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Technical journal for welding and allied processes Issue 2/2011

DVS

The Welding Institute

INSTITUT DE SOUDURE

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WELDING AND CUTTING

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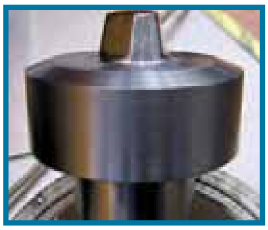
Career Management – Whose job is it anyway?

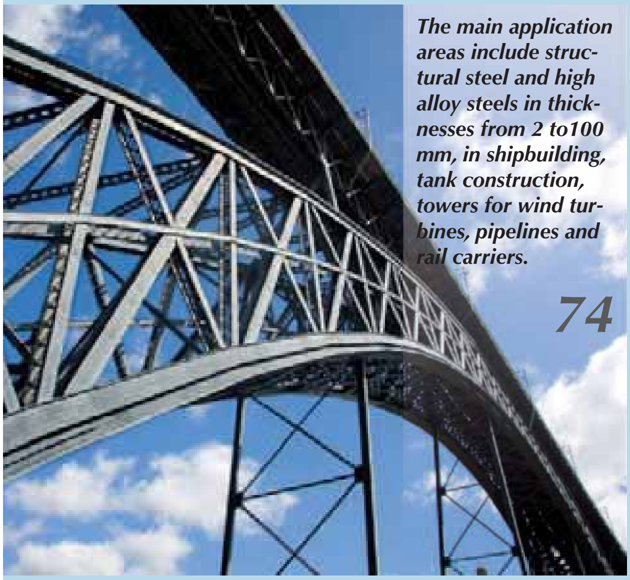
A successful career depends on some help and some luck. Mine has depended on rather more luck than I would like. Not that I would choose to do things differently but I am delighted to say that The Welding Institute is making efforts to inspire, guide, mentor, and encourage both new starters and the bright sparks already in our industry.

Please read more in the WJS Editorial on page 99.

Eur Ing Chris Eady CEng
Associate Director, Professional Affairs & Certification
TWI Ltd



70 Dean Carran, Deborah Seddon from the Engineering Council and Dr Peter Mason, Dean of the Faculty of Engineering, Kingston University, at the graduation ceremony (from left to right)



The main application areas include structural steel and high alloy steels in thicknesses from 2 to100 mm, in shipbuilding, tank construction, towers for wind turbines, pipelines and rail carriers. *74*

Even larger parts can be comfortably machined with the "PSM 400" series. *76*

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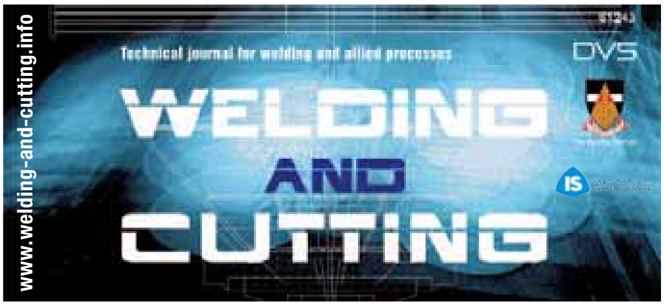

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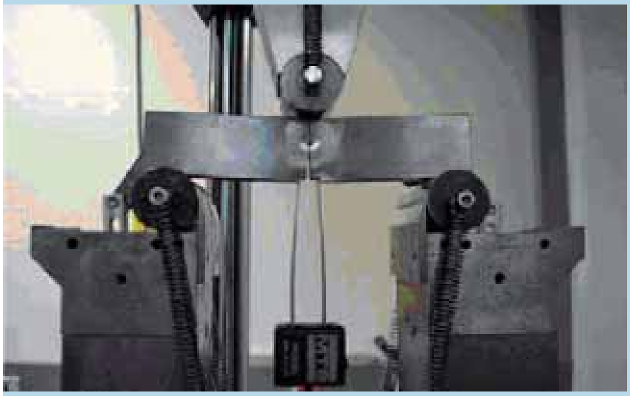
Produced in Collaboration between

SPECIALIST ARTICLES

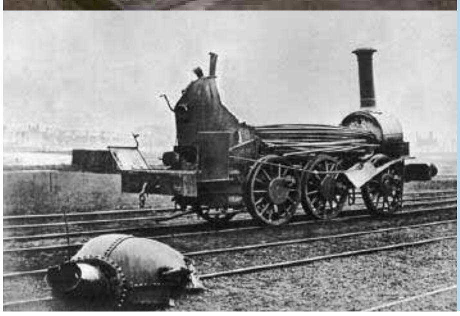
NATIONAL PAGES

Retrofit torch technology for "Power-max" systems.



Three-point bending set-up, CTOD determination.

Sizewell 'B' PWR (1988-1995). (All photos: courtesy of EDF Energy)



Early steam train boiler explosion.

New Masters course engineers a bright future for first graduate

With university tuition fees set to rise dramatically in 2012, studying for a first degree is likely to be a difficult enough financial choice for students, so deciding to take time away from work to do an MSc is going to be an even tougher decision. Now though, professional engineers are able to gain an MSc which counts towards Chartered Engineer (CEng) status without having to give up their jobs – thanks to a new Kingston University Masters degree programme.

Dean Carran, Deborah Seddon from the Engineering Council and Dr Peter Mason, Dean of the Faculty of Engineering, Kingston University, at the graduation ceremony (from left to right)

Dean Carran, who originally graduated from Kingston University in London/UK in 2006 with a BEng degree in aerospace engineering, became the first graduate of the MSc Professional Engineering programme when he picked up his certificate at a graduation ceremony held at the Rose Theatre in Kingston on 25 January 2011. The work-based MSc is part of the Engineering Gateways initiative launched in 2006 by the Engineering Council in collaboration with four universities, including Kingston.

After achieving his degree at Kingston, Dean set up his own engineering consultancy business and was initially, he said, just focused on getting it off the ground. "As my business grew and developed, though, I realised that there was a definite benefit in being recognised as a Chartered Engineer within the aerospace industry," he explained. "I couldn't afford the time to go back to university full or even part-time to gain the academic qualifications that would lead to Chartered status though, so the work-based Masters degree at Kingston seemed ideal as it let me build my Masters modules around my day-to-day work. It's been a real benefit to both me personally and my company."

