressure equipment is the century of design by analysis (DBA) to permit much higher allowable stresses for much higher strength materials than were acceptable for design by rule Codes. This quantum leap must be done with assurances of high reliability including documentation with a defensible paper trail of good engineering and quality control. Truly, major challenges and burdens are falling on today's welding engineers.

The increases in allowable stresses may be 50% or more. This more efficient use of materials developed with emphasis on cost effective alloying and controlled processing is a particular problem for the welding specialist. In the last half of the 20th century, welding specialists could overmatch strength properties and provide a reliable margin of safety against many failure modes. When justification was required, related experience could always be cited. Now, there is no relevant experience and past margins achieved by overmatching are more difficult to obtain. DBA requires elastic–plastic, multi-axial strain limits for weld regions as well as fracture mechanics and time dependent properties of welds and heat affected zones that presently do not exist and must now be obtained through creative specimen design and testing. Design and fabrication cannot be improved after a failure. They must be done right the first time.

The objectives of pressure vessel engineers today are remarkably different from those barely 30 years ago when equipment was to be built using proven technologies and very forgiving, proven materials. The emphasis then was on economies of scale i.e. bigger was more efficient (economical). There was the expectation that operating lifetimes would be limited. Replacement due to obsolescence would be in a generation. Today, the pressure vessel engineer must be concerned with prolonging the life of that equipment after it has been operating (and degrading) for 30, 40 or even 50 years. Fitness for service (FFS) or engineering critical (ECA) assessments must be done with assurances of high reliability and with a defensible paper trail. Truly, major challenges and burdens are apparent for today's pressure vessel and welding specialists that support them.

These challenges are occurring in a global economy. This means that a component may be designed in Country A, for installation in Country B, to be fabricated in Country C, of a material developed in Country D, but produced in Country E and welded using consumables produced in Country F. All of this must usually be in compliance with international Codes and regulations by engineers in every country along the way. There must be better understanding and control of essential variables associated with welding and weld materials.

An important part of both design and post-construction assessments of suitability for continuing service of pressure vessels is predicting fatigue behaviour of weldments. Fatigue of welds has been one of the most common failure modes. A master S-N curve approach has recently been accepted by ASME and by API for fatigue assessment of welded steel and aluminium vessel construction, and post-construction life prediction in service at ordinary temperatures. Extension of this method to other materials and higher temperatures requires more data and documentation of service experience. Additional work is needed to validate proposed approaches for accounting for environmental effects, methods to improve weld profiles and surface stresses, assigning quality factors, and analysing thermal stress cycles.

The master S-N curve approach is based on two key technical advances in fatigue analysis over the last decade:

1. A robust structural stress method that offers good mesh-insensitivity in stress concentration calculation.
2. Definition of an "equivalent" structural stress so that the master curve can represent a large amount of fatigue test data for various joint types, loading modes, plate thicknesses, etc with a relatively tight scatter band. Based on the statistical characterisation of over 1,000 weldment fatigue tests, the design master S-N curve shown below provides both a technically sound and reasonably conservative basis for fatigue evaluation for pressure vessel and piping components (*Figure 9.10*).

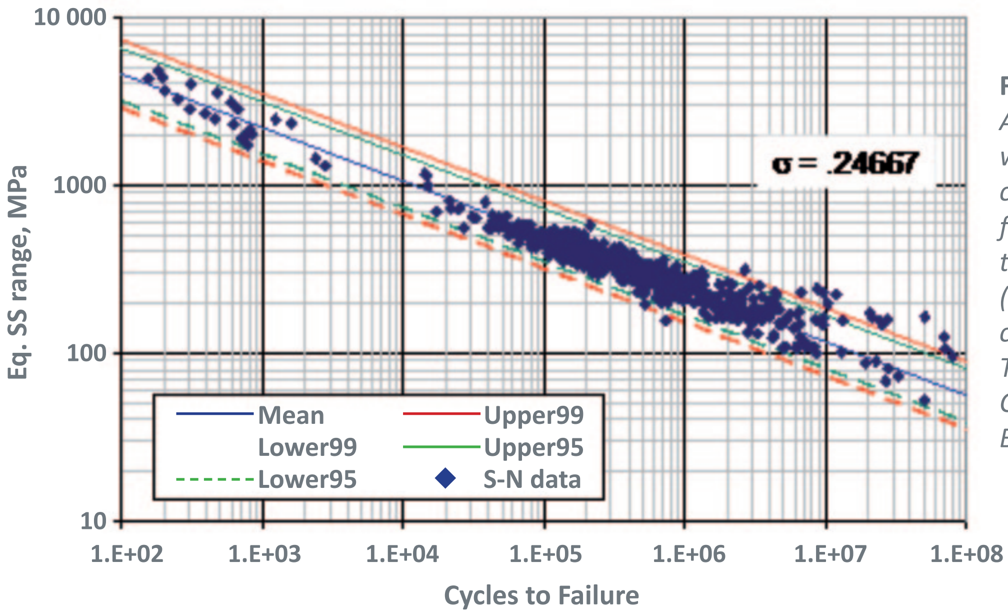


Figure 9.10 *A fatigue of weldments master curve was statistically fit to over one thousand test results (Reproduced courtesy: M. Prager, The Master S-N Curve Method, WRC Bulletin 523, 2010)*

9.5.2 Residual stress estimates for fitness for service (FFS)

In performing FFS or ECA fracture mechanics based defect assessment of a welded component, a through-wall residual stress distribution is required. A major concern is that drastically different residual stress distributions are given for the same joint configuration and welding conditions by various Codes and recommended procedures. Recent work has shown that although residual stresses may depend upon a large number of variables including joint geometry, material composition and welding process parameters, some of the distribution of residual stresses can be estimated with only a few important parameters for engineering assessment purpose. These governing parameters need to be better understood however in terms of their contributions to a through-wall residual stress profile. With that knowledge, functional relationships can be constructed to describe a broad spectrum of the residual stress distributions. Specifically, the underlying mechanics basis on which the residual stress profiles are being developed requires further study, Parametric functional forms for residual stress distribution characteristics over a wide range of geometries and welding conditions need to be explored (*Figure 9.11*).

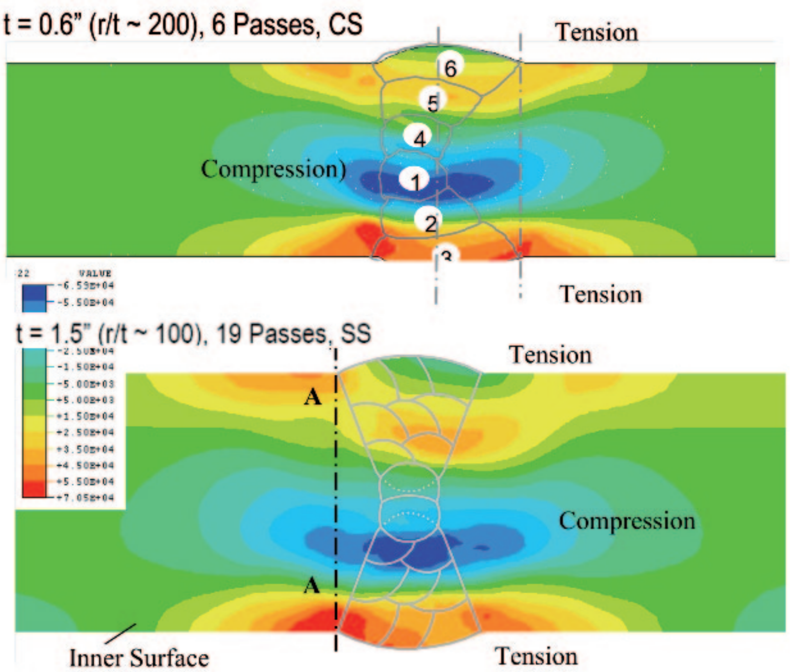


Figure 9.11 *Residual stress patterns were discerned after numerous FEA studies involving a broad range of welding variables (Reproduced courtesy: M. Prager, Recommendations for Determining Residual Stresses in Fitness-for-service Assessment, WRC Bulletin 476, 2002)*

Another "green topic", pressure equipment for the wide use of hydrogen as a substitute for fossil fuels, requires a large, international effort. It must be aimed at understanding, characterising and predicting the performance of welded materials in high pressure hydrogen. An effective testing programme first requires identifying objectives and a strategy based on true understanding of the phenomenon and potential damage scenarios. Certainly the residual stresses and microstructural changes caused by welding will make or break hydrogen as a practical alternative.

There is no shortage of data on hydrogen embrittlement of high strength steels. They will not be used, however. There is a need for data, appropriate to the specific infrastructural materials (lower strength steels in many situations) and their welds as encountered in the envisioned applications. There is not yet a cohesive engineering database applicable to these likely materials to be employed in long term cyclic contact with hydrogen as part of consumer's life style in the transportation industry and its supporting infrastructure.

The various manifestations of hydrogen embrittlement have been well known and studied for a century. Certainly many hundreds of millions of dollars have been spent on programmes on hydrogen embrittlement research. If new programmes are to make a difference they must be well conceived and lead to more practical knowledge than is currently available. Some of the significant issues are as follows:

There must be:

- A mechanistic appreciation of the fundamentals of the materials-environment interaction at the materials surface as affected by stress, stress concentrations, time, temperature, strain rate surface films, gas phase impurities and others.
- Comprehension of potential effects of materials fabrication and joining technologies that will be employed.
- Attention to detail so that effective quality assurance programmes may be established for welded construction.
- Correlation of conventional toughness measures with performance in high pressure hydrogen.
- An understanding of the role of minor elements on susceptibility to crack growth. Foreign and domestic materials specifications have different aim ranges.
- Adequate quality assurance/control of materials and processes. The requirements must be based on concepts of where and how hazards may be introduced inadvertently and what and how safety margins need to be developed and justified. The matrix of concerns needs to include properties under conditions resulting from accident, fire, hydrogen contamination, and long term ageing of welded components.

9.5.3 Hot topics

- The increasing trend to extremely high pressures and temperatures - allowable pressures up to 10,000 bar in food processing, powder metallurgy and waste treatment; allowable metal temperatures up to 1,250°C in the petrochemical industry and down to –273°C in air separation plants.
- Unification of codes and procedures for, and better understanding of, residual stress estimates for fitness for service.
- Utilisation of hydrogen as a "green" alternative to fossil fuels will require understanding, characterisation and prediction of the performance of welded materials in high pressure hydrogen environments.
- Economic considerations with regard to extension of equipment life, and ecological considerations with regard to leak-tightness and risk reduction.

- Globalisation: PEI is operating in a global market with fierce competition. Deregulation, unification of technical criteria, and, hopefully, a globalisation in codes and standards, are the necessary goals.
- The incredible advances in computing power and in the user-friendliness of numerical software, enable the increased usage of more refined calculation methods and an increase in the usage of Design by Analysis (DBA) in design checks of PE. This, in turn, may lead to a consolidated, consistent, and, possibly, internationally unified basis for Design by Formulae (DBF) sections, for the determination of required wall thicknesses. Usage of DBA will lead to an increase of understanding of the structures' behaviour, and it may increase the awareness of the effects of design details and of geometric defects, like out-of-roundness, peaking, misalignment, bulges and dents.
- Advances in welding technology, especially with regard to higher product quality, improvement of performance, homogeneity of weld joints and higher weld speeds, create pressure for a re-think of NDT requirements and defect acceptance limits. Present limits are mostly based on what can be detected and readily measured by RT, and what can be achieved by reasonably good manufacturing practices of long ago. Present requirements with regard to the amount of spot testing hardly reflect achievements in welding technology and design methods, nor do they take into account modern NDT methods, nor present in-service inspection requirements.

9.6 Automotive sector

The automotive industry is forecast to grow annually with 13.7% to be compared with >20% for China. BRIC (Brazil, Russia, India and China) stands for 40% of the growth. North America is expected to increase their car fleet with 9.5% per year (*Figure 9.12*).

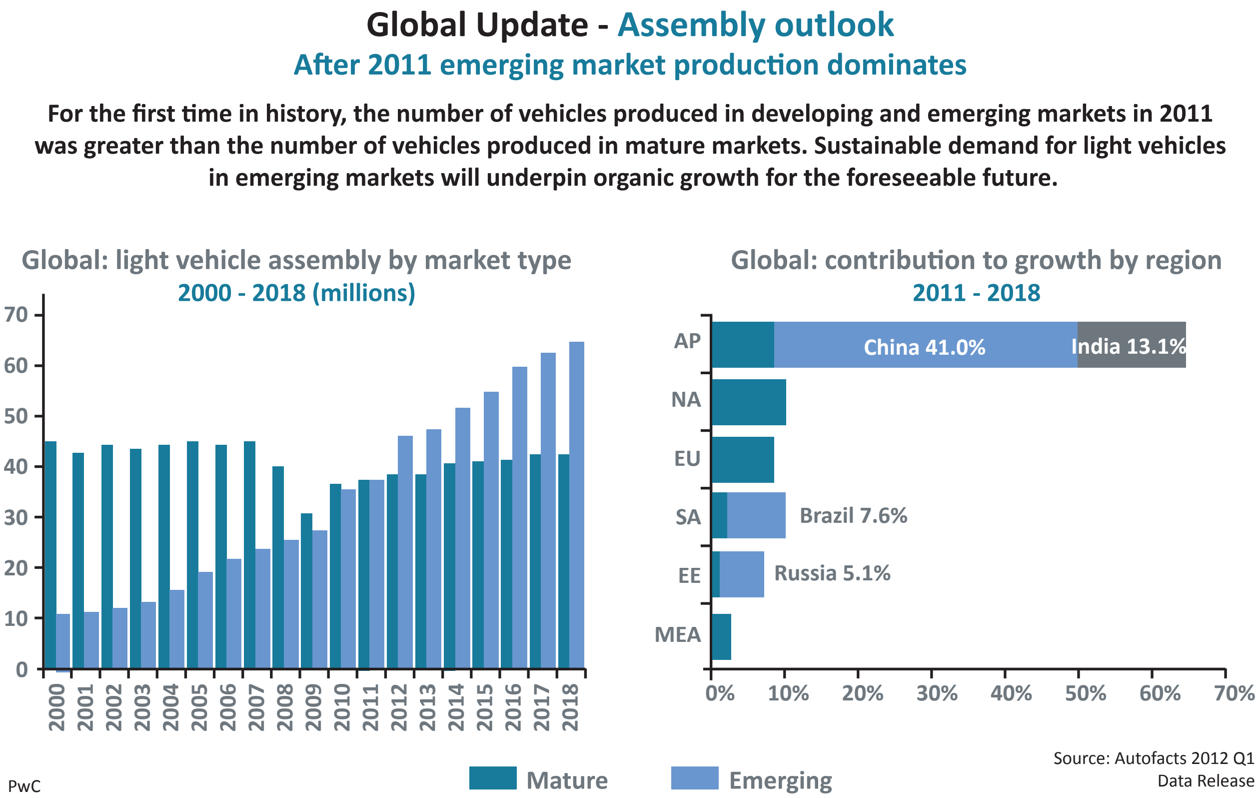


Figure 9.12 – *The car industry is the main driver for development of joining technologies for sheet materials (Reproduced courtesy: Autofacts BRIC Outlook)*

9.6.1 Industry trends

The most important factor which affects the welding in the automotive sector is the need to reduce CO_2 emissions in exhaust gases to fight global warming. The role the sector plays in reducing exhaust CO_2 gas include:

- Improvement of combustion efficiency.
- Reduction of vehicle weight.
- Reduction of loss of efficiency through friction.

Among these items which achieve savings in fuel consumption, weight reduction is the area where welding technology contributes the most, though weight reduction does not completely equate to the reduction of exhausted CO_2 gas. Recent trends show initial weight reductions counteracted by the addition of further equipment to improve driver comfort and convenience, particularly for distance driving, or by the addition of collision safety equipment.

The recovery rate of recycling waste material was raised considerably in the 1990s, though welding technology has not a great contribution to this field. There has been investigation of joining techniques which are reversible, but not much application has been found, particularly as it is difficult to balance the remaining life of each part of the vehicle.

Recently the safety of the body structure of vehicles has been improved from the conventional structures where the impact is absorbed locally, to an advanced structure for dispersing the impact to the whole body. This countermeasure caused increased body weight, so compatibility between weight reduction and impact absorbability is needed.

In the automotive market in Japan, it seems two trends have emerged lately. The first is the growth in the use of the mini car which is believed to be related to the increase in the number of advanced age drivers and female drivers, and these factors will be steadily intensified for the future. The next phenomenon is a change of mind among the young who enjoy personal computer or display games at home and regard the automobile as merely a measure of mobility. These trends suggest that one must reconsider the strategy and the role of the automobile in human life.

With reference to mass production, the optimum structures in the world are grouped in many automotive makers. The growing markets of BRICs (Brazil, Russia, India, China), which are thought to be some of the biggest markets in the future, are increasing steadily. To achieve smooth operation in these countries, it is important that a simple technique which is common to all countries should be prepared and standardised. Furthermore, the price advantage over other makers is also important in these newly-emerging entry car markets.

The US automotive industry is facing numerous challenges from many fronts. The first major challenge automakers are facing is addressing the energy and environmental issues related to their products. Federal, state and international governments are threatening to place huge hurdles in front of automakers through increased Corporate Average Fuel Economy (CAFE) standards, fuel taxes and tightened CO_2 emissions standards. In many cases, there are no market friendly solutions to these hurdles with today's technology. Some OEMs are now suggesting that a gas tax is the best way to change consumer behaviour.

Both federal governments and insurance organsations are continually raising safety standards. Over the last few years, most North American automakers have focused on addressing the pending roof crush standard which increases the required strength levels by more than 50%. Beyond roof crush, other regulations such as new front and side impact standards are increasing the performance standards for the vehicle's structure. No longer is safety merely a government compliance issue, but a loss of an insurance institute 5 star rating directly relates to a drop in sales.

At the same time as automakers are grappling with these challenges, the competitive landscape in the automotive market has increased significantly. The number of nameplates available for consumers to choose from has gone up significantly over the last decade. This broadened competition has turned it into a buyers' market, driving growth of incentives to outpace vehicle prices. To keep customers coming into the showroom, automakers must continually refresh their line-ups. The speed and cost of developing new vehicles combined with the ability to change model production to flow with market demand have become critical competitive advantages.

These challenges have a direct impact on the automaker's technical strategies. In discussions with Edison Welding Institute (EWI) members, three common technical areas emerge; powertrains, structures and safety systems.

Powertrains

The first technical area is the development of next generation powertrains, which have automakers focusing on near term, mid-term and long-term solutions. The near term focus includes the development of more efficient internal combustion engines (ICE). Most of the mid-term effort is on the development of hybrid vehicles. The lynch pin to these vehicles is the development of safe, affordable Lithium-Ion batteries. Long-term, every OEM has its focus on producing fuel cell powertrains. Two critical steps to make fuel cells a sellable reality in the market place are the ability to affordably produce the fuel cells themselves in high volume and the development of safe hydrogen storage systems. From a joining standpoint, these new powertrains require enormous numbers of critical welds. In the batteries, these welds will involve joining dissimilar materials like copper to aluminium. From a welding engineering standpoint, the fuel cell stack is a series of leak tight joints on very thin foils. To be produced affordably, these joints will require ultra high speed welding systems that are better than six sigma.

Structures and safety systems

Over the last few years the focus of automakers has been on the ability to meet the pending roof crush standards without taking a weight or cost penalty. Through the development of new steel grades, known as advanced high strength steels (AHSS), automakers have, for the most part been able to design vehicles to the new standards without a weight penalty. These new steels offer much hope toward developing lighter, safer vehicles. The challenge welding engineers face with these new steels is that steel makers and designers are implementing new steels at a faster rate than welding engineers can handle. To better handle the onslaught of new materials, FEA based weldability modelling tools are needed.

The next hurdle developers are grappling with is how to drive down the weight and cost of the vehicle structures. To achieve this, designers will likely call for new designs involving tubular construction. To make tubular designs work in a vehicle assembly, robust single sided welding technologies must be developed. Perhaps the biggest change that will occur if fuel prices and regulations require automakers build more efficient vehicles is the incorporation of multi-material vehicle designs (MMV). Today's vehicles are largely steel structures. An MMV would utilise a range of materials from Advanced High Strength Steels (AHSS) and Ultra High Strength Steels (UHSS), to aluminium, magnesium and composites. While a true MMV structure offers the protection of UHSS with the weight savings of aluminium and magnesium, it would also pose numerous manufacturing challenges in terms of corrosion, joining, and design. Automakers are looking for governmental, research and industrial organisations that will partner with them to research, develop and commercialise technologies that address the critical hurdles revolving around energy/emissions, safety and affordability. Collaborations to address these materials joining challenges, are necessary.

9.6.2 Materials development

High-tensile steel materials have been developed and utilised, and this has contributed to weight reduction by use of smaller gauges. If ultra-high-tensile steels are introduced, however, spring back of stamped sheets will become a problem. In welding jigs, fitting accuracy of ultra-high-tensile steel will be certainly inferior to former steels. Welding techniques such as the increase of electrode pressure force and countermeasures for electrode abrasion need to be investigated. Thin gauge sheets should not be applied to areas of the vehicle which influence the rigidity of the auto body due to potentially reduced safety of passengers. It is important therefore that applied portion must be selected thoroughly by use of structural analysis simulation.

As well as high-tensile steel, galvanised steel is necessary for automobiles from the viewpoint of corrosion resistance. For more than 20 years, galvanised steel has been utilised in the body for the purpose of preventing red rust which spoils the external appearance. It also has been adopted in the chassis parts for the purpose of preventing a decline of the strength which depends on plate thickness. In Japan, galvanised steel, thinly coated by hot-dipping can be supplied, but in consideration of the cooperation between Japan and foreign countries, recently the thickness of galvanised coating was unified. This change is making the coating thicker in chassis parts, and it is thought to be more difficult to weld in the case of arc welding in which porosity and spatter are increased considerably. Modern welding processes are able to deal with this challenge however.

To overcome the limitations of steel, the application of aluminium has been investigated, and it is used in covers such as the lid and hood of vehicles. There appear to be no obstacles to welding of vehicles so far. There are two issues with the application of aluminium however. The first is the price of material which is the main constraint on the production of an aluminium car. In the near future, however, the price of petrol will probably be raised through the exhaustion or oligopoly of petroleum resources, so lighter vehicles will be advantageous. The second subject is a lack of agreement on the value of aluminium vehicles from the view point of life cycle assessment (LCA). A large amount of CO_2 gas is exhausted at each stage in the alumina smelting process and when smelting waste aluminium. To offset this amount of gas it is calculated that 180,000 km of vehicle travel is needed in the case of all new material, and 100,000 km travelling is needed in case of all recycled material. Considering that the average vehicle life is about 10 years, it cannot be assumed that the application of aluminium in the automotive industry will lead to reductions of the total exhausted CO_2 gas. It will be necessary to develop complete recycling technology to reclaim body material from waste aluminium bodies. To prepare for the aluminium vehicle age, one of the challenges is to develop welding techniques which will efficiently join recycled materials.

9.6.3 Welding processes and challenges

Transistor inverter type power sources and electromotive pressure guns have been developed for use in the automotive industry, and now the advancement in this field seems to have slowed. Recently laser welding was applied to tailored blank welding for the purpose of raising the yield rate of material, and this technique contributed to optimum arrangement of plate thickness and strength of materials. New applications of laser welding for body assembly are popular. This process has been introduced to prevent the decrease of body assembly rigidity.

In resistance spot welding, which does not make continuous joints and requires holes merely to generate electrode pressure, the joint efficiency and the rigidity of body assembly decreases and these factors are regarded as issues for the use of resistance spot welding. Currently, however, more attention is given to the weak points of laser welding, such as low adaptability to fitting accuracy of the base material in lap-filet joints, and deviation of focus point in butt joints during mass production applications. To overcome these challenges, laser-arc hybrid welding and laser brazing are being trialled by almost all makers. Countermeasures for other issues with laser welding, such as porosity generation and irregular bead formation, are now in progress.

On the other hand, when looking at the welding process utilised for joining chassis parts, it is clear that many welding processes are converging with gas metal arc welding. This is because it is recognised that gas metal arc welding has many strong points, such as applicability to many types of joints, good balance between productivity and cost, and adaptability to robot welding. Consequently, it is believed that gas metal arc welding will be the major method from now on.

Laser-arc hybrid welding is expected to succeed in mass production. Thought there are some doubts about this becoming the major method for chassis part welding, such as the loss of flexibilities in torch operation and arc force direction, there are many merits far exceeding arc welding, including low distortion. If production efficiency is balanced between before and after processes by high-speed welding, however, laser-arc hybrid welding will be surely applied to some fields.

A new technique, friction stir spot welding, in now being introduced. Resistance spot welding and arc welding have been the major processes so far suitable for robotised welding. This is one of the reasons that enabled them to be propagated in the world. The friction stir spot welding is also flexible and suitable for 3-dimensional welding. Although friction stir welding is used for straight line continuous welds in train and airplane manufacture, its application in automotive production lines will depend on its flexibility and application to robotised welding. Although the application of the friction stir spot welding is currently limited to aluminium panels, its application to steel panels is being investigated, so it is expected to be successful in the future.

9.6.4 Hot topics

- Need to reduce CO_2 emissions to fight global warming through improved combustion, reduced vehicle weight and reduction of loss of efficiency through friction.
- Research and development of efficient welding technologies for high-tensile, ultra high-tensile, galvanised steels and other lightweight materials e.g. aluminium, tubular construction.
- Research and development of efficient welding technologies to support changing vehicle safety requirements.
- Development of next generation environmentally friendly powertrains such as hybrid and battery powered vehicles.

9.7 Mining, minerals and materials processing sector

The mining, minerals and materials processing sectors have been growing rapidly over the past 20 years in many parts of the world, in response to increasing world commodity demands. In Australia, for instance, this growth has been at 5% p.a., with that country currently generating thirty three-billion-dollar-plus per year mineral exports (coal A$11B, aluminium A$8B, iron A$5B, gold A$5B, copper A$2B, zinc A$2B). Many initiatives of the various sectors of the minerals industry have resulted, over the years, in a corporate focus on business performance, with a resultant decrease in exploration and longer-term research around the world. This decline has threatened the long-term viability of the industry by limiting the utilisation of new sources and restricting the growth of knowledge and capability to produce.

The current recent global downturn and reduction in demand has seen, however, a new focus by companies on the need for improved productivity and capital returns. While the boom in mining and minerals may have been overtaken by the global credit crunch, most industry and economic experts agree that the way forward is through innovation-led productivity growth. Welding, as an essential enabling technology in a wide range of mining infrastructure and equipment manufacture and maintenance applications, can contribute significantly to this new focus.

Any strategic approach involving welding covers critical equipment utilised in excavation, bulk handling, processing and transportation in the mining industry. This approach must encompass innovation and productivity improvements, delivered by skilled and trained personnel. Within the mining industry, welding technology also plays a key role in the sustainable development of the industry through safer, more efficient and cost effective mining strategies that safeguard the environment and minimise waste. Such considerations apply not only in the mining sectors in developed nations, but also, and possibly even more significantly, in the mining activities of emerging economies and developing nations. Here the ready availability of labour means that manual operation often dominates, and the health and safety of many thousands of people, often children, are affected.

Initiatives by IIW Member countries to establish an adaptable but simple IIW Welding Occupational Health and Safety Management System for use in such countries offers hope for improved working conditions and a sustainable environment for the future.

9.7.1 Hot topics

The specific aspects of this industry's challenges where welding and joining technology transfers are needed and contribute to meeting the industry objectives include the following:

- The need for the mining industry to become more cost effective by improving productivity, reducing down time on equipment and improving safety, has become predominant in the competitive global market.
- The need to improve the performance, life, repair and maintenance downtime of the different types of equipment used on mines. Such equipment must be manufactured /repaired/maintained to give high reliability, integrity and safety.

Any strategic approach will identify and develop unique areas of competitive advantage for companies in the mining industry sector e.g. laser cladding for refurbishment of worn mining equipment parts. Examples of specific applications and welding technology solutions that a strategy could analyse, prioritise, develop, demonstrate and disseminate with relevant stakeholders to help meet the challenges and create unique areas of competitive advantage for companies cover amongst others:

- More efficient manufacture and supply of equipment for use in open cut and underground mines.
- Avoidance of failures due to poor structural integrity, wear, erosion, corrosion, overloading.
- New methods of repair and maintenance both to avoid future failures and minimise degradation through modes such as erosion and corrosion.
- Light-weighting through increased use of higher strength materials and improved design.
- Better safety and on-site conditions and meeting the welding skills shortages.

This will be achieved through solutions, amongst others such as:

- Improved hardfacing and cladding material properties.
- Procedures for improved quality of weld repair.
- Fatigue improvement techniques.
- Arc and laser processes for direct application of hardfacing and cladding.
- In-service monitoring of equipment.
- Higher deposition rate weld processes.
- Improved occupational health and safety management.
- Use of IIW qualification and certification programmes and more sophisticated technology.

9.7.2 Welding in the minerals processing industry – Alumina case study

General process description

Alumina refining in general consists of the Bayer process, followed by calcination. In the Bayer process, caustic soda is used to dissolve (digest) the aluminium oxides and hydroxides in the bauxite ore at an elevated temperature of between 150 and 290 °C, the liquor is then separated from the sand and mud residue and precipitated, at reduced temperature of about 70 °C, as pure aluminium hydroxide. This is then calcined to convert the hydroxide to aluminium oxide, at a temperature of about 1,000 °C. A large number of heat exchangers are used to heat the liquor and slurry using both steam and process vapour, and to recover heat.

General vessel description

The alumina refining process uses a large number of holding tanks, thickeners and washers at atmospheric pressure, with tank diameters ranging up to 45 m. Precipitation tanks, also open to atmosphere, are typically 30 m high by 12 m diameter. Digestion vessels, and flash vessels used to flash down to atmospheric pressure, can have design pressures of up to 5 MPa. Heat exchangers typically operate at similar pressures.

The materials of construction for most tanks, vessels and pipes are various grades of mild steel, except for the calcination plant where high nickel superalloys are used, and the acid cleaning system (used to remove sodalite scale from heat exchanger tubes) which is made from different grades of stainless steel. Vessel wall thicknesses are usually 20 mm or less, but can range up to 40 mm at the bottom of high tanks.

Common welding procedures employed

Mild steel tanks, vessels and pipe spools are fabricated using conventional welding techniques and procedures. There are no special requirements apart from compliance with the normal quality and equipment codes, such as those for pressure vessels, piping, and tankage. There is one exception that post weld stress relief is required to guard against caustic embrittlement, a form of stress corrosion cracking, which can occur under certain process conditions.

Repair welding on site is usually done with MMAW and GMAW. There is also considerable interest in productivity improvement techniques that could be employed to reduce turnaround time in vessel and tank repair, eg FCAW. Some bauxite ore bodies contain large amounts of quartz, rendering the process slurries highly abrasive. In these cases there is a need for selective hardfacing of some process equipment, and it is common practice to use hardfacing consumable category 2560 for these. Tungsten carbide in a NiSiB matrix (with or without Cr) is also used.

Issues, Needs and Challenges

With regard to caustic embrittlement, there are issues with the quality of field thermal stress relief, and with the logistics as the codes prohibit the use of spot stress relief. If reliable alternative stress relief methods were available, they would find application. There are issues if welding in the presence of caustic residue, as this leads to cracking. There is a general interest in low stress welding procedures in the industry. As more duplex stainless steels are becoming commercially viable, such as 2906, 2003 and 2101, there will be a need for robust welding procedures for these alloys as there is potential application for these alloys in the alumina industry due to their resistance to caustic. There are occasional issues with preferential weld corrosion.

9.8 Shipbuilding sector

9.8.1 Industry trends

During the previous decades and due to the globalisation and progress of technology, the shipbuilding industry in Japan, South Korea and Europe, has undergone a fundamental shift from a mainly labour-intensive industry to a capital and know-how dominated high-tech industry, relying on the availability of a highly-skilled workforce. Currently, PR China is in third place of the world ranking list and is producing 13% of the total world tonnage. South Korea is the largest shipbuilder in the world, with 38%, followed by Japan with 28% of the world tonnage.