Mike Hope, leader of work-based learning at Kingston's Faculty of Engineering said Dean had made good use of his Masters programme both to enhance his own engineering learning and to boost his business, JNDC. "For engineering companies, having staff with Chartered status is important because this demonstrates the industry gold standard to their clients and denotes a high level of knowledge and experience," he said. For individuals, too, being a CEng means that their professional competence is recognised, which greatly adds to their employability in the workforce. "The new programme enables engineers to structure their MSc learning round the professional engineering tasks they undertake at work, without the disruption of time away from their company. In turn, this helps to attract people to the profession who might otherwise not have achieved professional status," Mr Hope said.

The Institution of Mechanical Engineers had already confirmed that Dean's MSc would provide him with the academic requirement for CEng registration. This, alongside the competences he has acquired through work, enables Dean to apply to IMechE for the CEng professional qualification, using work from his MSc to demonstrate some of the required competences.

Jon Prichard, Chief Executive Officer at the Engineering Council said: "We would like to congratulate Dean on being the first graduate of the MSc in Professional Engineering, and hope that he is the first of many. The Engineering Council has been very pleased with the take up of these degree programmes and has received positive feedback from students, employers, universities and the professional engineering institutions involved."

The new flexible pathways provide learning through work-based activities and projects, with individuals also able to access university resources electronically. Employers have welcomed the new pathway, in particular its flexible nature, which tackles issues and barriers faced by engineers seeking to enter the professions through higher education.

More than 70 individuals in a range of companies are now enrolled on the MSc Professional Engineering programmes at five higher education institutions, with numbers set to grow. Twelve professional engineering institutions have now signed up to support these programmes. Further details are available at: http://www.engc.org.uk/education-skills/engineering-gateways. For further information on the Kingston MSc in Professional Engineering please visit: http://www.kingston.ac.uk/postgraduatecourse/professional-engineering-msc/.

With more than 25,000 students, Kingston University is the largest provider of higher education in South West London, offering an extensive range of courses both in the United Kingdom and overseas. The University is renowned for teaching excellence, has established itself as a growing force in research and is a pioneer in e-learning. The Engineering Council holds the national registers of Chartered Engineers (CEng), Incorporated Engineers (IEng), Engineering Technicians (EngTech) and Information and Communication Technology Technicians (ICT*Tech*). It also sets and maintains the internationally-recognised standards of competence and ethics that govern the award and retention of these titles. (According to press information from the Engineering Council/Kingston University London)

Energy leads the way for welding equipment and consumables market in Europe

The welding equipment and consumables market is experiencing high growth opportunities from the projects in the power industries, pipeline and offshore sectors in Europe. According to the international management consultancy Frost & Sullivan, the demand for welding equipment and consumables is expected to surge with increasing pipelines being laid, newer power plants' constructions being planned and thrust toward renewable energy.

There is a lot of effort underway to reduce the dependence on imported energy sources and protect the long-term economic and political interests of the European Union (EU). The World Energy Council envisages that, by 2050, in a global energy mix of at least eight energy sources (coal, oil, gas, nuclear, hydro, biomass, wind and solar), none is expected to have more than a 30% share of the market. This indicates widening of the growth trajectory for welding goods in the energy sector.

Emphasis on renewable energy market drives new projects

The increasing wind turbine installations in Germany, Spain, Italy, France and the United Kingdom are expected to drive the welding equipment and consumables market. The EU policy, driving the need to develop renewable energy sources to reduce dependence on imported fuel, is expected to increase the welding activities, despite several projects in pipeline and offshore industries been abandoned during recession.

The market for arc welding equipment and consumables in energy industries is poised to reach US $3.0 billion by 2015 at a compound annual growth rate (CAGR) of 7.1 between 2008 and 2015. Power industry has been providing high growth opportunities, and to a large extent recession proof, with increasing installations of wind turbines in several regions across Europe. There is also a significant demand from the thermal boilers, hydropower projects and nuclear cells. The trend to automate and an increase in reliance on high-alloyed consumables for critical industries like offshore, contribute to the increase in revenues for welding equipment and consumables.

High quality welding consumables increase revenues

The market for energy is witnessing growth of automated technologies and high-alloyed consumables. Such automated welding systems are preferred for their better weld penetration, resistance to corrosive environments (like offshore, cut down fabrication costs and repair) and better return on investment. Despite higher prices of automated products, as opposed to manual ones, there was an increasing trend for such equipment during recession.

Welding in the offshore and LNG (Liquefied Natural Gas) units are becoming increasingly automated owing to the lack of trained and skilled welders and increasing labor costs. The industries in energy generation like offshore, LNG tanks and the pipelines are prone to high corrosion, which results in susceptibility in the different areas of the weld joint. The use of alloyed metals with better resistance to environment, regular repairs and maintenance in pipelines and offshore also aids in stable growth of revenues for the welding consumables from the energy industries.

Central and Eastern European economies stimulate growth

Eastern European countries that are witnessing increasing investments in the energy sector with specific interest in developing the renewable energy are driving the market for welding equipment and consumables. In the past few years, the region has received a lot of support and aid from multi-lateral organisations such as the EIB, EBRD and the World Bank. Green Certificates supports from the Government have favoured the energy market invariably creating a demand in the welding market. For example, the Polish government supports solar power providing 45% subsidies and the market is expected to see high installations by 2013. Estonia and Romania are expected to see high wind turbine installations, while Bulgaria is expected to be supported through solar projects. Additionally, Eastern Europe has a higher growth potential as most of the welding is not automated in this region.

Optimistic future

Recently, the energy industry has been a major area of focus in the policies of the European Union. There has been high investment on the renewable energy sources like wind and hydroelectric power in all the European regions which is benefiting the welding equipment and consumables market. The market focus is gradually shifting from price to quality and technology in the energy industry and this is also true in the case of welding equipment and consumables market.

Quality is expected to play a prominent role in the market and high-alloyed consumables will be a dominant market in the energy industries. Increasing demand for austenitic steels consumables in the European regions, especially for welding power plants, is expected to continue. Such development and high investments in the renewable and low-carbon technologies, which are gaining importance, will oblige higher revenues in the European welding equipment and consumables market in future.

R. Padmanabha Govindan,
Research Analyst – Industrial Automation and Process Control

EAL Managing Director calls for clarity and parity on the apprenticeship issue

Ahead of National Apprentice Week (7-11 February 2011), Ann Watson, Managing Director of specialist engineering and manufacturing awarding organisation EAL (EMTA Awards Limited), Watford and Leeds/UK, has called on the UK Government to build on the momentum generated in recent years to finally put vocational training on a par with its academic counterpart.

"The last two years have seen a dramatic shift in the way Government has viewed apprenticeships. For too long now, this country channelled our brightest and best down the degree route, suggesting it was the only option. University becomes the gold standard for school leavers at the expense of our skills sector. Today, the situation has changed and a degree is no longer the guarantor of a job in the way it was 20 years ago. In the meantime, the skilled sector – for example manufacturing and engineering – is crying out for new blood and can provide life-long, engaging careers for students."

"As a country, we need to ensure that both university and vocational training are promoted equally to young people who are deciding on their next move. Bright children, regardless of background, should be made aware of the merits of vocational training; an apprenticeship, for example, provides a mix of academic and on-the-job learning that can make the student incredibly valuable once they have finished their training."

Watson continues: "We have recently seen signs of improvement in the manufacturing sector, and it has been reported time and again how sectors like this will play an important role in leading the UK out of recession. But how can this happen if they don't have the skills within the workforce?"

Watson highlights how the Government's latest initiative, the Specification of Apprenticeship Standards for England (SASE), is likely to be highly detrimental to engineering and manufacturing industries when implemented. She concludes: "A one size fits all mentality does not work for skilled industries whose apprentices require training programmes bespoke to their trade. We need to see both clarity and consideration when it comes to apprenticeships; clarity when it comes to the Government's plans for the future of the skills sector, and consideration for the needs of the highly skilled industries which are vital to the country's economy and industrial heritage."

EAL (EMTA Awards Limited) is a leading UK Awarding Organisation for vocational qualifications in the engineering, manufacturing and building services engineering sectors. With more than 40 years experience, EAL's qualifications are recognised as representing the highest standard of practical achievement. For more information, visit the website at: www.eal.org.uk. (According to press information from EAL)

*Nominations are now open for living individuals to be inducted into the **Plastics Hall of Fame**, it was announced by SPI – The Plastics Industry Trade Association, Washington D.C., representing the third largest manufacturing industry in the United States. To be eligible, nominations must be submitted no later than 30 September 2011. SPI is administering the nominating process on behalf of The Plastics Academy, whose officials will make up the initial screening committee. The induction ceremony and gala banquet will take place on 2 April 2012 during SPI's "NPE2012" exposition in Orlando, Florida. "Election into the Plastics Hall of Fame is an honor bestowed on individuals who, by consistent dedication and extraordinary accomplishments, have contributed to the growth of the plastics industry," said John R. Kretzschmar, chairman of The Plastics Academy. "Individuals from any country in the world may be nominated, and submissions may be made by anyone using the official form provided by the Academy and accompanying it with appropriate supporting information." More information and nomination forms are available online at www.plasticsindustry.org or by e-mail from Susan Douglas at douglas@plasticsindustry.org.*

*The new **"Shielded Metal Arc Welding Pipe – Downhill" curriculum** from the Hobart Institute, Troy, Ohio/USA is now available on two DVDs with student workbook, instructor guide, tests and answer key. The completely revised course includes demonstrations and exercises on 2-inch and 6-inch pipe in the 5G and 6G downhill positions. There are topics on safety, health and weld quality. Students are provided with instruction on downhill welding in pipeline construction including how to read and apply welding procedures. The student workbooks provide students the opportunity to follow the DVD step-by-step while the instructor guide provides a resource for the teacher to complete the curriculum. More information is available from the Hobart Institute, e-mail hiwt@welding.org, Internet www.welding.org.*

*The Gedik Education Foundation (GEV) and the Turkish Welding Technology Academy (TKTA) invite welding scientists, engineers from industry and academia to take part in **IIW International Congress "AWST 2011"** in Antalya, Turkey on 21 and 22 October. The event aims to bring leading scientists and engineers to share recent advances in welding & joining sciences and technologies to achieve cost-effective, environmental friendly, safe and long-lasting welded systems in construction, energy and transportation. The congress will be chaired by TKTA President Dr. Mustafa Koçak. For more information please visit the congress website at www.awst-2011.com*

Aerospace sector set to benefit from industrial research collaboration

A £ 3.8 m (Euro 4.4 m) industrial research collaboration announced on 2 February 2011 is set to have a significant impact on the worldwide aerospace industry by speeding up the production of composite materials. Composite materials are used increasingly in aircraft with the demand increasing on a global scale but the rate of production is hampered by the speed at which the composites can be inspected during the manufacturing process.

A four-year research project led by TWI Wales, based in Port Talbot/UK, is designed to speed up the inspection process by 400% using advanced non-destructive testing technologies. IntACoM (Improving the Inspectibility of Aerospace Composite Materials) which has had funding from the Welsh Assembly Government, involves an industrial collaboration with Rolls Royce, GKN Aerospace and Bombardier Aerospace, with academic support from Swansea University, Swansea Metropolitan University and the University of Wales.

Launching the project, Lesley Griffiths, the Welsh Deputy Minister for Science, Innovation and Skills, said it had the potential to make a significant contribution to industry, specifically the aerospace sector: "It's great news to hear that Wales is leading the way on the research and development of highly sophisticated technologies with the potential to make a significant impact on the production of composites. I am particularly pleased the Welsh Assembly Government is supporting this research and that Wales is taking the lead and working with major players in the aerospace sector and benefiting from academic support from our Universities. Our Economic Renewal strategy highlights the need to build upon the expertise that exists within Welsh universities and businesses to harness the commercial opportunities of innovation and research. This is a good example of such collaboration between the private and public sector and between industry and academia."

Philip Wallace, Regional Manager of TWI Wales, explained that the advancement in composites had not been equally matched by an advancement of inspection capability: "Composites inspection is a difficult and highly complex area but is not yet sufficiently developed to meet industry needs. The time it takes to carry out inspections at different stages of the manufacturing process is actually hampering and slowing down the entire process. Our aim is to increase the process by 400% without losing reliability or sensitivity and once we have developed the inspection technology at the manufacturing level we will further develop testing and inspection capabilities for in service maintenance and repair."

Composites, such as carbon fibre composites, are increasingly being used in aircraft construction and other areas such as wind turbine blades, because of their exceptional strength, superior physical properties and increased mechanical performance. Initially composite materials were only used in secondary structure but with the development of materials, their use in primary structures such as wings and fuselages has increased to the extent that in some aircraft they account for around 25% of the weight. Composite components and reinforcements are also being more widely used in aircraft repair technology.

For more information, please contact Philip Wallace at philip.wallace@twi.co.uk. (According to press information from TWI)

TWI hosts Chinese delegation

On 10 January 2011, over 50 delegates from Chinese industrial companies made an hour-long visit to TWI – The Welding Institute in Cambridge/UK. The group was led by Mr Sun Guangbin, Director, China Chamber of Commerce for Import and Export of Machinery and Electronic Products.

This is the second trade visit to TWI by a high ranking Chinese Government official in less than a month. In December 2010, UK Trade and Investment (UKTI) led a visit by Chinese Minister Counsellor. Mr Zhou Xiaoming was so impressed with TWI and the company's strong links with China, that he advised this delegation to find out for themselves the potential business opportunities at TWI during their UK Trade Mission.