The booming shipbuilding industry at this moment differs markedly from the oil tanker boom, 35 years ago, a trend that was driven primarily by growth in the oil business - but collapsed during the oil crisis. The time in shipbuilding today is not dependent on a single product, but on the growth in global trade, producing a growing demand for new ships. It should be noted that this development is driven to a large extent, by the exploding economic growth of China.

The shipyard industry is dominated by Japan, South Korea and China with close to 90% of all ships built in these three countries (*Figure 9.13*). China is committed to become the world largest supplier of ships by investing heavily in new shipyards and upgrading the existing ones. The increase in Chinese market share is already now demonstrating the commitment. During the last two years, China has increased its market share by 4% at the sacrifice of Japan and South Korea. The European shipyards are however relentlessly fighting for survival by developing and introducing more efficient manufacturing processes. The Meyer Shipyard in Germany has made large investment in a panel-line, in which the laser hybrid welding is applied. There are few other shipyards in Europe using the laser process. So far the Finnish, German, French and Italian shipyards have almost 100% of the market for cruisers. Finland is judged to have one fourth of this market but in total Finland has only 0.4% of the world market in all types of ships.

The struggle to retain market share in this world market, is forcing European shipyards to make structural changes, with the objective of increasing productivity and improving flexibility. The basis for reaching a sufficient increase of productivity is among others, the ability to introduce and apply advanced manufacturing technologies and improved instrumentation. Europe is building the most complicated ships in the world and is the basis of maritime innovations. Two problems exist in many European shipyards with a fully booked order intake:

- To find initial capacity, because delivery times threaten to be too long. It is true, that increasing capacity is not always the only solution. Also the order book of the supply companies, are full and not always able to deliver in time.
- Shipyards have a number of vacancies, which are difficult to fill.

The number of students coming from technical schools is causing considerable concern and too few trained people are available. There is a good reason that the sector's future plans must focus on training and education. This has stagnated in the past few decades, even so, this is the foundation for the future. One has to stay on top of this, from high school to Technical University.

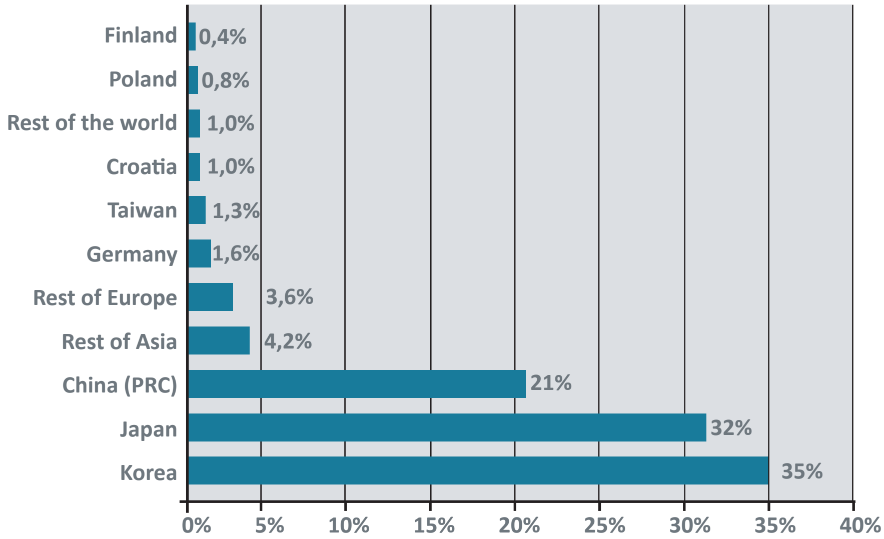


Figure 9.13 *Distribution of the total order book 262, 7 MDWT for shipyards in July 2006 (Reproduced courtesy: B. Pekkari)*

Investing in personnel's knowledge is a part of shipbuilding's future. In order to be able to keep up with competition, knowledge and its further development are of vital importance. Education and research are needed at every level. In addition to extra training, setting up specific shipbuilding education is a possible option. At the same time there must be even closer collaboration between shipyards, the shipbuilding educationalists and the knowledge institutions, to equip the knowledge infrastructure with maximum information.

The biggest stimulus is the growing world trade and the important role that sea transport plays in freight transport, especially between Europe and Asia. As a result of this, freight transport is expected to double in Europe during the coming years. Rail and highway transport cannot follow this level of growth. The expectation is that the role of sea transport will continue to increase. As result of this growth, demand for ships will increase in the near future.

The expectations for offshore are also favourable, because, the demand for energy - oil in particular - will increase considerably through 2030. A large wave of investment growth in this sector is expected.

This picture appears to be rosy - and in a certain sense it is. It is not certain how long the growth of demand for new ships will continue after the global financial crisis but with continued growth in China and India for energy, growth should be positive.

9.8.2 Naval shipbuilding – versatile and innovative in a changing Navy market

As a result of the changing distribution of power in the world, the market for naval ships has changed considerably. Naval ships must still be in a state of readiness, but within a revised operational and strategic structure, in which world-wide peace-keeping operations and activities to counter-act disasters occupy an increasingly important position. The amphibious transport ships, equipped with aid equipment, crew, vehicles and other means of transport are extremely suitable for this. As a result of the decline in demand for frigates and corvettes and the threat of over capacity resulting from this, competition between the world's naval shipbuilders is becoming stiffer.

Some remarkable developments in naval shipbuilding can be mentioned. Blohm & Voss, a company of ThyssenKrupp Shipyards, developed the MEKO design concept, based on a platform "ship", which is specifically designed for flexible installation and removal of machinery, weapons and electronic systems as standardised modules. Modularity is the key to the MEKO technology. Many modules have been installed on

board approximately 60 delivered or ordered frigates and corvettes, which have been designed accordance to the MEKO concept.

Another air versus sea transport development is the Theatre Support Vessel (TSV), designed and manufactured by Incat Tasmania Ltd, in Australia, is a vital part of the US Army's plans for transportation. This new high speed catamaran vessel will greatly enhance intra-theatre deployment and logistics support for Army units world-wide. The TSV planned capabilities- speed (over 40 knots), capacity (1,250 tons) and flexibility (shallow) draft, lightweight aluminium construction, streamlined hull shapes - will provide the Army with a new and potent capability for rapidly responding to crisis situations anywhere in the world.

Another Combat Ship, the Littoral Combat Ship (LCS), is built with Austal Trimaran Technology, by Austal Ships in Henderson in Australia. Austal is the designer and builder of the General Dynamics LCS. A lightweight aluminium construction for the US Navy, it utilises the inherent advantages of the trimaran, large cargo bay, high payloads, flexible layout, shallow draft, manoeuvrability, high speed in a seaway, resulting in improved crew comfort and aviation capabilities, to enable a new breed of surface combatant for near shore duties.

9.8.3 Innovative shipbuilding

The maritime industry world-wide, became a highly innovative sector, with a large variety of shipyards focusing on standard, special and complicated vessels. The European shipbuilding industry in particular, building the most complicated ships and is also a source of maritime innovation. Most yards have succeeded to have full order portfolios for the coming years. There is some movement to introduce more production automation also among the middle size and smaller shipyards, a dominating part of the total shipbuilding industry. One can observe an interesting development in these yards. They receive orders for not one single ship, but for a number of identical vessels. Outsourcing of production to low labour cost countries is for different reasons not an ideal solution. In the boom period in European shipbuilding, the characteristics of the smaller shipyards will become effective: they are flexible, able to commit for special features and they can deliver. Series production of high quality production of smaller ships can proceed. This means that their programmes are aiming at streamlining the whole shipbuilding process.

9.8.4 Integrated shop floor technology

Welding and cutting robots in production are important tools in the continuing process of automation and are now considered as well known and well established production systems for the large shipyards in Japan, North-Korea, China and Europe. For the middle size shipyards, without experience in automated production systems, the transfer from old-fashioned arc welding technology to robot welding and cutting systems is a difficult decision. Management will further discuss the return on the investment in automation and robotisation for their production. We can be sure that the situation and decisions in each yard depend very much on the company's culture and even the country's culture. One can try to identify the major problems in the efficiency of the steel fabrication process as mentioned below:

- Out-of-date assembly processes established in order to compensate for the lack of flexibility in the workforce and equipment, resulting in limited square meter output, complicated logistics, exaggerated accumulation of inaccuracies and low resource utilisation due to frequent job mobilisation.
- Extraordinary level of variability in product and facility quality state, resulting in accuracy in planning data input and thus insufficiency in planning accuracy leading to inappropriate resource spending and subsequently managerial frustration.
- Inflexible top down management structures combined with out-of-date human motivation ideologies, resulting in reduced flexibility in the work force, inappropriate resource utilisation and insufficient learning effect.

This situation is unsatisfactory and is threatening the survival of the shipbuilding industry in modern societies. Delayed transition into modern technological shipbuilding also threatens the survival of the shipbuilding industry in these modern societies.

For many middle size shipyards, the implementation of change from conventional to high-tech shipbuilding technology is difficult and has to be done carefully. Internal resources at individual yards are very often not available as regards to the wide range of knowledge required for the technological changes.

9.8.5 Laser technology – A revolution in shipbuilding

The need to retain market share in the world market of shipbuilding has forced many European yards to make structural changes, with the objective of increasing productivity.

The German maritime sector, like Blohm & Voss GmbH shipyard in Hamburg, has highly innovative production, with a close interaction with other shipyards to maintain and improve competitiveness of its maritime cluster. This yard manufactures high-tech ships as frigates, corvettes, fast cruise ships and mega-yachts. Achieving a satisfactory increase in productivity based, among other things, on the ability to introduce and apply new production technologies and improved measuring techniques. In this context, the concept of precision manufacturing in steel shipbuilding has become important.

Precision manufacturing means production to very narrow tolerances, minimising assembly costs by removing the need for straightening and adjustment. Precision manufacturing is particularly notable in reducing rework and minimising throughput time at critical points, thus increasing productivity. Current sectional shipbuilding methods involve the prefabrication of huge modules (volume components consisting of walls, decks and bulkheads) in large shops. The following technologies and methods have been introduced in the field of pre-fabrication:

- Combining laser cutting and laser welding in one production line, along with complex clamping technology that renders exact pre-positioning and tack-welding of components unnecessary.
- Automating the precision manufacture of shipbuilding panels with considerably less thermal distortion than when using conventional joining methods.
- A new approach to designing steel ship internal structures from modular, standardised, precision steel subassemblies, referred to as parts families.

Within the hull (shell plating) there are numerous decks, walls running fore and aft and transverse partitions, such as bulkheads and transverse walls, all connected to form a supporting framework. This makes it possible to use plate and sections of much reduced thickness compared with, for example, container ships. Reinforced plates with a thickness of 4 mm are not uncommon. The numerous flat panels in the ships from the shipyard can be particularly prone to distortion, due to the reduced thickness of the plate and the sections.

Laser technology with a much smaller HAZ, is setting new standards in shipbuilding production technology in terms of minimal thermal stress. 240 km of laser welds for each ship gives an idea of the potential savings that can be achieved by the introduction of this technology.

9.8.6 Aluminium ship fabrication

For fabrication of ship hull and superstructure in aluminium, labour hourly cost amounts to 60-65% of total production cost for an average ship. The greater part of this cost consists of forming and assembly of plates and profiles and welding. For ships built of steel the same cost is only 20-25% of total production cost. A major reason for this difference is the much lower degree of mechanisation and automation within welding in the aluminium industry. Here, the technology that can be offered has not yet reached the same

advanced technological level as for steel fabrication due to lower priority in the past by fabrication and welding systems manufacturers.

There is a great potential, in particular for aluminium ship structures for further improvement. Development is carried out in close co-operation between shipyards, research institutes, fabricators of production systems and welding supply companies. Suppliers offer technologies and systems for robotic welding of ship structures. Off-line programming based on CAD data combined with a high degree of automatic generation of the complete control programmes for welding is required to fully realise the capacity and potential of the welding station.

The main objective for using sensors in robotic welding of aluminium ship construction, is the need for localising the point where to start welding and then to follow the seam. There are remaining challenges and problems, which have to be solved before the technology can be considered to be ready for implementation in the production of aluminium constructions in shipyards. The future work will be focused on the off-line programming. So far it has been focused mainly on the problems connected to accuracy. The strategy for handling the huge amount of data for a complex hull section and the welding required is not clear and has to be emphasised in future work.

Generally, the business drivers in the shipbuilding industry include reducing both the cost of producing new ships and reducing the total ownership cost over the life of the ship.

9.8.7 Hot topics

- **Improved Joining Technologies for Ship Structures:** There is the need for continued improvement and the application of "World-class" processes that increase efficiency, reduce rework, and shorten construction time. Joining processes such as precision arc welding, friction stir welding, and hybrid laser arc welding continue to be of high interest. Additionally, the shipyards have interest in expanding the use of automation for large marine structures using smart adaptive welding systems.

- **Process Control:** Application of process control that will result in more standardised production processes, improved accuracy control, and improved cost, quality, and schedule performance. Interest areas include advanced measurement techniques, expanded use of statistical process control, automated data storage, analysis, and transfer. Distortion prediction and accuracy control are important subsets of this. Controlling weld distortion continues to be a challenge for shipbuilders and the problem increases as lighter and lighter structures must be built. Technology needs include improved modelling and simulation tools and the development and application of workable manufacturing processes capable of controlling distortion during fabrication. EWI has field demonstrated a novel automated technology, dubbed Transient Thermal Tensioning, for control of buckling distortion on thin panels.

- **Joining Non-traditional Materials:** There is a need for increased performance (e.g. speed and manoeuvrability) and this is driving the requirement to reduce ship weight. This results in the use of non-traditional materials including non-metallic composites, high-strength steel, aluminium, and titanium. There are needs for materials joining processes for these materials and processes to join dissimilar combinations of these materials.

- **Advanced Non-Destructive Inspection Techniques:** Shipyards want to minimise the cost of inspecting welds. New solutions include the implementation of advanced non-destructive inspection technologies. These technologies include processes for improved inspection under lagging, ultrasonic and digital radiographic inspection of welds, inspection of composite structures, and the

implementation of smart systems. In addition, there are needs for inspection of new processes such as friction stir welding and new materials that are not typical in the shipbuilding industry.

- **Cost Control:** There is a need to apply Lean Principals to create more efficient fabrication operations and eliminate non-value added activities.

- **Standards:** Material standards and standardisation includes items that support the application of “best-practice” commercial and government standards that support rapid data acquisition, design engineering, and efficient production operations.

- **Occupational Health & Safety:** Technologies are needed that improve worker safety, health, and reduce environmental impact while not significantly increasing the cost of time of ship construction.

- **Workforce Development:** The shortage of skilled welders and other skilled crafts leads to the need for innovative methods of workforce education, training, and development. This area includes programmes to attract, develop, and retain qualified welders and other personnel to support shipyard operations.

9.8.8 The IIW select committee Shipbuilding

The IIW select committee Shipbuilding was established as a working group during the IIW Annual Assembly in San Francisco in 1997 to bring greater collaboration in international shipbuilding in the IIW member countries. The objective of the IIW group, was and still is, to create an international forum for technology transfer and information exchange and should be a meeting point for shipbuilders. The basic programme is achieving the correct emphasis on practical, useful approaches to industrial management in shipbuilding. Based on the scientific and experimental research efforts, the activities are application oriented. The WG goals have been achieved by sharing knowledge in the various areas to the extent that this is possible, without revealing confidential information vital to the individual shipyard’s competitive situation.

9.9 Building sector

The general term “buildings” encompasses the whole array of structures, including those used for offices, factories, schools, hospitals and apartments, to name a few. Domestic houses are exempted from the general category of buildings.

Buildings are inherently large structures, typically involving shop assembly of the building’s components followed by field erection. They are often one-of-a-kind structures, eliminating the option of design by trial-and-error. Buildings are expected to last for many decades, and during the life of a building, the structure may be modified for new uses.

Thousands of lives are dependent on large buildings being reliable, even when subjected to the often hard-to-predict forces of nature, whether due to tsunamis, hurricanes, tornados or earthquakes. Buildings are also the target of terrorists where blast loads from street-level truck bombs are of concern.