Graham Wylde, TWI Associate Director said: "We were delighted to be chosen by the Chinese Embassy in London to host part of the delegation's Trade Mission tour in the UK. We have a long history of working with Chinese companies, which goes back twenty years – TWI staff spends more than twenty weeks a year servicing their Chinese customer base to maintain good relations and look at future business opportunities. Today has been extremely productive and we have received positive feedback from the delegation, with many companies keen to meet again and explore how our services could further benefit their future business. Working together with UKTI and Embassies abroad, in hosting events for vitally important trade missions like these, is a great opportunity for TWI." (According to press information from TWI)

Delegates from Chinese industrial companies visited TWI in Cambridge/UK.

Expanded silicate in welding technology

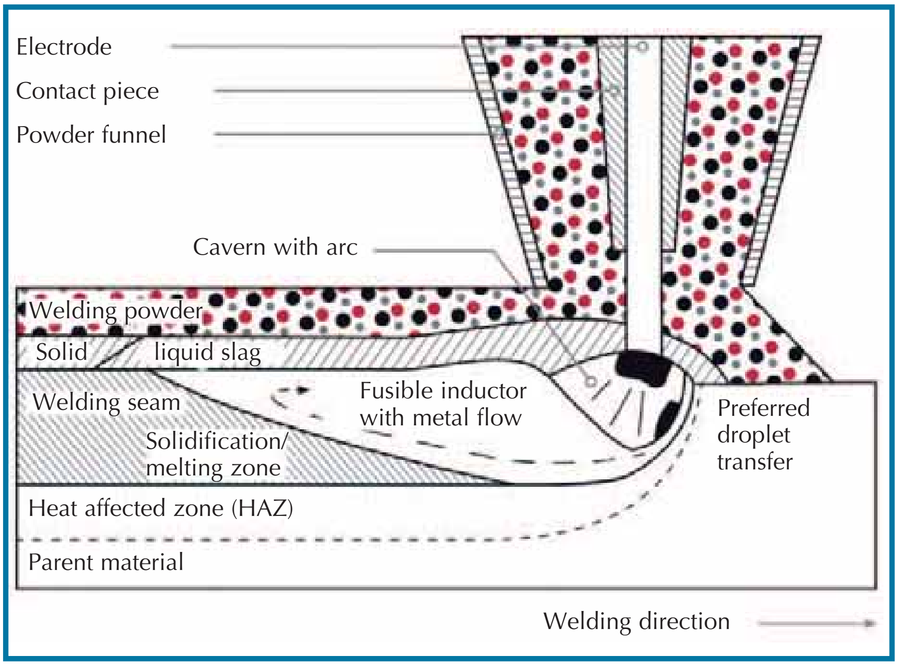


Fig. 1. *In general, spatter-free welds at a very high quality are achieved provided appropriate welding techniques are used. By selecting a particular combination of wire and powder, the chemical composition of the weld metal can be influenced, due to the occurrence of a transfer efficiency of alloying elements through reactions of molten metal and slag in the cavern.*

Fig. 2. *High temperature proven during formation, the processed expanded silicate "Rotocell" plays a critical role during the submerged arc welding process with its important contribution to quality and efficiency.*

High temperature proven during formation, the processed expanded silicate "Rotocell" plays a critical role during the submerged arc welding process with its important contribution to quality and efficiency. For decades "Rotocell" the expanded silicate has been used in welding technology for the submerged arc welding process. Submerged arc welding (SAW welding, EN ISO 4063: Process 121) is a fully mechanised process used to achieve high deposit rates. It is mainly used for industrial large-volume welding seams or thick-walled components. Usually, the powder is fed automatically and protects the weld from oxygen by forming slag and improves the conductivity of the arc gap. The main application areas include structural steel and high alloy steels in thicknesses from 2 to 100 mm, in shipbuilding, tank construction, towers for wind turbines, pipelines and rail carriers.

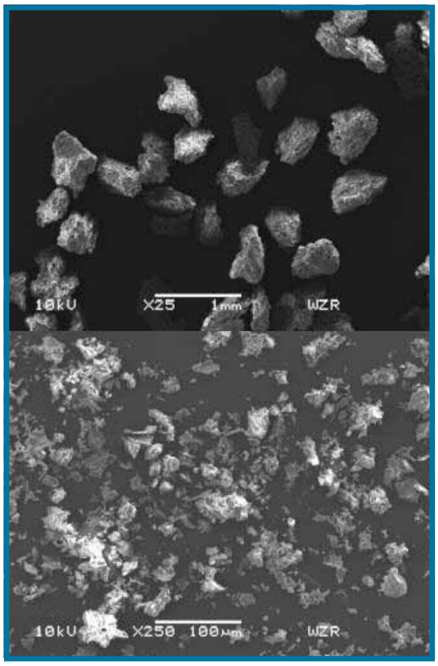


Fig. 3. *The welding process is "sub-merged" by a layer of coarse mineral flux. The granulation of the welding powder (0.4 to 2.0 mm) is performed with the addition of "Rotocell" (types 0.09 to 0.3 mm, 0.09 to 0.5 mm or 0.25 to 0.5 mm).*

For submerged arc welding, the welding process is "submerged" by a layer of coarse mineral flux. The granulation of the welding powder (0.4 to 2.0 mm) is performed with the addition of "Rotocell" (types 0.09 to 0.3 mm, 0.09 to 0.5 mm or 0.25 to 0.5 mm).

The flux will melt from the heat emitted by the arc formed directly on the molten liquid slag that floats on the metallic weld pool due to its lower density. Because of its low bulk density of 360 g/l, its fine grading

Fig. 4. *The main application areas include structural steel and high alloy steels in thicknesses from 2 to100 mm, in shipbuilding, tank construction, towers for wind turbines, pipelines and rail carriers.*

curves and its chemical composition, "Rotocell" plays a decisive critical role. In this process the liquid components of the liquid glass can be well bound due to its lightness and the micro pores of "Rotocell" that is the carrier material. Through the slag layer with "Rotocell", the melt pool is protected from atmospheric contamination. The arc burns in a gas-filled cavity under the slag and powder. After the welding process, the slag layer typically resolves on its own, the unmelted powder can be reused.

Particularly noteworthy is the minimal emissions achieved by this process, due to the arc being submerged which burns below the powder layer allowing only small amounts of smoke to be released. Because of the coverage of the process, the method has a high thermal efficiency, but limits the use to large sheet metal thicknesses.

For a high quality weld seam, the very low phosphorus content of "Rotocell" plays a pivotal role. Additionally, the micropores of the expanded silicate granulate of about 0.005 to 0.03 mm encourage the gas release of the melt. Therefore the addition of "Rotocell" in the production of granulated welding flux, to produce a high quality weld seam, is decisive. (According to press information from Rotec GmbH & Co. KG)

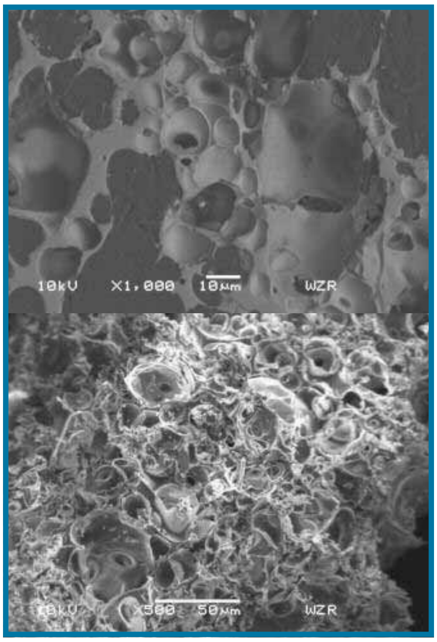


Fig. 5. *Due to its lightness and the micro pores (5 to 30 mµ) of "Rotocell" the liquid components of the liquid glass can be well bound and the melt pool is protected from atmospheric contamination through the slag layer.*

"BladeWelder" welds challenging alloys

After a successful start one year ago, Schunk Laser Technology from Lauffen/Germany, has intoduced a second version of their "PSM 400" laser welding machine to the market. With its high-performance laser source, the "PSM 400 BladeWelder" is particularly designed for welding high-temperature nickel, or cobalt base alloy, an ideal precondition for machining turbine blades and high-alloy tool steels. Moreover, its fibres absorb harmful reflections.

Fig. 1. The "Blade Welder" is suitable for machining turbine blades and high-alloyed tool steels.

Scaleable pulse duration of up to 200 ms

The "PSM 400 BladeWelder" is an expert for working with materials which are difficult to weld, as they are used in modern gas turbines. Its highly developed laser welding process allows crack-free, quick and cost-efficient machining of challenging materials. It can be used for manufacturing, for build-up/overlay and repair welding. The peak pulse output of the Lasag laser source amounts to 8 kW. Thereby the machine achieves a pulse energy of 120 J. Via a freely scaleable pulse shaping and modulation the laser parameters can adjust to the specific characteristics of the materials. The pulse shaping can be enlarged to 200 ms. An adaptive closed-loop control assures that the lamp-pumped solid-state laser is working precisely and is performance stable. In order to avoid reflecting laser beams that could damage the fiber when reflecting materials are machined, powerful fibres are used for the "BladeWelder" which can absorb such reflections.

Flexible in use

The high-precision laser welding machines of the "PSM 400" series are exceptionally flexible in use. They can be used for machining small and large components quickly and comfortably. An electrically height adjustable, double-sided swivelling machine table, as well as a slidable and swivelling laser welding head provide a high level of flexibility in the working area. The operators have access to all the machining, programming and control functions, independent from the workpiece size.

The user-friendly look-ahead control unit and the unique teach function for lines, arcs, circles and splines of the innovative family-owned company are quickly adjusted and programmed. The "PSM 400" series is setting standards in machining individual items, small and medium-sized series. Free formed surfaces for which no geometry data exists, can be quickly adjusted. For fine adjustment the teached points in the spline mode can be connected to a curve. This shortens the teaching process and the soldering path becomes easier to follow. Even complex workpieces, workpieces with a surface damage or wear can be quickly connected in three dimensions, making time-consuming external programming works unnecessary.

High-precision linear and rotating axes assure that the machine is working at maximum precision and repeat accuracy. The welding lines are variably off-set which produces constant and process reliable laser welding results. The standard machines of the "PSM 400" series are also available as a 3-axes CNC machine. On request, it can be quickly and cost-efficiently modified to a 5-axes laser welding machine. The Schunk Lasertechnik GmbH is the youngest company of the Schunk group, an expert in clamping technology and gripping systems, and was founded at the beginning of 2010. (According to press information from Schunk Lasertechnik GmbH)

Fig. 2. Even larger parts can be comfortably machined with the "PSM 400" series.

Laser tracking system for robotic welding

Meta Vision Systems, a leading international manufacturer of laser vision equipment for welding automation, has launched the "Smart Laser Pilot", a new seam tracking system for robots that sets a price-performance point that was previously unattainable in the market. The distinctive capability of the "Smart Laser Sensor" (SLS) on which the system is based, namely integrating high performance image processing functionality within the sensor head itself, makes it possible to simplify the overall architecture while simultaneously enhancing robot interface flexibility. The "Smart Laser Pilot" represents a leap in the marketplace, as it creates a new class of flexible robot guidance system that is powerful, easy to use and less expensive than previous generations.

Meta's SLS technology at the heart of the "Smart Laser Pilot" integrates a high-resolution megapixel camera, a laser stripe projector and advanced image processing hardware and software within a compact and rugged sensor head design. Integral cooling (gas or chilled air, or optionally water for more arduous applications), front window blow-off and an integrated weld spatter shield ensure the sensor will survive in the most hostile of welding environments.

The SLS central to each "Smart Laser Pilot" system is mounted just ahead of the welding torch on the robot end effector and acquires data at 30 full frame images per second. Much higher frame rates are possible using a windowing function that concentrates image analysis on a defined region of interest. All image processing is done in the sensor head itself and a tracking accuracy of ±0.1 mm is possible in both the horizontal and vertical planes with a field of view of 50 mm.

SLS features several advancements that simplify setup and operation of the system and that greatly improve performance on shiny and other difficult surfaces. This includes an automatic laser intensity control function, exclusive to Meta, which solves laser reflection problems that are common in applications involving variable material surface conditions.

Meta's new "Smart Laser Pilot" laser-based seam tracking system for robotic welding.

For example, when welding two different materials together whose surfaces have been prepared differently or when fillet welding shiny aluminium components, the laser line from a conventional sensor may appear too bright in certain areas and dull in others. This may also cause the laser light to reflect brightly, causing the vision analysis software to make poor and inaccurate measurements.

Automatic laser intensity control in the SLS rapidly varies the intensity of the laser stripe so that darker areas become brighter and brighter areas become darker. The result is an image of more uniform intensity along the entire length, contributing to more reliable and accurate measurements. This also simplifies the setup process, as varying surface conditions no longer need to be considered while setting up a system.