For major structures (over five storeys high), two primary building systems exist: steel construction and concrete construction. Both types are in fact “composite” construction, employing components made of both materials. Steel construction uses steel beams and columns with foundations and floors made of concrete. Concrete construction utilises concrete columns, beams, floors and walls, but reinforcing steel (“rebar”) gives concrete the ability to resist tensile loads. For pre-stressed concrete construction, steel cables are used to induce compressive stresses.

9.9.1 Needs and Challenges

Perhaps nothing is more important to improving the quality of life than protecting life itself. During major natural catastrophes, buildings can collapse, resulting in human fatalities that can run into the thousands. Investigations of the ruins frequently reveal the consequences of substandard design or construction practices, regardless of the basic method of construction, whether timber, masonry, concrete or steel.

Some buildings are simply not required to be designed in accordance with modern standards and the disastrous performance of structures is predictable, given the nature of the construction standards that are locally accepted. In such situations, the local building codes need to be raised.

In other situations, appropriate codes have been adopted but the lack of adherence to the applicable standard is the problem. Such practices may be the result of ignorance of the significance of the requirement. Reports of illegal bribing of oversight officials persist and substandard construction materials are yet another problematic area. Fraudulent substitution of unacceptable materials occurs. A challenge is to emphasise the importance of construction quality and the consequences of non-conformance. When responsible standards are adopted and enforced, quality steel construction will be seen as more economical, and hundreds of lives will be saved in future catastrophic natural events.

For many years, steel structures have been the preferred type of structure when the forces of nature attack. Yet many local communities lack the expertise in steel design concepts, or do not have easy access to affordable steel, or lack the workers needed for quality steel construction. Education and training are key challenges in this regard.

Since buildings are field erected, much of the welding is performed manually. The size of the structures results in significant variation in fit-up which makes automation difficult. The one-of-a-kind nature of buildings makes each construction site unique, and again precludes easy automation. The challenge is to develop the required technology to make automated and robotic solutions viable under these conditions. Such systems must be robust under field conditions.

With respect to concrete construction, welded splices are often made with poor quality. Automated, resistance butt splicing methods have been shown to be inconsistent. Manual and semiautomatic welding methods also result in irregular quality, particularly for direct butt splices. Inspection of such welds is difficult. New or improved welding methods, training and inspection are needed for concrete construction.

Seismic loading subjects buildings to extreme loading conditions. Most structures are designed to resist these infrequent but large loads by permitting localised yielding to occur in select locations, typically within the steel members themselves (as opposed to within welded regions). The required material properties of welds and base metals, as well as required weld quality, acceptable weld details and other factors will likely be the subject of ongoing investigations following major earthquakes since laboratory investigations will likely never predict all that damage that post-earthquake investigations will reveal.

Blast-resistant design will likely, but unfortunately, be an ongoing topic of interest. Blast-resistant design attempts to preclude disproportional collapse, even in front of considerable structural damage. Acceptable overall structural design, material properties, details, quality levels and expected performances due to different blasts are areas where research still needs to be performed.

9.9.2 Hot topics

- Raising and enforcement of building code standards in emerging countries to a global standard.
- Training, qualification and certification of personnel to ensure industry's ability to design and implement steel construction in all countries.
- Research and development of robust field welding automation.
- Improved welding, training and inspection for concrete construction.
- Continued research and development of seismic and blast resistant structures.

9.10 Bridge sector

Bridges are essential links in the transportation system, whether used by trains, trucks, buses or cars. Besides the obvious functional differences, bridges are differentiated from other structures such as buildings by the nature of loading: bridges are subject to "live loads" created by moving traffic. This loading results in the potential for fatigue cracking in the structure. When fatigue cracks grow to a critical size, fracture of structural elements can occur, leading to collapse of the structure.

Bridges are exposed to the environment where ambient temperatures affect material properties, as well as to fog, rain, snow and industrial pollutants that challenge paint systems and cause corrosion to unprotected materials that rust. In climates where salt is applied to control ice on roadways, and where bridges cross waterways with salt water, corrosion is even a greater problem.

Major bridges today are made of steel or concrete. Significant amounts of welding are done on steel bridges, allowing the engineer to choose from a variety of material thicknesses and strengths for optimal design. Concrete construction typically involves pre-tensioning cables and little welding on the primary structural members is involved, although miscellaneous components such as cable anchors may be welded.

In developed countries, the inventory of bridges typically includes many that are structurally or functionally obsolete. These structures may carry greater loads than ever anticipated, or have already done so for longer than planned, or simply cannot handle the current volume of traffic. Many of these structures are riveted and may have been made with unweldable or difficult-to-weld steel.

9.10.1 Needs and Challenges

Avoidance of fatigue crack initiation is critical for bridge safety, and welded connections have an unfortunate history of such cracking. The art and science of fatigue crack avoidance is well developed and understood by experts in the field. In practice, however, errors are still made in the design and detailing of bridges. The cracking that results from such error typically takes years to occur, and may be discovered only after the problematic detail was been incorporated into many other bridges. Thus, the challenge is to improve the process by which such structures are designed, detailed, reviewed and approved, as well as in the training of the professionals involved.

Closely related to the preceding, in-service inspection of such structures for fatigue cracking is an ongoing challenge. Today, most inspection is visual, since economics and practicality preclude non-destructive inspection of each and every fatigue sensitive location. Visual inspection is difficult, however. Access to all the various connections is often restricted. Peeling paint, corroded surfaces, bird droppings and other foreign material may hide such cracks. The challenge is for quick, economic and reliable methods of identifying the onset of fatigue cracks.

Bridges are classified as redundant and non-redundant. With non-redundant bridges, certain elements are deemed “fracture critical”. If fracture critical elements fail, the entire bridge is expected to collapse. The foregoing challenge of inspection is all the more critical for such structures.

A major challenge to steel buildings is corrosion. Bridges have been painted for years, but painting is expensive, not only for a new structure, but as an ongoing maintenance cost of existing structures. The greatest cost is when severe corrosion is not detected and members fail due to loss of section. Weathering steel has been used successfully in some applications although it offers no advantage in situations involving salt spray. Hot dipped galvanised members have also been used, but the economics are typically unacceptable. Thermal Spraying with corrosion resistant materials is yet another technically viable option that lacks cost effectiveness. New materials with better corrosion resistance or more viable coating methods will result in better bridge systems and will expand the role for welded metallic structures.

The development and refinement of fatigue enhancement methods, both for existing structures as well as new structures is an ongoing opportunity for the bridge segment. For more widespread application of such technologies, the degree of enhancement must be carefully defined, and the means of application must be safe, practical, repeatable and verifiable.

Breakthrough designs are needed to make steel bridge construction more cost effective with concrete alternatives. Such advancements will likely make use of other than I-shaped girders. Innovative composite designs with concrete filled tubes for example should be pursued. As the strength of steel used is increased, welding-related problems such as fabrication cracking and in service fatigue will be of greater concern.

Fracture mechanics analysis suggests that as material toughness levels are increased, there exists the potential for increases in allowable stresses, or relaxed inspection and acceptance criteria. Accurate characterisation of material properties, particularly for multiple pass welds and for heat affected zones, as well as accurate models for prediction of fatigue cracking may reduce the frequency for ongoing in-service of bridges.

Bridges are essential to the transportation of goods and people. No form of surface transportation can survive without them. Bridge needs vary from country to country (for example in financing, planning, method of construction, and maintenance of bridges), but all nations have strategic issues in common.

Rather than routine engineering details for designing, construction and maintenance of bridges, focus on the strategic goal of what one may call “transportation solutions” that are vital and significant but more importantly that are influenced by the bridge industry and particularly relate to welded steel bridges and welded products, is dealt with here.

To advance integrated bridge technology to meet transportation needs for planning for long lasting bridges, several factors must be considered:

- The impact of growing population.
- The need to travel faster but safely and efficiently.
- A greater emphasis on protecting the environment.
- Information that is available to practicing bridge engineers today through research and technology developments.
- New avenues and values because of expedient communication and globalisation.

These factors, in addition to the routine considerations for cost effective bridges using conventional standards for design, construction and maintenance, are significant in meeting challenging demands of the communities that must be considered and supported by the government, bridge industry and academia in a coordinated manner to meet today’s demands on bridges.

9.10.2 Welding industry role

As design and construction continue to evolve, the lessons of redundancy, load carrying capacity, and reliability, as well as the efficient and effective maintenance of bridges, must not be lost to ensure uninterrupted service to the maximum extent possible. Now, with the advent of high performance materials, emerging advanced technologies, and emphasis on strategic goals, the global perspective in the highway industry has to change towards rapid construction of highways which in turn requires that bridge components need to be fabricated rapidly, assembled quickly and maintained effectively and efficiently.

This is where welding technology and professionals have a key role in ensuring success in building infrastructure not just for transporting goods and people but in supporting the industries essential to our daily needs to national defence and security and beyond. Welded products for bridges alone constitute a multi-billion dollar global industry and the cost is many times more counting buildings, automobiles, airlines and industries manufacturing equipment for highway construction, mining, farming, and aspects of our daily life. Just as bridges are needed to transport goods and people to support industries, these industries are equally important in building and maintaining bridges. These industries face many needs but have an essential need to ensure that the welding and joining technology and the welding industry will continue its support to keep them operating.

The IIW has been working on the global front in partnership with national welding organisations around the world, such as American Welding Society (AWS) in the USA, with their customers in such industries as shipbuilding, automobiles, pipelines, steel bridges and manufacturing and supporting industries in fields relating to fabrication, construction and maintenance of welded components, and welding products. These industries have been striving to move closer to their vision of improving the quality of their products for more efficient transportation service around the world. Improving quality and efficiency helps the global economy, quality of life, and the defence and security of nations.

For example, the researched information and database available from the IIW is a phenomenal resource for welding professionals in finding improved engineering solutions to such areas as:

- Producing quality welded products.
- Maintaining long service life of welded components for moderate to very complex structures
- Training and qualifying welding personnel.

Due to lack of resources and other factors, however, there is a need to improve the process for disseminating information from institutions such as IIW and national welding organisations to the practicing engineers and others around the world.

To illustrate how useful and effective the deployment of available researched information and technology transfer can be in improving service life of steel bridges, consider the recently imported technology of ultrasonic impact treatment (UIT) to the USA. It began in 1995 from a presentation by Dr. Efim S. Statnikov and the discussions in the IIW Commission XIII on "*Fatigue of Welded Components and Structures,*" for enhancing steel component life by arresting fatigue cracks in components. Recognising how significant UIT technology could be for mitigating fatigue failures of steel bridge components, the USA imported this technology. By adopting this new UIT technology, bridge owners have saved considerable time and millions of dollars, when compared with the traditional methods of repairing fatigue damaged bridges. The UIT technology is gaining recognition in other countries as well because of the USA leadership in validating and adopting the technology for welded bridges.

Similarly, sensor technology offers high potential and can help avert failures in bridges by detecting and monitoring a growing flaw from fatigue, corrosion or other reasons. Many lives have been lost because of

excessive fatigue damage and corrosion loss that went unchecked. To prevent this, considerable research is ongoing in the bridge health monitoring arena. A variety of sensors are available in the market that can be incorporated in a warning system to alert bridge owners to conduct timely maintenance, or in case of imminent failure, to shut down a bridge to save lives.

Nations will benefit by adopting and implementing appropriate, ready-to-go researched information and technologies, products, or processes that can result in economic or qualitative benefits. A comprehensive list of such items to meet the needs of all countries is not possible in this paper, but here are a few broad items that are considered as significant and have high potential for bridges, including welded steel bridges.

- **Global Positioning System (GPS):** GPS uses satellites that transmit signals continuously and has many highway applications including surveying pavement and bridge deck conditions, and inventorying highway assets. GPS offers increased accuracy and reduces labour, time and costs.

- **Accelerated construction:** Accelerated construction is an approach to highway construction employing many techniques and technologies. This approach will bring to the attention of the highway community many innovations and research results currently available but not generally applied. Concepts and ideas must be defined if plans to implement them into highway engineering practice are to be fulfilled. Using accelerated construction techniques or technologies will accelerate the construction of highway projects with extended service lives to reduce user delay and community disruption.

- **Prefabricated bridge elements and systems:** Prefabricated bridge elements and systems may be manufactured on-site or off-site, under controlled conditions, and brought to the job location ready to install. These systems minimise traffic impacts of bridge construction projects, improve construction zone safety, make construction less disruptive for the environment, increase quality and lower life-cycle costs. Using these systems reduces traffic and environmental impacts by minimising the need for lane closures, detours, and use of narrow lanes.

The key is to reflect changing times and customer expectations that have broadened the job facing the welding industry. Today, the job is not just putting welded components together to build a bridge, but to find ways to join and erect the members rapidly to enhance mobility and productivity, which are the core of the transportation industry.

The leadership in the welding community has been striving to identify critical performance gaps that must be addressed as short-term solutions and these must align with long-term strategic direction. This should help support welding needs of related industries in any country. For example, the following table identifies (a) Short-term technical elements and (b) Long-term strategic direction for meeting USA transportation needs for highways (from the Strategic Highway Research Programme Report 260). For success in meeting transportation needs, all partners and contributors, including welding professionals, working to close short-term gaps and to meet long-term strategic goals must identify their respective needs and align them accordingly.

Short - term performance gaps	Long - term strategic direction
• Safety • Congestion • Environmental Streamlining & Stewardship	• Safety • Mobility and Productivity • Human & Natural Environment • National Security • Organisational Excellence

While items and directions may vary in different countries over time, this illustrates the importance of obtaining adequate funding and resources to close short-term gaps and meet long-term strategic goals. A task force of professional practitioners at a national level will have to ensure that cost estimates for the needs are reasonable and that the available resources will meet their specific programme needs including programmes for welded bridges identified in areas of research, design, construction, maintenance and operation. These needs should be considered by those who are in a position to fund and support the programme.

In summary while engineering details for designing, constructing and maintaining bridges are important, the significance of integrated bridge technology in meeting short-term goals and long-term needs for transporting people and goods safely, economically and efficiently cannot be overestimated. It behoves one to provide adequate resources in meeting programme needs of welding professionals and welding organisations for deployment of available researched information, technology transfer to improve transportation and economy so as to achieve prosperity and security for people around the world.

9.10.3 Hot topics

- Improved bridge design including review and approval, and inspection techniques to reduce fatigue cracking.
- Training, qualification and certification of appropriate personnel to achieve this.
- Research and development of materials and corrosion resistance.
- Improved global dissemination of information from international and national organisations to industry for improved quality of welded products, monitoring of service life of welded components and training, qualification and certification of welding personnel.
- Uptake of existing information, technologies, products and processes by developing nations e.g. global positioning systems, accelerated construction, prefabricated bridge elements and systems.

9.11 Rail track sector

The European Rail Research Advisory Council (ERRAC) was set up in 2001 with the ambitious goal of creating a single European body with both the competence and capability to help revitalise the European rail sector and make it more competitive, by fostering increased innovation and guiding research efforts at European level. The strategic research agenda (SRA), RAIL 21, published by ERRAC has defined major guidelines for the challenges and targets to achieve excellence in operations and increased efficiency in railway systems. Within strategic research priorities of the RAIL 21, *innovative materials and production methods*, as well as *development of light-weight, safe and higher performance tracks and trains* directly correspond to the possibilities and innovation of welding and joining sector.

9.11.1 Rail welding

Continuously-welded rail (CWR) has largely replaced jointed (fish-plated and bolted) track as the accepted method of rail joining for construction of new railway track, and in maintenance activities such as re-railing, replacement of rail defects, etc. Welding processes in most common use are flashbutt welding and aluminothermic (thermite) welding. Alternative welding processes such as gas pressure welding and electric arc welding are also used, but to a lesser extent.

Selection of the optimum rail welding process for any particular application is dependent on the rail grade and section, location at which the welding is to be carried out, number of welds involved, etc. Other factors to be taken into consideration include the service conditions (e.g. axle loads and train speeds), and the required performance or reliability. Of the above processes, flashbutt welding is generally considered to provide the most reliable and consistent weld performance; this process is used for fabrication of long-welded rail, and increasingly for in-track welding, the latter using mobile welding machines.