The "Smart Laser Pilot" communicates with the robot controller using an ethernet connection. Provided with each system is a break out board incorporating an Ethernet switch, laser safety circuitry and a 24V DC power supply for the SLS. The break out board allows the use of a single cable for ethernet and power between the robot controller and the sensor.

The ethernet switch can route the SLS signal to the robot controller or to the user's own Windows XP/Vista/Win7 computer running Meta "Smart Laser Pilot" tools software supplied for setting up and changing system operating configurations. The laser safety circuit is incorporated as required by international regulations to manage and control how and when the SLS laser is activated.

Ease of use is leveraged further using a dedicated graphical user interface touch screen device (GIO). Housed in its own protective enclosure, the GIO displays the analysed weld joint profile and other data as processed by the SLS, providing an important tool for production monitoring and problem rectification.

The GIO is implemented as an independent yet convenient means to display data of interest to the user coming from the SLS head via the ethernet interface. The use of an ethernet interface also makes it easy for the sensor to be used more generally when information on the position of a feature or its surface profile is required by another application to achieve greater levels of integration.

The "Smart Laser Pilot" is able to control virtually any robot that has a real-time ethernet interface. If a robot is not equipped with an ethernet interface, an optional ethernet I/O board (EIO) is available to convert the ethernet signals and send them to the robot controller via a serial or analogue/digital interface.

In many critical applications, robots that are performing automated arc welding without some form of external guidance will produce defects if the parts to be welded are not in the proper position. While costly, high quality joint preparation or complex fixtures may be employed to ensure the robot does what it is programmed to do, a more precise and less costly alternative is to use a non-contact laser sensor to track the weld joint and to adjust the robot's path while welding. This allows the welding torch to follow the actual joint position and to correct for changes in part positioning in real time. (According to press information from Meta Vision Systems Ltd)

Volvo relies on safety – CMT welding of hot-stamped steels impresses bodywork manufacturer

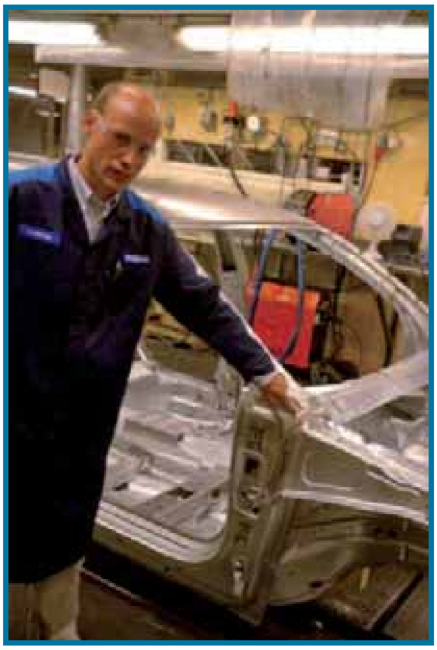


Fig. 1. Mikael Carlsson shows the critical joining areas of the Volvo "V 70".

Volvo is well known for its perfectionism with regard to the safety of its cars. Quality and responsibility for the environment have a high priority in the production process. In the production areas, the primary objective is to deliver and ensure the highest possible product quality at a reasonable price. To do this, developers and production experts compare their technologies and methods with those used in other factories. As a result, engineers at the main factory in Gothenburg/Sweden, found CMT technology to be the best way of MAG-welding hot-stamped high-strength bodywork panels to meet their stringent demands for quality and economy.

Within the Ford Group – the parent of the Volvo Car Corporation – technical managers and experts maintain an intensive transfer of knowledge and information. It was in this way that Johnny K. Larsson, Technical Specialist BIW Joining Technologies, Joel Lundgren, Welding Technician, and Mikael Carlsson, Process Engineer Manufacturing, first became aware of CMT (Cold Metal Transfer) technology. This welding technology often produces impressive results in situations where conventional MAG (Metal Active Gas) welding is not adequate for users with stringent demands in terms of quality and economy, or where particularly difficult materials are to be welded together. The special arc welding process was developed by Fronius from Wels/Austria and has exceptional properties when joining light-gauge sheet, such as good gap bridging, low heat input, low distortion of the welded components and almost complete freedom from spatter, with less need for rework as a result. At the Gothenburg body assembly plant, these criteria play a vital role in the production of the Volvo "S80", "V 70" and "XC 70" models. The fact that sheets such as Usibor is coated and Boron are non-coated means that specific requirements exist in terms of production reliability, shorter welding times, attractive seam appearance and the option of using thinner and specially coated sheet steels.

Hot-stamped steels and gas metal arc welding

Car manufacturers primarily use hot-stamped high-strength steels for lightweight construction. The specific mechanical characteristics of these materials are obtained by heat treatment and quenching during the forming process. This thermo-mechanical process lends them excellent quenchability and good structural homogeneity, the prerequisites for a good strength response to high levels of mechanical stress. In practice, these steels exhibit an unusually high fatigue strength and impact resistance. Compared with standard steels with a higher yield point, they can achieve weight savings of up to 50%. An aluminium-sirconium coating protects the metal against oxidation (scaling) and decarburisation during hot stamping. This coating also has a benefit further down the line, as final parts have improved corrosion resistance after painting.

Typical applications are for safety and structural parts, such as bumper beams, door reinforcements and, above all, the A-, B- and C-pillars as well as reinforcing the floor and roof of the body shell. However, the Volvo experts maintain that despite the many positive properties of Usibor and sim-

Fig. 2. Four seams join 1 mm thick sheets in the body shell area between the windscreen, A-pillar and the front side panel.

Fig. 3. The CMT systems have been integrated into the production process and the existing welding cells without having to modify the body shells.

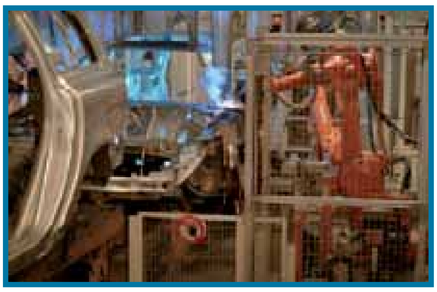


Fig. 4. Volvo integrated the original CMT trial system into the ongoing production process just one year after the initial idea.

ilar steels, experience shows that they suffer from several disadvantages when using gas metal arc welding. These mainly concern the welding of door hinges and body frames.

The considerable heat input during the GMAW process causes distortion of the welded components and hence a reduction in precision and quality. Welding spatter – especially on visible components – increases the amount of rework necessary and the risk of visible defects. A very restricted process window reduces the availability of the welding cells. As the process cannot be efficiently automated, the labour-intensive production and rework results in high costs. Further cost drivers are the necessary destructive material tests and the personnel required to carry them out.

Specific recommendations for the welding parameters when joining Usibor to Usibor, for instance, or other steels were not available. The parameters had to be determined by individual test runs for each combination. In these tests, the Volvo welding experts varied the wire feed speed, for example, from 2 to 8 m/min and also the range from a short-circuit arc to a spray arc. The torch offset was also changed, as were the welding positions and the diameter of the G3Si1 filler metal from 0.8 to 1.0 mm. The correct parameters for each combination of sheet thickness also had to be determined on a case-by-case basis. An example of this is the joining of 1.0 and 1.2 mm Usibor sheets. For this combination, however, it was not possible to find a suitable set of parameters that would permit reproducible production. Serious welding defects such as massive fusion penetration and burn-through occurred repeatedly. To some extent, the

Fig. 6. *To find potential for improvement, the Volvo engineers critically evaluate the key production and welding data.*

results of the experiments involving the joining of thicker sheets were less discouraging. However, they did not satisfy Volvo's requirements for reproducible series production. There was also a requirement that particularly bothered Joel Lundgren: "What we can see with CMT is that we have a possibility to weld boron steel combinations that was not possible with MAG and also sheet combinations with thinner base metal and also reduce the amount off spatter in production."

From Volvo's point of view, the problem could be solved in the following ways: 1. accept an increased repair and failure rate, 2. design the joints so that a process other than gas metal arc welding could be used, 3. find an alternative colder arc welding technology which generates less heat input. The Volvo engineers went for this third strategy and subsequently opted for CMT.

"Cheaper than laser – better quality than GMAW"

That's how Johnny K. Larsson summarises his experience with CMT. For the Swedish automobile experts, this positive view has a very short history. They heard about the CMT process from their colleagues at Ford. Samples of material for the welding tests were provided by the steel supplier. Axson, Volvo's welding equipment partner, obtained more detailed information and carried out the initial welding tests. Their welding expert Patrick Gyllén remembers: "We started the CMT welding tests without having any experience of Usibor as a material. After just a few weeks we obtained increasingly better results and at the same time an ever larger process window."

The results encouraged Volvo to try it for themselves. The R&D department therefore hired a CMT system from Axson in the summer of 2008. Larsson reports on the results that followed: "After initial scepticism from many colleagues about arc welding, CMT turned out to be very impressive. We found that we could make considerable savings in comparison with laser welding. The quality was also much better when we compared the results with the conventional GMAW process. This applied to both the product and the process itself."

Very shortly afterwards, in October 2008, Volvo engineers integrated the original CMT trial system into the ongoing production process. Volvo purchased two new "TransPuls Synergetic 4000" CMT systems, which have been operating in the welding cells of the body shell production line since mid-May 2009. Welding is carried out by existing ABB robots. "That was a new record for us. We'd integrated the first CMT system into production just one year after the initial idea. Everyone worked well together and it all went very smoothly right from the start. All those involved, both internally and externally, were always highly committed," noted Mikael Carlsson during a visit to the welding cell four weeks after it was commissioned. At that time the system had been working for a whole week without interruption, which confirms the current trend.

Three Usibor modules are integrated e.g. into the Volvo "V 70": The rear bumper beam (1.6 mm thick), the external body sill (1.3 mm) and the C-pillars (1.0 mm). The characteristic values for the coated steel sheets after hot stamping are 1,050 to 1,100 MPa yield strength, 1,500 to 1,550 MPa tensile strength and 5 to 7% elongation. The hot-stamping process modifies the microstructure

Fig. 5. *The CMT systems join high-strength hot-stamped steels such as Boron and Usibor to the body shell of the Volvo "V 70" with almost no spatter.*

of the approx. 45 µm thick coating and the boundary region of the steel beneath. Fronius supplied Volvo with synergy characteristic curve 1,053 for the CMT welding of the sheets. The parameters for welding the 1.0 mm sheets to the 1.2 mm sheets are: shielding gas ATAL5 with 82% argon and 18% CO_2, 20 to 22 mm gas nozzle diameter, 1.0 mm diameter G3Si1 (EN 440) filler metal, 4 m/min wire feed and 14 mm/s welding speed. These parameters provide a welding range within which the Volvo engineers can weld satisfactorily. For joining thicker sheets, only the wire feed speed and welding speeds are modified, e.g. to 8.5 m/min or 16 mm/s. "The fact that we're now able to consistently weld thinner sheets with CMT fits in very well with our plans for a lightweight construction. It helps us achieve even greater weight savings. The ability to join sheets which could not previously be welded gives our designers even more flexibility," explains Mikael Carlsson. Larsson adds: "In the future, we'll prefer using CMT for gas metal arc welding. From our point of view, the higher investment is offset by easily justifiable and distinct technical and commercial benefits in production and product quality."

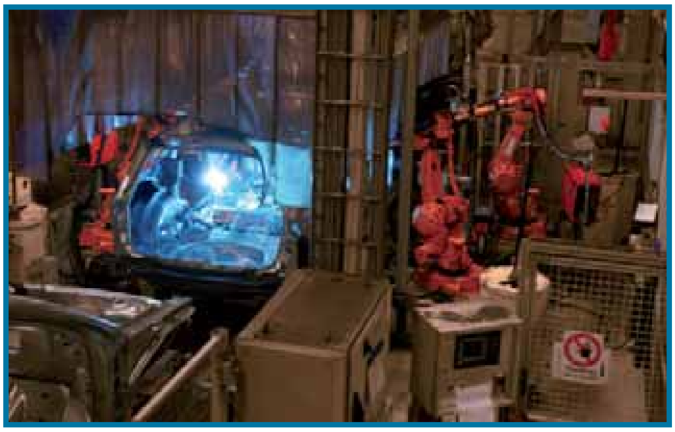


Fig. 7. *The CMT system enables Volvo to reduce cycle times in the pressing plant.*

Experience benefits everyone

The developers and production engineers in Gothenburg painstakingly record their experiences. They established that the MTBF (Mean Time Between Failure) value for welding without CMT is about 19.5 hours, with an average interruption of 5 minutes. This is based on a total welding seam length of 274 mm produced by a robot as its contribution to each body shell. Compared with the situation prior to the introduction of CMT technology, system availability has increased considerably and quality has improved several times over. With CMT, the trend is most definitely towards further positive results. In Gothenburg, however, the most impressive aspect is quality. "Compared with conventional arc processes, the significantly cooler CMT technology gives a better seam appearance, and above all there's no spatter to stick to the bodywork. It's also worth noting that we no longer need to protect the threads in weld nuts, yet they still do their job. We can therefore increase the cleaning intervals for the gas nozzles. This is an important outcome that increases productivity and which we'll utilise in the future. The higher welding speed of CMT allows us to reduce the cycle times in the welding cell," comments production expert Joel Lundgren. The arrival of CMT in body production has brought about a change in production conditions.