In combination with other improvements in track design and construction procedures, CWR has contributed to a reduction in track maintenance requirements and increased rail lives. From a metallurgical and engineering perspective, however, flashbutt, gas pressure, aluminothermic and electric arc welding procedures will always result in a discontinuity in the rail section. Material characteristics such as microstructure, hardness (or strength) and ductility will vary throughout the welded region. In addition, residual stress levels will be increased over those present in the parent rail, and the presence of the weld collar or reinforcement in aluminothermic welds alters the section dimensions, and hence the stress distribution under the action of wheel loads. Aluminothermic welds and electric arc welds are also more prone to welding defects than flashbutt and gas pressure welds, increasing the risk of service failures.

The differences in material characteristics and quality between parent rail and weld may have a detrimental effect on rail performance, such that the service life of the weld will be less, and the risk of component failure higher, than that of the parent rail. This is of particular concern at the higher axle loads typical of heavy haulage operations, where the rate of weld deterioration may be much higher than under general freight and passenger operations. High speed passenger rail operations also impose tighter tolerances on weld quality, although in this case the major concern is longitudinal alignment, and minor irregularities, particularly in the running surface, can result in unacceptable impact loading factors at speeds of 200 kph and above. Typical deterioration and failure modes may include:

- Excessive weld batter (dipping) and rolling contact fatigue damage, associated with the variation in hardness and microstructure through the weld, and
- Fatigue failure, initiating in the head, web or foot of the rail.

Weld batter contributes to increased impact loading, which in turn can result in localised breakdown in the rail support conditions (e.g. due to ballast crushing), hence increasing impact loading and the risk of fatigue failure. The consequences of unacceptable weld performance can therefore range from increased track maintenance costs to failed welds and increased risk of derailments.

Significant improvements in the quality and service performance of rail welds have been achieved though a number of developments, including:

- More widespread use of mobile flashbutt welding equipment for field welding, and improved (automated) process control during the flashbutt welding cycle.
- Improved process designs for aluminothermic welding, in particular the introduction of single-use crucible processes, and
- The availability of improved mathematical and experimental techniques that can be used for research into rail welding procedures, and which offer the potential for further optimisation of existing welding processes.

9.11.2 Hot topics

In spite of these developments, rail welds continue to present a higher risk of defects and failures compared to parent rail. This risk can now be reduced to some extent by the use, where possible, of longer rail lengths (up to 120 metres), compared to the previous industry standard of 25 metres. Further improvements in rail welding and joining technology are expected to offer benefits to the rail industry; such improvements may include the development of new or improved rail joining techniques that:

- Reduce the variation in material characteristics (hardness, microstructure) across the joint, and hence reduce the tendency for weld batter; this will be of particular importance for high strength, heat treated steels such as the hypereutectoid grades that offer substantial improvements in wear and rolling contact fatigue behaviour.
- Result in lower residual stress levels; and provide reduced welding cycle times, particularly for field welding under traffic conditions.

9.12 Water transmission sector

Water Management is a key issue within most Governments' strategic policies which address the need for sustainable and cost effective delivery of water and waste water services. A sustainable environment is critical to all stakeholders in any country and hence in their national interest. Though access to water is a basic human need and right, it is estimated that some 3 billion people in the world live without access to clean drinking water and sanitation. Welding technology can contribute significantly to addressing critical strategic challenges including drinking water quality, water wastage eg, leaking pipes, environment issues related to effluent discharge and irrigation issues and for industry to meet these challenges in a productive and competitive manner.

It is important to identify and develop unique areas of competitive advantage for companies in the Water industry sector e.g. the application of water-jet cutting of degraded reinforced concrete pipe supports to facilitate low cost repairs of corroded pipe.

Examples of specific applications and welding technology solutions that countries could analyse, prioritise, develop, demonstrate and disseminate with relevant stakeholders to help meet the challenges and create unique areas of competitive advantage for water companies cover amongst others:

- Manufacture and construction of mainstream pipelines.
- Manufacture of pipework and structures in water and waste-water treatment facilities.
- Manufacture and construction of de-salination plants involving materials such as titanium alloys.
- The growing use of different materials such as stainless steels, titanium alloys, PVC, polyethylene, polypropylene and polybutylene, ABS and Glass Reinforced Plastic (GRP), as against existing materials such as grey cast iron and steel.
- Installation and maintenance of water storage liners and floating covers.
- Repair and maintenance of aging infrastructure.

These challenges could be achieved through solutions, amongst others such as:

- Joining and NDT testing techniques for liners and covers.
- Avoidance of failures due to poor structural integrity through better design and inspection technology.

- New methods of repair and maintenance including the use of composites.
- In-line inspection of butt fusion welded plastic pipe.
- Mechanised welding of external and internal joints on mainstream pipelines.
- High-pressure water-jet cutting of damaged concrete support structures for low cost maintenance of in-service pipelines.
- High integrity mechanised welding of titanium.

9.12.1 Hot topics

The specific aspects of challenges where welding and joining technology transfers are needed and contribute to meeting the national objectives include the following:

- Urgent need for a country to upgrade its water catchment, storage, treatment and distribution and waste water infrastructure in both urban and rural applications.
- Minimisation of resource wastage and the risks of serious health and supply breakdown due to failing pipes/distribution.
- Maintenance of aging infrastructure.

9.13 Advanced steels sector

The use of advanced steels with enhanced properties can contribute to the improvement of ordinary life in many aspects. Welding of advanced steels in similar and dissimilar configurations poses challenges, however. For example, High Strength Low Alloy (HSLA) steels with ultimate tensile strengths not less than 780 MPa were developed by many steel companies, but their welding is faced with the following problems:

- Lack of knowledge about the metallurgical factors of the weld metal necessary to obtain required mechanical properties.
- Requirement of preheat at temperatures rising with the base metal strength.
- Welding residual stress that increases with the base metal strength and limits the tolerable ultimate and fatigue strength of the weld to levels much lower than the base metal.

9.13.1 Metallurgical challenges

With respect to the metallurgical factor, the acicular ferrite, which forms through $\gamma \rightarrow \alpha$ transformation intragranularly nucleated at oxide inclusions, is generally accepted to be a desirable one with sufficient ultimate strength and toughness for the weld metal for HSLA steels of 580 MPa class or less. The acicular ferrite, however, is thought to be insufficient to bear the mechanical load required for the steel of more than 780 MPa classes, and so a microstructure harder than the ferrite, like a bainite and martensite (B+M) microstructure, is expected to be suitable for the weld metal of the steel with higher strength.

An important difference between the weld metals of acicular ferrite and B+M microstructure is the effect of oxide inclusion that is indispensable for the formation of the acicular ferrite as a nucleation site. For the B+M structure, however, the oxide inclusion is unnecessary for their formation, and has significantly harmful effects on the toughness at volume fractions introduced during conventional arc welding processes except for tungsten inert gas (TIG) welding and metal inert gas (MIG) welding. Although TIG and MIG welding can produce weld metals with much lower oxide contents, they are difficult to carry out at high heat inputs, and so inferior in the welding productivity to the other arc welding processes.

9.13.2 Preheat

Preheating is carried out in the welding of HSLA steel mainly for the prevention of hydrogen induced cracking. As is generally accepted, the hydrogen cracking is controlled by three factors: (i) hydrogen content, (ii) residual tensile stress, and (iii) sensitivity of microstructure to the cracking. The preheat reduces the cooling rate of the weld thermal cycle, and lowers the hydrogen content of the weld metal by increasing the released hydrogen content during the cooling process of the weld thermal cycle. Since the residual stress (ii) increases with the base metal strength, a higher preheat temperature is required for the welding of the high strength steel. It exposes the welder, however, to severe working conditions and raises the cost for the welding process, which in some cases leads to insufficient work or careless mistakes that may cause serious trouble or accidents afterwards. In order to avoid these, counter measures to factors (i), (ii), and (iii) listed above are necessary.

TIG and MIG welding have the advantage of low hydrogen content compared with those processes using flux, though they are not suitable for high welding heat inputs.

9.13.3 Residual stress

As for the residual stress, it should be noted that the $\gamma \rightarrow \alpha$ transformation of the steel weld metal is accompanied with dilatation sufficient to relieve a significant part of the tensile stress generated during the cooling process of the weld thermal cycle, provided that it occurs at temperatures close to room temperatures. The effect of the weld metal with a low transformation temperature on the reduction of the tensile residual stress was already proved by Shiga et al. Its effect on the hydrogen induced cracking, however, remains unclear. In particular, the retained austenite, which is usually introduced into steels after a transformation at lower temperatures, will have important effects; i.e. the retained austenite has higher solubility and lower diffusivity of hydrogen than ferrite and martensite, and so can act as a trapping site of hydrogen, which reduces the mobility of hydrogen in the weld. This effect can contribute to the prevention of hydrogen induced cracking by retarding the hydrogen accumulation at spots where the residual tensile stress is concentrated. It is, however, also pointed out that the retained austenite may have a detrimental effect on the hydrogen induced cracking, if it ejects hydrogen when transforming to martensite by stress assisted transformation or subzero treatment. Thus, better understanding of the effect of retained austenite on the behaviour of hydrogen is necessary in order to utilise the weld metal with a low transformation temperature for the steel with high strength.

Since the microstructure consisting of bainite and martensite mentioned above also involves the greater amount of retained austenite than those of the acicular ferrite, the effect of the retained austenite on the hydrogen behaviour must be taken into account for the development of the weld metal for the steel of more than 780 MPa classes in general. Several authors reported that the hydrogen induced cracking occurred in the weld metal in the arc-welded joint of the HSLA steel of more than 780 MPa classes, while it occurred in the HAZ in those of the steels of 580 MPa class or less. Only little information, however, is available about the mechanism or controlling factor of the hydrogen induced cracking in the weld metal, which is a subject to be investigated further.

It was already reported that the reduction in welding residual stress by the use of the weld metal with low transformation temperature could improve the weld fatigue strength for the steel of less than 580 MPa classes. We can also expect an improvement of fracture toughness by the retained austenite present abundantly in the weld metal with low transformation temperature. It is known well that the retained austenite with a suitable chemical composition undergoes the stress-induced transformation at the ambient temperature. This transformation is accompanied with transformation-induced plasticity and relieves the stress concentration at the crack tip, increasing the fracture toughness. Thus one can expect various beneficial effects of the weld metal with low transformation temperature on the mechanical properties of the weld. In addition to the adverse effect on the hydrogen induced cracking as suggested

above however, the retained austenite reduces the mechanical strength, and so an optimum microstructure control is necessary to obtain a weld metal with required mechanical properties and resistance to hydrogen-induced cracking.

As mentioned above, the MIG welding is suitable for producing the weld metal for the HSLA steel of more than 780 MPa classes, in which the contents of both oxide inclusion and hydrogen must be low. The heat input of the MIG welding, however, controlling the productivity, is practically limited to a significantly lower level than most of other conventional welding processes, and this is an obstacle to its wider application. It was believed that the practical heat input was limited by the instability of the arc plasma due to the scattering of the cathode spot in the weld pool. Hiraoka et al., however, showed that the arc instability could be resolved by stabilising the wire electrode rather than the cathode spot. Therefore, it can be expected that the MIG welding can be carried out at much higher heat input by stabilising the wire cathode and thus the obstacle to the wider use of the MIG welding to the advanced steel can be removed.

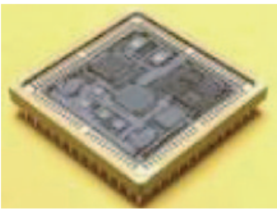
In Japan, a national project on the innovation of welding for advanced steels has been undertaken with the cooperation of universities, governmental research institutes, and industries. As exemplified by the HSLA steel of more than 780 MPa classes, the desired microstructure of the weld metal is different from those of lower strength steels, and the weldability, a measure of hydrogen embrittlement susceptibility of weldment, depends on factors other than the carbon equivalent of the base metal. Thus, one needs to establish a new paradigm of the weldability for advanced steels like HSLA steel of 780 MPa class. It is also required to develop a welding process that enables one to produce a weld metal with low oxygen content at high productivity. A comprehensive approach based on the microstructural design and control of the weld metal, development of the welding process involving high energy density beam welding, and the control of residual stress and strain will contribute to solving these problems and eventually to the improvement of the quality of global life.

9.13.4 Hot topics

- Research and development of welding processes and technologies for the joining of advanced steels e.g. high strength low alloy.
- Research in the metallurgy, preheat and residual stress of advanced steels.

9.14 Electronics sector

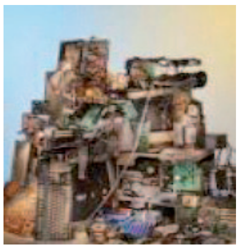
(*Images in Section 9.14, 9.15 and 9.16 reproduced courtesy of TWI Ltd*).



High density electronic package

Electronics, combined with sensing technology, form the fundamental operating systems for nearly all modern industrial products and systems from mobile phones to power stations. As electronics becomes more sophisticated its integration into products is increasing, to a point where many systems (e.g. automotive, aerospace, assembly equipment, welding power supplies) cannot be operated without electronic/computer/sensor assistance.

The electronics sector is also a key influencing factor in environmental issues. On one side it can be used to significantly save energy through intelligent system management (e.g. motor controls, consumer product energy usage) and renewable energy controls (e.g. solar, wind and tidal). Conversely, it is the major contributor to the growth in landfill waste (e.g. consumer products - mobile phones, TVs, games machines etc.). Future developments in terms of materials and assembly processes will influence the overall balance of electronics' environmental sustainability.

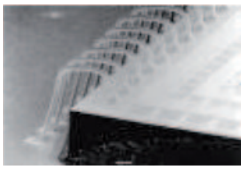


Electronics for landfill waste

The electronic products industry sector includes both consumer electronics and electronic devices that are incorporated into other components, including medical devices, aerospace, automotive, and defence products. The market is divided into applications such as consumer, communications, computer, industrial, and automotive. The world electronic product market was $1.8 trillion in 2006 and was expected to increase at a compound annual growth rate of 9.5% over the next five years.

Industrial products accounted for 39.6% of the sales in this market, and consumer electronics made up 13.4%. Industry reports break down the consumer electronics market into four categories, computer, personal communications, home media devices, and luxury devices. In a 2005 industry report published by In-Stat the top three devices in terms of growth were portable digital audio players (57%), LCD televisions (52.3%), and DVD recorders (51.4%).

Rapid advances in computer and associated electronic systems can only be sustained by advances in joining methods adapted to a miniature scale of operation. There are six basic joining operations in the assembly of electronic products: package fabrication, attachment and interconnection of active and passive components, package sealing, package attachment and other devices to PCBs and the mounting of electronics in a fabricated enclosure. The joining techniques commonly used for these operations are shown below.



Thermosonic wire bonded silicon chip

Welding is fundamental to the assembly and performance of electronic devices. For example, 25 µm-diameter wire welds (thermosonic/ultrasonic) are used to interconnect silicon chips per year in excess of 5 trillion. In harsh environments (e.g. medical implants, chemically active or high temperature) the quality of the package sealing weld (e.g. laser, electron beam) can directly influences the electronic device reliability and life.

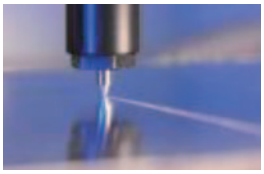
Table 9.1 *Joining processes used in the electronics sector*

Activity	Joining process
Metal/ceramic package fabrication	Brazing, Soldering, Resistance welding Laser, electron beam and arc welding, Glass fusion
Attachment of active or passive components to substrate circuitry	Soldering Adhesive bonding
Interconnections to solid state circuits	Thermosonic/Ultrasonic hot pressure welding Soldering
Package sealing	Plastic encapsulation, Glass fusion Resistance brazing, Resistance, laser and EB welding Cold pressure welding, Soldering, Adhesive bonding
Attachment of packaged and other devices to circuit boards	Soldering, Adhesive bonding Resistance welding
Fabricated enclosure	Mechanical fastenings, Adhesives, Plastic and metal welding

The opportunities for welding in this field are growing due to the increasing number of devices being manufactured, the growing complexity of the systems, their application in harsher environments and environmental legislation. Benefits of welding include:

- Low thermal impact.
- High temperature capability joints and high welding speeds.
- Very small weld profile/footprint capabilities.
- Relatively lower energy consumption and lower electrical resistance joints.
- Replacement of lead based solders on lead-frames and electrical terminations (e.g. motors).
- Replacement of adhesives and mechanical fasteners on polymer and metal enclosures – easier to recycle and reuse polymer at product end-of-life.

The challenges are primarily concerned with the miniaturisation of the welding processes (including jigging and fixturing) adapting processes to suit very thin and film materials and persuading "customers" to change from "tried-and-trusted processes" and design products for welding.



Microfriction stir welding 0.5 mm thick Al sheet

Furthermore, the following are some of the trends that affect materials joining for the electronics market.

The disposable electronics market is expected to grow to $26.2 billion by 2015 [Dunn]. Applications such as smart cards, security, packaging, displays, and toys are expected to lead the printed electronics arena. In 2015, RFID tags are expected to partly replace barcodes and generate $12.4 billion in revenue. E-paper technology is predicted to grow to $1.6 billion in 2015 as point-of-purchase displays become popular. In general, future electronics will involve:

- Increased integration with mechanical, optical and biological type systems (e.g. more complex materials joining and packaging technology).
- Reduction in the use of mineral resources and assembly processes with high environmental impact.
- The further development of lower energy consumption devices and systems that can reduce energy use in external equipment/plant.

9.14.1 Hot topics

- **Environmentally friendly materials**: One of the most significant trends in the electronic device market is the transition to lead-free components. The European Union's Restriction of Hazardous Materials (RoHS) went into effect July 1, 2006, and the electronics industry is now moving to products that are free of hazardous materials. Manufacturers are struggling with the risk of being out of compliance with lead-free laws and creating products that are more likely to fail due to the absence of the hazardous materials that help stabilise the parts. This trend has spurred interest in developing advanced solder alloys to assist manufacturers during this transition phase worldwide.
- **Miniaturisation and cost control**: The trends of miniaturisation and outsourcing manufacturing are relevant for the electronics device market. Miniaturisation of electronic devices is being driven by the portability needs of consumers in today's global environments and marketplaces. Contract manufacturing of electronic devices is also being driven by cost-control and core competence issues similar to those in the medical devices market.

✦ **Portable power**: In the Portable Power market, growth is being driven by high-drain wireless consumer devices. Primary portable power applications include consumer products, industrial and professional products, personal communication devices, portable computers, and military portable electronic devices. Rechargeable batteries and small engines will lead gains among established technologies. Solar cells are projected to remain niche items, while miniature and micro fuel cells become a major factor within this market by 2013. In the area of fuel cells, portable electric power is viewed as one of the earliest market applications. Much of the complexities related to hydrogen infrastructure are not an issue for portable electrical power applications, as is the case with many other fuel cell applications.

9.15 Microjoining sector

Pressure sensor incorporating, laser, electron beam and thermosonic welding

The involvement of microjoining in the electronics, instrument, actuator and sensors industries is as important and as extensive as that of welding in other manufacturing industries. The proper functioning of small mechanical devices and electronics systems, as employed in the aerospace, medical, telecommunications, computer, automotive, oil & gas and consumer industries, is critically dependent upon the use of efficient and reliable joining techniques. The increasing complexity and miniaturisation of micro and miniature devices are placing more stringent demands on assembly techniques for, and the performance of, microjoints.

The full range of welding, soldering and adhesive bonding techniques is being pushed to the limits to cope with increasing miniaturisation, process speeds and rapid changes in design. Additionally, the global drive to environmentally acceptable products is resulting in a review of assembly and disassembly techniques which is forcing a rethink in terms of the use of materials, joining and assembly processes. Although the term microjoining is widely used, it is difficult to define exactly. For the purpose of this review it is taken to include the joining of sheet and rod materials up to 1 mm in joint thickness.

Ball/wedge wire bonded die assembly

Ultrasonic welded electrical terminations

Micro friction stir welded 0.5 mm thick Aluminium sheet

Welding is extensively used in microjoining applications such as silicon chip interconnect (e.g. wire bonding- thermosonic welding), package sealing (e.g. laser and resistance welding) and sensor/mechanical system assembly (e.g. EB, arc and resistance welding). There is the potential however to increase its use by exploiting its capabilities in terms of local/low heat input, rapid processing capabilities and enabling more environmental assembly/design as illustrated.

9.15.1 Hot topics

- Replacement of soldering on low/medium production volume electrical applications such as leadframe/busbar joining and wire terminations.

  Benefits: rapid, local heating resulting in:

  Lower energy usage (process energy saving), Monometallic joints (easier to recycle), Lower resistance joints (energy saving/improved performance), Joints can be closer together (aids miniaturisation), Joints can be closer to temperature sensitive materials/devices (aids miniaturisation/less material employed).

- Replacement of adhesives on polymer and metal components.

  Benefits: Reduction in chemical usage, No added impurities (adhesive) resulting in easier recycling/ reuse, Lower cost production cycle.

The primary challenges to more widely adopting these welding techniques in microtechnology are:

- Refining the welding and jigging systems to accommodate the reducing geometry and automated assembly process.
- Developing welding process (e.g. micro-friction stir) for some difficult to weld, very thin materials (e.g. Al-SiC, <0.5 mm in thickness).
- Establishing customer acceptable inspection/validation techniques.

In summary, microtechnology is fundamental to the operation of a wide range of products across all industrial sectors. Key to its development is joining technology and there are significant opportunities to increase the use of welding to solve new assembly problems (e.g. complex multi-functional devices), reduce costs and environmental impact (e.g. lower energy processes, environmentally friendly materials, low impact disassembly).

9.16 Medical devices

The medical device market is composed of multiple segments devoted to the diagnosis and treatment of human disease and/or disorder. According to a Health Research International (HRI) report sponsored by Medtech Insights, the medical device and diagnostics (MD&D) market generated close to $220 billion in global revenues in 2005. The U.S. is among the top three markets for medical devices with 48% of global sales, followed by Europe and Japan. The US market for medical devices was estimated to increase at a compound annual growth rate of 3.62% and reach $85.99 billion in 2010. High growth is expected in cardiovascular, endoscopy, and orthopaedics markets. Growth rates for the medical technology markets in other countries with expanding economies – Brazil, PR China, Korea, India, Taiwan, and Mexico – are higher than that of the U.S. China is the world's fastest growing medical device market, with 28% annual growth in recent years. The market is expected to continue to grow to over $320 billion worldwide over the next five years.

Over 72% of sales within this sector have been generated within the top 50 companies. Johnson & Johnson companies accounted for over $15 billion in global sales in 2004, which is an 8% overall market share. The second largest provider, with $10 billion in sales is Medtronic. With the acquisition of Guidant, Boston Scientific will be a close contender for Medtronic for second place in global sales according to the HRI report.

The HRI report indicates that almost half of the 2005 revenues were generated from four major segments including cardiovascular disease therapies, in vitro diagnostics (IVD), diagnostic imaging equipment/services/ contract, and orthopaedic devices including spine. Ten clinical applications/conditions were identified in

the HRI report which accounted for 64% of global MD&D product sales in 2004; cardiovascular disease, musculo-sketetal disease, cancer, dental care, urology and renal conditions, diabetes, respiratory/ pulmonary conditions, gastrointestinal disease, ophthalmic conditions, and hearing impairment and diseases of the ear (otology). Of these, cardiovascular disease related components accounted for over 19.2%. The Orthopaedic sector had a $26 billion global marketplace in 2006. Both the spine and trauma sectors experienced the significant growth in 2006.

The following are some of the trends that affect materials joining for the medical market.

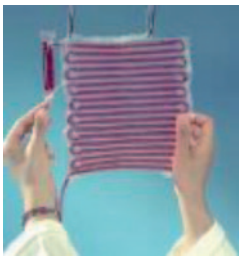
9.16.1 Hot topics

- **Miniaturisation**: One continuing trend in the medical device market is the expansion of Minimally Invasive Surgery (MIS) procedures. Expansion of the MIS market is due in large part to replacement procedures for conventional, open surgery, treatment methods. The percentage of MIS procedures (as a percentage of all surgical interventions) is expected to increase from the current level of 15-20% to about 70% by 2010. Increased use of MIS in emerging markets of the Pacific Rim and Latin America are likely to contribute significantly to this growth. As more and more surgical procedures migrate to less invasive approaches, the drive to minimise the size of the medical devices will continue.

- **New materials**: Another important trend in the medical devices market is the increasing use of biocompatible metals for the design and fabrication of surgical and implantable devices. Because there is a drive to minimise the size of the devices for MIS or interventional cardiology procedures or for implantation, medical device designers frequently must develop methods to directly join two dissimilar metal materials. Key considerations in this joining include the biocompatibility and resistance to bio-corrosion not only for the base metals, but for also any intermetallics formed by the joining process. The radiopacity of the metals and/or intermetallics is also a concern, as the surgeon must be able to use radiography to monitor the position of the devices within the body during the procedure.

- **Increasing performance requirements**: For implantable devices, fatigue life of the joint is extremely important, since the device is often left in the body and therefore must not fail for the remainder of the patient's life. Other key concerns are corrosion of the component, due to the environment and the ability to use magnetic resonance imaging (MRI) after surgery; since metal and other materials properties could interfere with the ability to use MRI as a medical diagnostic tool.

- **Cost control**: Medical device manufacturers are increasingly outsourcing manufacturing and assembly of their products to contract manufacturers. One reason behind this shift is cost pressure; specialised labour can be expensive for the assembly of sophisticated medical devices.



Laser welded blood bag

Medical devices cover a very broad range of products from very simple sealed bags to very complex 'active' implants. In general, medical devices, whether temporary or permanent, used externally or inside the body, are becoming more complex and sophisticated both in terms of their performance specification and structural complexity. As a consequence, many devices in current use are multi-component and require assembly in production. Joining is one of the key issues. Medical devices, whether used outside the body (e.g. instrumentation, control systems or surgical tools) or inside the body for diagnostic monitoring or therapeutic purposes (e.g. sensors, catheters, pacemakers or prostheses) usually consist of many materials which may need to be joined.

A range of processes are used for joining, including mechanical fasteners, welding, brazing, soldering and adhesive bonding. The choice of process tends to be made on an assessment of the materials, joint design, mechanical/environmental performance and cost. Unique features of the medical device field are that most products need to be tolerant to sterilisation techniques (e.g. autoclave, radiation) and some require surfacing techniques to make them biocompatible or anti-soiling. Additionally, the technology employed in these devices is developing very rapidly and assembly techniques (e.g. joining) have to adapt accordingly. Welding techniques are currently used on a range of products such as:

- Laser welding of precision instruments and hermetically sealed cases/packages.

  Benefits: Low distortion, Reduced machining, Reduced thickness of casing/materials.

Cardiac pacemaker-laser welded case

- Arc welding catheter guide wires.

  Benefits: Rapid heating/cooling cycle allowing the joining of difficult materials and heat sensitive devices.

- Ultrasonic and thermosonic welding for electronic device interconnection.

  Benefits: High speed, Low temperature, Reliable.

- Resistance welding for heated catheter tools.

  Benefits: No additional materials, Will withstand high temperatures.

- Laser welding polymer fluid transfer devices (e.g. blood and colostomy bags, lab-on-a-chip):

  Benefits: Rapid assembly, no additional materials (e.g. adhesives), Recycled–improved sustainability, Avoids cross contamination and enables

- Welding PEEK optima for orthopaedic joints:

  Benefits: Replace adhesive, which reduces number of materials, retains material properties and avoids re-qualification.

"Welding" processes are now also being adapted to provide surface engineering and 3D shape generation e.g.

- Laser Direct Metal Deposition – orthopaedic and dental implant generation, customisation or surface texturing.
- Electron Beam surface texturing/sculpting - enhance implant to bone attachment, provide drug release surfaces.
- Thermal/Cold Spray - orthopaedic implant coatings (e.g. hydroxyapatite) to enable bonding to the bone.

Orthopaedic hip joint

The new medical products that welding assists in manufacturing can have a profoundly beneficial effect on patient life-style, well being and reduce healthcare costs: Surface engineering can extend implant life, miniaturisation can reduce surgical trauma. Smart implants/monitoring systems can restore a more active life and reduce time in hospitals.

Challenges include: increased miniaturisation, "smarter" systems, longer life implants, improved surface coating (e.g. bio-implant and wear-resistant interfaces).

9.16.2 Joining live tissues and coatings

Joining of live tissues and coatings is a new emerging area with great innovation potential. The E.O. Paton Electric Welding Institute in the Ukraine developed and practically realised the possibility of making permanent joints on live tissues. Welding of live tissues was tested and approved for use in surgical operations (without restrictions) by medical supervision authorities. There is a need to get a deeper insight into the principles and nature of joining of live tissues and their regeneration in a living body. Investigations should continue to study biological peculiarities of joining of live tissues with implants. The range of artificial organs is widening, and there is a need to develop principles for their joining and compatibility with living organisms. New methods of hyperthermic treatment show high promise.

High-temperature surgical technique is a new area in surgery, the development of which was started in Ukraine early in the 1990s. High-temperature (100-10,000°C) effects on tissues of a living body allow performing separation (cutting) and joining (welding) of live tissues, arresting of bleeding (punctuate and parenchymatous), treatment of wounds for their sterilisation, acceleration of healing and prevention of wound infection.

One of the promising fields in high-temperature surgery is affecting live tissues with flows of low-temperature gas-discharge plasma or heated gases. First of all, here one may distinguish such medical technologies as plasma cutting (destruction), coagulation and welding (joining) of live tissues. The jet of the low-temperature argon plasma required to implement these technologies is generated by special devices, i.e. indirect-action arc plasma torches.

Another method for joining live tissues is thermal-spray welding, which consists in affecting tissues with a flow of hot gas generated by special devices. This method provides restoration of integrity of hollow organs and suppression of bleeding in surgical interventions by achieving a positive physiological effect and adequate recovery of tissues in the zone of welds (no-ligature). This method is also efficient for treatment of purulent wounds, as it exerts a deleterious effect on wound infection and prevents its development. Plasma and thermal-spray methods of high-temperature surgery have been studied for the last five years in live animal experiments on white rats, rabbits and pigs. The results obtained are indicative of a high promise of further technical and medical studies of the above methods, development of new equipment for their wide clinical application, and development of new medical technologies.

9.16.3 Hot topics

The main areas in welding of live tissues are:

- Utilisation of new sources for thermal-biological treatment of welded joints.
- Investigation of the nature of formation of joints on live tissues and biocompatibility of implants.
- Development of methods for joining live and artificial organs by welding.
- Optimisation of joining equipment and materials, widening of clinical practice.

9.17 Nanotechnology and nanojoining sector

Nanotechnology stands for the exploitation of nano effects. These are special material properties which a material displays from a certain size - as a rule from 100 nanometers and below (1 nm $=10^{-9}$ m). These special properties, which the material does not display on a macroscopic level, result from surface properties that predominate relative to the volume properties and that cause a quantum-mechanical behavior of the building blocks of matter. An effect that is very widely known, for instance, is the Lotus effect. The use of

nano effects is not new in technology (e.g. in the glass industry), but has generally never been known by this name.

While developments in nanotechnology can be utilised in joining technology, joining technology itself on the other hand is an essential step in manufacturing and assembly of nanodevices and nanosystems, to provide mechanical support and integration, electrical connection, optical coupling, environmental protection, etc. just like welding and joining at macro- and microscales. At the moment, there are two fields that are on the forefront:

- The utilization of nano effects for joining technology, such as the application of nanomaterials in joining technology.
- Joining of nanomaterials, or nano-scale building blocks, for applications in nanodevices and nanosystems.

9.17.1 Nanotechnology for joining

One example in this field is nanoparticle-alloyed filler metals for welding that can lead to nano-structurised solidification of the weld pool and hence to a structure with the same base metal properties. This can be combined with no or low heat input welding processes as well for the joining of nano alloyed materials, e.g. nanoalloyed steels for conventional use. Additionally the expected energy saving can be a sustainability aspect.

Similarly, nanoparticle-based pastes are suited as a filler material, with the right composition, for joining with low heat input, in particular of electronic components, e.g. to replace lead-free solders. Up to now, the nanoparticles in the pastes, as a rule, are wrapped up in organic substances. When submitted to temperature, these organic coatings evaporate and thus the nanoparticles are released. Under low pressure, they bond, via a sintering-like process, with each other and with the material surfaces to be joined, in a firmly bonded manner by diffusion. The current developments go in the direction of substituting the organic coating substances with others in order to avoid the bothersome vaporization products and to further reduce the joining temperatures as well as to reduce the required pressure.

Another option for the use of nano effects for joining is the use of Nanofoils®. These multi-layer bands, made up of layers that are 25 to 90 nm thick and comprise different materials, when laid between the surfaces to be joined, lead to a self-progressing exothermic reaction after ignition as a result of their negative binding energy. The heat required for welding is thereby generated directly in the joining zone. The very costly production of the tapes is disadvantageous.

Nanoparticle-based adhesives with good adhesion, and electrical and other properties are also being developed and are used in the field of microelectronics.

9.17.2 Joining of nanomaterials

Nanomaterials are materials comprising nanoparticles (nanotubes, nanofoams, nanofibers, nanowire) which are made of equivalent or different materials of the same kind and have the respective properties. The technical use of such materials requires bonding them with each other and with other materials to be assembled into nanodevices and nanosystems.
In doing so, of course, the special properties of the nanomaterials are meant to be preserved as much as possible. Respective technologies and processes are currently being developed. For example, femto-second lasers are high performance pulse lasers with pulse durations in the femtosecond area (1 femtosecond = 10^{-15} seconds). By the use of such extremely short-pulsed lasers, new options arise for material machining

(material removal, welding, surface pattering, etc.) for the control of the heat input, in particular its reduction. The material changes are thereby substantially reduced in the so-called heat affected zone. By this, for instance, components in microelectronics allow themselves to be welded instead of soldered. However, developments are still very much in the early stages.

9.17.3 Hot topics

- Nanojoining technology, while still in its infancy, is starting to develop rapidly and will become a key technology in commercially viable manufacturing of nanodevices, nanosystems and nanoalloyed materials.
- Most current nanojoining work is on technological aspects, especially on developing new and modified processes to provide solutions for functional nanodevices and nanosystems.
- Work is, however, needed on fundamental aspects of nanojoining for the long term progress of this area. These include the mechanisms of joining at nanoscale, such as driving forces, oxide removal, surface roughness effects, the formation of chemical bonds and crystallographic orientations across the bondline, especially in dissimilar material combinations, and effects of joining on the functionality, whether physical, chemical or mechanical, of nanoscale building blocks.

9.18 Aerospace sector

Airframes of commercial aircraft are primarily made of riveted Al-alloy skin and stringer construction and called “differential” or “built-up” structures. The manufacturing of these conventional riveted airframes is a very time consuming and expensive process. Aerospace industries have been exploring new technologies that have the potential to improve airframe design and fabrication processes, as well as reducing cost and weight. Knowingly, major aerospace industries have been intensely working on the development and technological implementation of advanced joining technologies (laser beam welding, LBW and friction stir welding, FSW) to replace the differential structures with welded integral airframe structures.

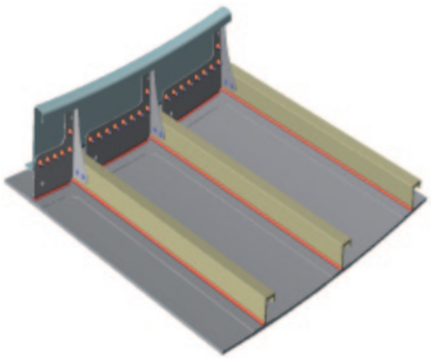


Figure 9.14 *Laser beam welded Al-alloy fuselage part demonstrating LBW joints of skin-stringers (already flying) and skin-clip (future application) (Reproduced courtesy: AIRBUS)*

Driven to higher and higher levels of performance, novel ways of fabricating structures in metallic and other material systems are of increasing interest. Such structures eliminate the cost and weight of conventional riveted structures and also provide improved aerodynamic performance, increasing fuel economy which is of increasingly critical interest. With the part count of a 747 being one million, half of these are rivets and other fasteners, mostly for the aerostructure. Partial or substantial elimination of these rivets and other fasteners dramatically reduces assembly time and lowers inventory cost.

Development and use of advanced welding technologies associated to new aluminium alloys for the “Integral Structure” or “Rivet-Free” Al-alloy airframes are considered as an innovative technology needed to achieve lighter and low cost metallic airframes. Currently, in some civil aircraft fuselages (including the

A380) laser welded (skin-stringer) panels are used and efforts are being made to increase the use of such components in future aircraft (*Figure 9.14*). The challenge, however, is coming from reinforced composite materials technology and competition between the welded metallic option and composite structure for cost and weight savings will decide future aircraft technologies. This trend and development are accompanied with the differences in damage tolerance performances of both manufacturing routes (*Figure 9.15*).

Welding technologies together with new weldable high strength Al-alloys and with the use of “local engineering” are capable to generate damage tolerant, safe components. This position, however, needs to be maintained or reinforced with numerous scientific and technological developments in design and improvements in understanding of the damage tolerance behaviours. It is expected that the major challenge will be in the development of advanced joining technologies for the fabrication of “material-mix” or “multi-material” (e.g. metal-composite components) of future airframe structures.

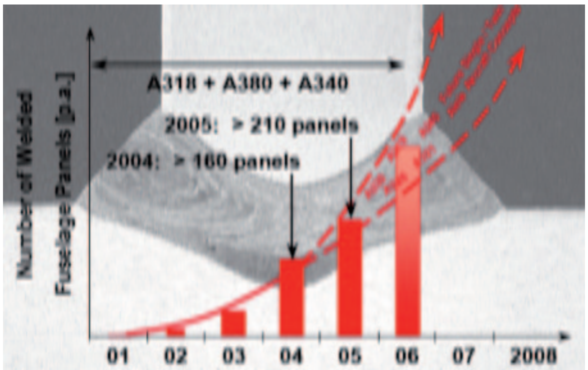


Figure 9.15 *Trends in use of welded panels for European aircraft A380, A340 and A318. (Reproduced courtesy: AIRBUS)*

Development of new filler wires beyond currently used 12%Si containing wires for LBW process will significantly contribute to the potential use of the welded airframe panels.

Additionally, new developments in design, inspection (structural health monitoring), fatigue and fracture aspects will enhance the competitive position of the welded Al-alloy airframe components against adhesively bonded composite structures.

In addition to the current use of laser beam welding technology in lower shell regions of the European commercial aircraft, such as the A380, A340 and A318, side and upper fuselage regions of these aircrafts should be new application targets for welded fuselage assemblies. Design requirements of upper fuselage parts, however, are different from lower shell regions and hence higher damage tolerance properties are needed for the welded skin-stringer assemblies. This will be a new challenge for the welding mechanics.

In addition to the challenges of LB welding of thin-walled Al-airframe structures, described above, the following topics are considered as major areas of interest in aerospace applications.

9.18.1 Hot topics

- **Dissimilar materials joining**: The drive towards maximum structural efficiency is pushing the need for joining technology for dissimilar materials. Such joints allow point-to-point optimisation of material properties, including strength to weight ratio, high temperature stability, etc. Riveting results in point load stress management and corrosion potential, adding weight and cost while reducing reliability and lifetime. Adhesive bonding and other joining methods, including welding, soldering, and brazing, offer alternatives for structural efficiency and increased temperature performance. NDE of joints combining complex material arrays requires updating and development.

Furthermore, in the field of dissimilar combinations of metallic, ceramic and carbon-carbon materials, the following areas are creating challenges.

- Technologies for joining (welding) the above materials by using new pulsed heating methods, electromagnetic or mechanical effects, and hybrid solid-state joining processes.
- New welding consumables in the form of films, foils, powders and pastes, including multilayer foils, capable of entering into reaction of high-temperature synthesis of intermetallic phases in local volumes (spaces).
- Building of new types of structures from materials with a minimal specific weight, i.e. foam materials, sandwiches, dissimilar compositions, volumetric billets of typical shapes (cylinders, cones, hemispheres), ribbed panels and panels with cavities.
- Building of armoured and fireproof welded structures through a combined use of dissimilar materials and their joining methods, as well as compact transformable billets, which can be transformed into large-volume structures (tanks, compartments, habitable rooms, etc.).

- **Manufacture of Thermal Protection Systems**: Near- and trans-space structures require efficient thermal protection systems (TPS) to deal with reusable, multi-re-entry vehicles. The selection and combination of materials for maximum thermal, structural, and weight performance is crucial. The joining technology that is flying today is over thirty years old. Improvements in materials joining methods are enabling technologies for advanced flight concepts. Welding, brazing, soldering, adhesive bonding, and NDE are all pertinent to this field.

- **Repair**: Manufacture, repair, and overhaul continue to be a major driver of joining technology innovation in the aerospace industry. Repair technologies are driven by two competing factors; low metallurgical damage to the substrate and high deposition rates. These features, however, are generally mutually exclusive. This has driven technology innovations such as laser powder build-up, cold metal transfer and cold spray. There is also a push towards near net shape repair. This is attaching pre-formed repair elements, reducing the expense of post-deposition machining.

- **Reducing material usage**: Improving material buy-to-fly ratios, is a key element in reducing the overall costs of manufacture. To this end, welded components are increasingly replacing those machined out of single blocks of materials. Generally, two penalties are paid for replacing a fully machined component with a welded one. The first is loss of properties in the weld and heat affected areas. The second is geometric stability of the final part. New processes, better process control, better predictive capabilities, etc. will all be necessary to address this new generation of welded components.

- **Implementation of low cost manufacturing technologies**: Reducing the overall costs of manufacture continues to be a major driver for technology innovation in the aerospace industry. To this end, there is increasing interest in standardisation of parts, and subsequent increases in manufacturing volumes for those components. Higher volumes permit economies of scale. This has placed focus on higher productivity joining processes. Higher productivity joining ranges from increased deposition rates with existing processes, to the use of newer approaches. In this regard, laser processing, resistance welding, etc., with their inherent advantages in higher production volumes, will see increasing use in aerospace construction.

- **Development of novel solid-state processes**: Manufacturability of hardware through novel solid-state welding processes offers distinct advantages to the aerospace industry reducing buy-to-fly ratios and production costs. Ultrasonic additive manufacturing (UAM) is one such technology based on solid-state welding, joining successive layers of material to produce near net shape hardware. Producing hardware in this fashion requires minimal material consumption while producing highly accurate components. Fabrication of such hardware also allows for the development of smart

structures where reactive embedded materials can serve as sensing devices and/or actuators. Advancements within this technology will permit fabrication of hardware with advanced materials such as titanium, stainless steels, and nickel based alloys, increasing widespread use.

- **Additive manufacturing**: A suite of potential tools for additive manufacturing is being qualified through a five stage process for certification for their use in aerospace markets. Leading processes are laser/powder and laser/wire, as well as electron beam free form fabrication (EBFFF). Much work remains to be done to qualify these and other processes (e.g. model and control distortion) for implementation into end use applications which include titanium alloys, stainless steels, and nickel based alloys, with particular emphasis on increasing the buy-to-fly ratios for expensive and long lead time articles such as titanium forgings, and increasingly expensive high alloy materials.
- **High-efficiency Al and Mg alloys**: Welding and joining of micro and nano-sized composite materials (with insoluble particles; with fibres and nets; multilayer macro-sized; multilayer micro- and nano-sized).
- **Heat-resistant materials**: Building of new generations of aircraft and rocket engines will require development of new processes for joining advanced materials and new specialised equipment. Widening of applications of nickel-base alloys with single crystal structure, heat-resistant and radiation-resistant alloys, refractory metals, ceramic and cermet composite materials can be anticipated. It should be planned to work on making structural components of engines by using new welding methods, as well as manufacturing them by micro-layer growing from liquid-vapour matrices. New structural materials will be developed based on optimisation of their weldability. Elaboration of the new principles for decreasing degradation of welded joints in operation of structures will provide their long service life and high performance.

9.19 Welding in space

Predicted development and challenges of welding and related technologies for space applications can be summarised as following:

Welding equipment: Electron Beam (EB) and Laser Beam (LB) welding processes, EB brazing, laser brazing, deposition of coatings using EB and LB heating, equipment developments for mechanised and manual processes.

Auxiliary equipment: Manipulators, tilters, robotised welding systems.

Power supplies: Solar energy converters, power generation (life support low-power reactors), thermoelectric converters.

Moon exploration prediction:

1. Utilisation of transformable large-size welded shell structures for construction of long-term lunar outposts (LLO).
2. Application of EB and laser technologies for carrying out different operations on the Moon:
   - Assembly and damage control operations using welding, brazing and coating.
   - Processing of moon rock to produce oxygen.
   - Melting of moon rock to produce different metallic and non-metallic materials.
   - Floating-zone melting to produce super pure perfect semiconductor materials, composite materials and intermetallics.

9.20 Small and medium enterprises' needs and contributions

Small and medium enterprises (SMEs) present a dilemma. They are the companies in the greatest need of technical support and technology transfer to maintain competitiveness, however:

- Most don't see technology as a strategic priority.
- Few are willing to pay commercial rates for services.
- The SME market is inherently fragmented and unstable.

It is therefore impossible to run a commercially freestanding economically viable technology transfer programme directed at SMEs. Public funding is necessary to overcome this market failure. This is also true for the SMEs operating in welding and joining sectors. This conclusion is supported by data (rounded) derived from a number of national technology transfer programmes relating to numbers of companies engaged at various levels of the programmes.
For example:

- Number of companies contacted via the outreach/awareness activities – 150,000
- Number of companies making enquiries as a result of the above – 10,000
- Number of significant technical enquiries where expertise added value – 2,000
- Number of expert one-on-one interventions (product and process reviews) – 500
- Number of feasibility studies emanating from the above reviews – 50
- Number of commercial contracts (i.e. commercially sustainable activity) – 12

SMEs however, or a proportion of them, are seen as the engine for economic growth. The effective proportion appears to be quite small, though clearly of great importance. Some years back researchers from Warwick University, UK, conducted a survey of the UK's SME population which concluded that roughly 10% of them are high growth companies, the other 90% being lifestyle companies or likely to fail within a five year period. Within the top 10% more than 50% of employment growth came from only 4%. Technology transfer programmes, therefore need to contain elements appropriate to the range of companies within this spectrum if they are to have a beneficial effect on a significant fraction of the total population. A comprehensive multi-level approach to technology transfer for SMEs may be necessary.
For example:

- Raising awareness and stimulating interest within the manufacturing base through a range of promotional activities and communication routes.
- Providing a single point of contact on welding, joining and materials engineering and other technologies reached via a telephone help line - that offers access to expert engineers- or via e-mail for expert response.
- Demonstration of relevance through interactive workshops and one-on-one contacts to explain the details and potential applications of technologies.
- Providing on-line advice and information through password-controlled access to web-based knowledge management tool.
- Carrying out Product & Process Reviews (PPRs) to define relevant issues and strategies for development of capabilities in engineering manufacturing companies.
- Completing Feasibility Study projects which verify PPR conclusions and provide support required to assure successful adoption of innovative or best practice technologies.

- Forming linkages with regional training and skills brokerage organisations to access education and training to encourage improved levels of skills and competence within industry and provide essential underpinning for innovation and change.
- Focusing on supply chains as a key element in innovative process change and product development.
- Networking with regional resources to provide an enhanced technical capability.
- Networking with and agreeing suitable referral systems with existing publicly funded signposting and support activities.

9.21 Strategies to meet challenges of industrial sectors and implementation

Improvements in the global quality of life and breakthroughs in industrial sectors are constrained by various challenges and limitations of current levels of science and technology of welding and joining. These are different in nature in different areas of welded fabrication and hence require different strategies for successful implementation.

The objective of research relating to welding technology is to provide greater productivity and enhanced quality for welded components in the manufacturing industry. Improving productivity and quality by incorporating cost-effective solutions into the manufacturing process requires innovative developments in welding technologies and processes. This necessitates collaborative research among various disciplines in basic and applied sciences. Research in welding technology is carried out at R&D establishments, educational institutions and manufacturing industries that include welding equipment and welding consumable manufacturers and fabrication industries.

Thus, the welding community has to synergise the efforts of users of welding techniques and technologies as well as the companies, universities and other organisations that provide equipment, materials, processes, support R&D, services etc. A key component for the application of the latest in welding science and technology is the availability of qualified and trained human resources, especially availability of skilled welding personel. In this aspect, the IIW provides an important resource for welding technology education through its Authorised National Bodies (ANBs) in the majority of its member countries.

Focused research in welding science, engineering and technology across the globe has resulted in significant progress in understanding and modelling the physical processes in welding, microstructural evolution and the correlation between microstructure and mechanical properties of welds, and intelligent control and automation in welding, etc. Welding technology has reached a stage where welding processes based on scientific principles can be designed to tailor the composition, structure and properties of the weld. IIW through its Technical Commissions is in a unique position for enhancing R&D programmes in welding science and technology to achieve innovative, cost-effective solutions for welding industries and in deploying newer welding processes and technologies.

With respect to existing structures and components such challenges are met by respective life time extension, often achieved by extensive repair procedures. In order to accomplish this, materials have to be selected exactly for the appropriate purpose. This means that base and filler materials will increasingly be chosen for a very specific application of joined components to match the respective microstructural, mechanical and corrosion properties.

The technical and economic development in modern joining technology is predominantly characterised by cost and weight reduction. With respect to new structures and components such challenges are met by the use of new design principles, advanced materials and innovative joining technologies. Furthermore, new design approaches may aim novel material-mixed components which create new challenges for joining

and assessment. Multi-material design of welded structures can be considered as a key technology for the future. Respective IIW Working Units have already responded to this development.

Many of the high performance stainless steel, nickel base alloy and aluminium base alloy filler metals are sensitive to solidification cracking, liquation cracking and/or ductility dip cracking. Understanding of these various forms of “hot cracking” is still largely incomplete, which limits application of these alloys.

The International Institute of Welding has provided, and continues to provide, a major resource for attacking these problems. The IIW pioneered both the measurement of diffusible hydrogen in welds and in understanding of the phenomenon of hydrogen induced cracking. Indeed, the international standard for measurement of diffusible hydrogen, ISO 3690, is a direct product of the collaboration of experts within IIW Commission II. Likewise, ISO TR 17844 *Welding – Comparison of standardised methods for the avoidance of cold cracks* provides guidance on selection of pre-heat temperatures for various conditions of restraint and various levels of diffusible hydrogen.

The weld shrinkage restraint influences the cold cracking susceptibility of a joint by a respective stress increase and also changes the hot cracking tendency. A challenge for the IIW in future will be to transfer the knowledge about shrinkage restraint effects to respective weldability and cracking tests, in order to develop more realistic weldability testing procedures. This would represent a major step forward to reach the final goal of a consistent transfer of the results from laboratory weldability tests to real components and vice versa.

10 Short, medium and long-term strategic agendas of the world of welding and joining technology

10. Short, medium and long-term strategic agendas of the world of welding and joining technology

10.1 Objectives of Strategic Agendas (SAs)

The International Institute of Welding through this White Paper is providing short, medium, and long-term strategic agendas (SA) related to the technological and societal needs of the welding and related industries. Consequently, the resultant challenges, trends and effects should be considered in various time-scales to suit different countries and regions of the world.

Due to the complex nature of the items and their wide-range of areas, the following sections give SAs under general technological and societal headings.

10.2 Short-term Strategic Agendas

IIW has 56 member countries representing more than 80% of the world's GDP. Its strategies could also apply to non-IIW members as well.

- The key to improving the global quality of life is ensuring the integrity and reliability of welded products whether an energy-producing plant, bridge, pipeline carrying water to an African village or artificial heart. Conformity Assessment or compliance of the product to standards, codes or specification is therefore a key issue requiring immediate attention. IIW will guide industry on this.
- Culture defined as "a way of life or life style summarised in a system of particular values and attitudes which result in characteristic actions and customs" will determine the success of the application of welding technology in a community. Successful strategies to inculcate cultures of quality, workplace health and safety (WHS), environment, skills, ethics, morality, corporate governance and product compliance into people, companies and authorities in all countries are critical, and will be promoted by IIW.
- IIW will continue introducing its personnel Education, Training, Qualification and Certification (ETQC) programmes and company certification programmes into all countries based on companies having a welding coordination team linked to quality, WHS and environment.

- Since education needs to transform through a continuous imaginative change, to build capacity, capability and global culture for doing science and technology, business, etc a judicious mix of contact teaching, learning software modules and experimentation needs to be continually evolved.
- Support will be sought from organisations such as UNIDO, the World Bank, government aid agencies etc. to help countries establish a national welding Institute in countries where they do not exist, as well as introduce all the IIW ETQC programmes through the IIW Weld Care programme.
- The need to bridge the wide gap between countries which are developed, emerging and in transition is best done through training, certification, education, giving mentorship and providing inspirational objectives to young leaders. A programme suited to young leaders (region wise and at global level) may be developed.
- IIW will produce resources and action plans for member societies to approach industry and governments in their countries for assistance to meet their welding-related needs.
- IIW will assist countries with information and strategies on improving the "Image of Welding" in their countries.
- The value of, and importance of, welding to a nation's economy and quality of life will be promoted in each country.
- IIW Ambassadors or IIW Member Society representatives will have meetings with governments to explain the IIW White Paper and its benefits.
- IIW will prepare PowerPoint presentations on this IIW White Paper for IIW Members to use in presentations to different target groups.
- IIW will implement a campaign to purchasers to support the IIW ETQ&C programmes as well as request suppliers to meet certification of companies to ISO 3834 through the IIW Manufacturer Certification Scheme According to ISO 3834 (IIW MCS ISO 3834), including compliance to ISO 14731.
- IIW will assist with guidance for the analysis of the needs of a country and plan to assist countries in the implementation of solutions. The IIW WeldCare Programme could be used for developing countries in the regard.
- IIW technical Commissions and other Working Groups will elaborate further on the identified "hot topics" to transfer this information for take-up and further action both in IIW and its Member countries.
- IIW will provide a "Knowledge Resource Bank" for public use containing resources such as eminent website linkages, lists of text books, hand books, expert technology tools and other documents, particularly from IIW Member Societies.

10.3 Medium-term strategic agenda

10.3.1 Introduction

In the medium term, IIW will focus to strengthen the outcomes of its Working Units, and through its journal Welding in the World and other peer-reviewed scientific and technological publications, will contribute to the development of knowledge-based industrial activities as well as high level and effective dissemination methods and use and implementation of the research results.

10.3.2 Typical hot topics

In the medium term, the "hot topics" continually identified for each industry sector by members of IIW technical Commissions, the IIW Technical Management Board and IIW International Authorisation Board (IAB), will be further investigated to provide solutions for implementation across the globe.

10.3.3 Co-operation, competition and help

IIW will continue to support the principles of balanced and appropriate co-operation, collaboration and competition as a means of improving the world and its people's quality of life.

IIW believes that co-operation is the best means of helping developing countries to improve their quality of life towards that of leading countries. Hence, it will promote and encourage:

- Co-operation and collaboration between all countries.
- Assistance in welding to less developed countries by advanced welding member countries for example through:
  - IIW publications and information - free or at a small fee
  - Member countries education and training notes and other technical data - free or for a small fee
  - Member countries providing education and training, guidance, lectures etc. to neighbouring poor countries - e.g. IIW WeldCare Programme.

All involved will benefit since it will help to promote knowledge and good relations, reducing tensions and improving trade.

10.3.4 Improve Communication

IIW will improve its communications to all countries in recognition that information which is hidden or not known to countries is useless and there is a paucity of knowledge in some developing countries.
IIW supports in principle the actions proposed in Table 8.1 for technology diffusion and encourages all to take heed.

10.3.5 Global Welding Knowledge System

IIW will initiate a global system of welding knowledge which co-ordinates (not repeats) the documented knowledge of IIW, its member countries and others who wish to co-operate.

All others will co-operate as far as reasonably practical by clearly listing on www or internet details and availability (free-of-charge) of documented knowledge. Knowledge is proven facts and information is power and will benefit all. Those who develop it, find it, record it or use it, can improve both their own and their countries' performance.

10.3.6 Conformity Assessment or Compliance

IIW will produce a guidance document specifically dealing with this subject in relation to welding. This will recommend use of appropriate quality systems particularly ISO 3834 or equivalent, plus suitable levels of auditing or inspection. (i.e. Use of quality systems and inspection to give the suitable level of assurance that the welded related product and service is intended for).

10.3.7 Research and Development and Innovation

IIW will continue to promote and encourage coordination and collaboration in R & D and Innovation into welding technology use and related issues by:

- IIW Commission discussion, papers, Welding in the World, etc.
- IIW Welding Research Forum (or system) to act as a global focal point to co-ordinate (not repeat) welding R & D by member countries and others who wish to participate. It will be on the internet and upgraded as needed. Thus all can gain by voluntary cooperation, avoid unnecessary duplication, and encourage further R & D.
- Developing a guide on welding innovation.
- Support, in principle, the actions recommended in Sections 4.6 and 5.6 (see also 9.21).

10.3.8 Education, Training, Qualification and Certification (ETQ&C)

IIW believes that ETQ&C are vital for the successful progress of people, companies, countries and the world and so will:

- Continue to harmonise welding qualification and certification on an international basis.
- Strengthen people, create interest in upgrading people and bodies through optimum E&T.
- Request member countries to identify the various E&T documentation and systems which could help all - and in particular - developing countries.
- Encourage assistance by developed countries.
- Support in principle actions in Section 6.5.

10.3.9 Standards

IIW recognises the importance of standards and will continue to support the updating and development of ISO/IEC Standards – and for its members in respect to their national standards, supports, in principle, strategies in Section 7.4.11.

10.3.10 OHS and Environment

IIW will continue its:

- Work through Commission VIII on OHS and Environmental issues.
- Initiative on welding technology in relation to the local and global environment.
- Support for actions proposed in Section 6.5.

10.4 Long-term strategic agenda

IIW will continue its overall objective of enhancing the science and technology of welding and joining as well as enhancing the competitiveness of industries by generating new knowledge and disseminating it for innovative applications.

IIW will continue to gather welding and joining societies and experts world-wide and provide strategic guidance for emerging needs and challenges by integrating scientific knowledge and new technologies. Each IIW Annual Assembly and Working Unit activities should continue to develop capacities to gather new knowledge and technologies while providing expert platforms to generate high added-value welded products benefiting from its different disciplines.

A major issue will be to identify and integrate innovation and research activities in member countries while enhancing the dialogue with industries, in particular with SMEs, and with society at large. This has to be complemented by focused activities aimed at education, and skills development of young welding personel, engineers and scientists.

10.4.1 Essential infrastructure and resources

IIW recognises the vital importance of infrastructure and the need to maintain and repair aging equipment and the need for long life new infrastructure e.g. desalination plants.

Hence IIW will encourage members and others to report and to exchange experiences (good and bad) to ensure global improvement (e.g. current selection of stainless steel weldments in a marine atmosphere).

Thus all will gain – Note that infrastructure covers most of the plant dealt within Section 9 including that for food, water, shelter and clothes.

10.4.2 Laws and government

IIW members and all will assist governments and law makers in framing and upgrading laws and their implementation e.g. OHS, Environment, Trade, labour to ensure they are optimum for their particular country (or state) and preferably globally. IIW supports in principle the actions in Section 7.4.

10.5 Human Factors

IIW, in acknowledging that virtually all progress and failures are attributable to humans, will gradually develop and issue further global welding comments and, guidance notes on various issues such as:

- honesty
- discrimination
- ethics
- conflict of interest
- fair play
- racism
- sexism
- bullying
- corruption

This should help to improve various countries' cultures in welding technology and generally, and improve progress and reduce losses.

10.6 Conclusion

Welding science and technology will remain key elements in designing, constructing and maintaining products and structures and hence major infrastructure and industrial plants. In the future, this will continue to hold true and provide numerous welding applications from welding the fuel rods for nuclear industry, joining the structural steels for tubular structures, ships, pipelines, vessels, tanks etc., Al-alloys and dissimilar (multi-material) systems for airframes, car bodies and ships etc. It will be used to construct and seal canisters that will house the spent fuel of nuclear industry in long term storage.

In some countries due to the shortage of competent welding personnel, especially welders and welding operators, there will be keen competition for the available talent and a cottage industry to train willing workers in this important field. Unionised labour is now focusing on growing their ranks with the hope that they will be able to place their members at the forefront of this surge. For the future of welding professionals to improve, the general population and specifically parents will begin to realise that skilled trades are of equal value to civilised society as more academic pursuits.

The combination of good welding science and technology with competent welding and joining personnel and the correct cultures in a country will lead to an improved quality of life in that country.

10.7 Improvement

Comments are welcome to improve and add value to this document.

The IIW White Paper will be updated and improved as, and when, IIW experiences a paradigm change, or after three years when there is enough additional collective experience and knowledge to revise it.

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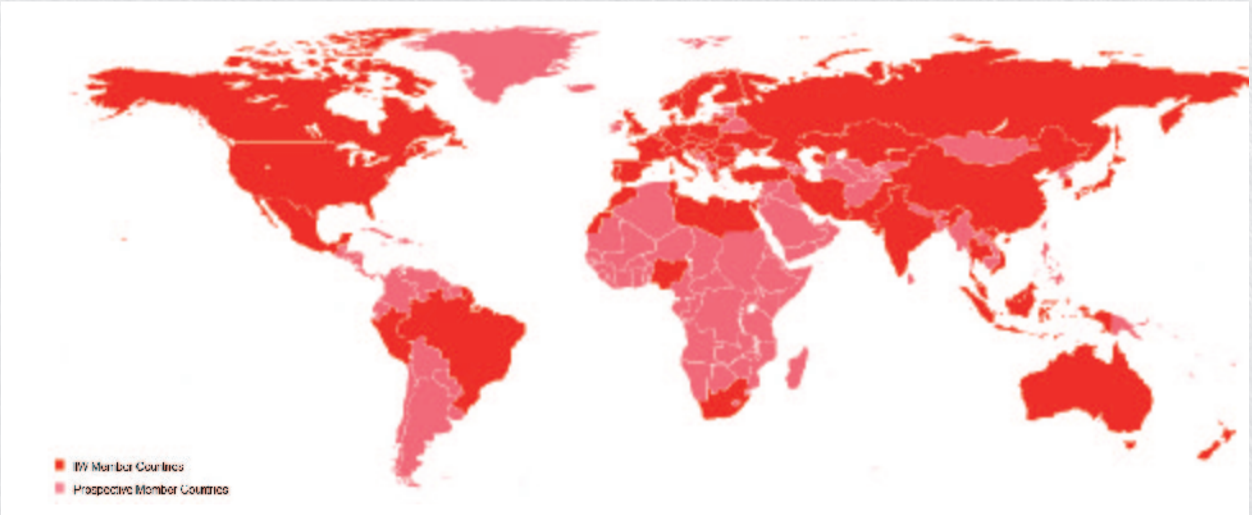

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> *Welding is an enabling technology that plays a critical role in almost every industrial sector in every country of the world, whether developed, emerging or in transition.*

The International Institute of Welding (IIW) brings together experts from industry - large, small and medium sized enterprises, universities, research centres, training providers, welding associations and public authorities in the field of welding and joining and allied processes. A non-profit organisation, the IIW, founded in 1948, currently has 56 member countries, representing 80% of global GDP, and ranging through developed, emerging and transitional economies world wide.

IIW provides a unique platform to enhance excellence in the fields of welding and joining sciences and technologies, and their uptake and implementation through education, training, qualification and certification worldwide. It also contributes to the global awareness of environmental and workplace health and safety imperatives, and plays an important role in global standardisation.

This White Paper, compiled by the members of IIW, has the following five primary objectives:

- To identify the challenges for welding and joining technology in the global arena.
- To recommend the implementation of strategies to find solutions to meet these challenges.
- To agree on directions to arrive at solutions.
- To promote the implementation of identified directions for solutions on a national, regional and international basis through greater collaboration, shared knowledge and partnerships.
- To improve overall global quality of life i.e. health, safety, food, water, fair trade, environment, education opportunities.

Needs and challenges for the global industry are detailed in the paper, while "Hot topics" are identified for each industry sector in Chapter 9 to highlight the specific challenges which need to be met along with potential solutions.

Chapter 10 details short, medium and long-term strategic agendas to meet these identified needs and challenges.

The editors:


Mr Chris Smallbone


Dr Mustafa Koçak

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