The exchange of information within the Ford Group is very good. Engineers from all the plants get involved and pass on their knowledge and experience. Everyone knows what's going on. The same applies to CMT and the results that Volvo has obtained in Gothenburg. Johnny K. Larsson summarises: "The introduction of the new technology couldn't have gone better. And I mean both from a technical and a time point of view. It was important for us to introduce a new joining system into the ongoing production process without having to modify the product. This means we haven't had to obtain new certifications." Joel Lundgren adds: "From production point of view, the almost spatter-free welding is very important. We save both on the rework of the body as well as the equipment wearparts in the welding cell."

Gerd Trommer, Gernsheim/Germany

Retrofit torch technology for cutting systems

Fig. 1. Retrofit torch technology for "Powermax" systems.

The wait is over for "Powermax1000" and "Powermax1250" owners interested in upgrading to the latest Hypertherm torch technology. Beginning today, those customers can enjoy all the benefits of Hypertherm's "Duramax" torch series, including more durability and longer consumable life, while using their existing Powermax systems.

Similar to the new Duramax torches introduced last fall with Hypertherm's new "Powermax65" and "Powermax85" systems, the torches were designed with durability in mind. They can withstand impacts five times greater than the previous generation of torches and are more heat resistant so they can easily conquer the most demanding job.

The Duramax torches use a "Conical Flow" nozzle and spring electrode for longer consumable life. Hypertherm testing shows an up to 55% increase in the life of the Duramax consumables, which translates into a 30% savings on consumable costs.

"We were using five sets of tips per week. Now with the new retrofit torch, we use the system more and are using only one set per week," said Travis Bering, a manufacturing foreman at JMH Trailers, a U.S. fabricator from Hamburg, PA/USA. Bering estimates the money his company is saving on consumables will help JMH buy another plasma system for their shop.

The Duramax retrofit torches also offer convenience. They are designed with the same Easy Torch Removal (ETR) connection as the standard "Powermax1000" and "Powermax1250" torches, enabling switching from the older torch to the new in just seconds. These retrofit torches use the same consumables as Hypertherm's "Powermax65" and "Powermax85", allowing customers with a mix of systems to simplify their consumables stock. In addition, "Spring Start" technology, a new patent-pending design eliminates moving parts within the torch for greater reliability.

The Duramax retrofit torches are available in either an ergonomic, 75° hand torch (HRT) or a 38 cm full-length machine torch (MRT). Similar to the standard Duramax machine torches, customers have the ability to convert the MRT into a 15 cm short-barreled machine torch perfect for robotic and pipe-cutting applications.

Hypertherm designs and manufactures advanced cutting systems for use in a variety of industries such as shipbuilding, manufacturing and automotive repair. Its product line includes handheld and mechanised plasma and laser systems, consumables, as well as CNC motion and height controls and cutting software. Hypertherm systems are trusted for performance and reliability that results in increased productivity and profitability for tens of thousands of businesses. The company's reputation for plasma innovation dates back more than 40 years, to 1968, with Hypertherm's invention of water injection plasma cutting. The company has more than 1,000 associates along with operations and partner representation worldwide. (According to press information from Hypertherm)

Fig. 2. Hand torch "Duramax HRT".

Fig. 3. Machine torch "Duramax MRT".

Short Messages

Aluminium for future generations

The International Aluminium Institute (IAI), based in London/UK, has announced the launch of a website highlighting the recycling advantages of aluminium products. Recognising the demand from customers, consumers and policymakers around the world for up-to-date and easy to access information, the IAI has developed the site to demonstrate the economic, social and environmental benefits and the future potential of aluminium recycling. Launched in February at the International Aluminium Recycling Congress, the website (Fig. 1) features interactive content, based on the IAI's long-running "mass flow" research and extensive statistical database, as well as recycling success stories from around the world. The site also provides data on recycling rates and energy and emissions savings; measures that are central to the aluminium industry's sustainability strategy of

Fig. 1

reducing the environmental impact of its facilities, increasing the use of aluminium in energy saving applications and maximising the recycling of products at the end of their useful life. The recycling website follows on from the success of the IAI's recent green building (greenbuilding.world-aluminium.org) and transport websites (transport.world-aluminium.org) which have proved popular with architects, car manufacturers, policymakers and academics who are looking for quantitative data and real life examples of aluminium use in sustainable products. Please find more information on website: http://recycling.world-aluminium.org

Acquisition of an orbital welding systems manufacturer

Lincoln Electric Holdings, Inc. from Cleveland, OH/USA has acquired substantially all of the assets of Arc Products, a privately-held manufacturer of orbital welding systems and welding automation components based in Southern California/USA. Orbital welding systems are designed to automatically weld pipe and tube in difficult to access locations and for mission-critical applications requiring high weld integrity and sophisticated quality monitoring capabilities. The acquisition will complement Lincoln's ability to serve global customers in the nuclear, power generation and process industries worldwide. Arc Products has annual sales of approximately $5 million and employs over 40 people. Terms were not disclosed.

"Orbital welding is one of the fastest growing segments of our industry," said John M. Stropki, Chairman and Chief Executive Officer. "Arc Products has a robust and cost effective line of orbital welding products that, combined with Lincoln's advanced welding power sources and applications engineering expertise, will allow us to quickly build a global leadership position in this important segment." "Joining with Lincoln will enable us to service and support end-users on a global basis, and will further accelerate our rapid growth in orbital welding systems," said Victor Miller, President of Arc Products. "We have been impressed with Arc Products' strong product line and R&D capabilities, and we believe that Arc Products will help expand and deepen our relationships with key customers," said Mr. Stropki.

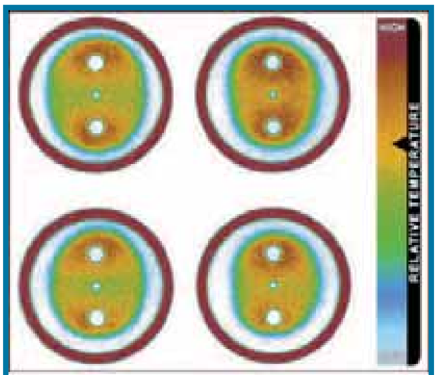
Polysoude on tour around the world

TIG hot wire welding: A technological process is going around the world to boost productivity threefold. Polysoude from Nantes/France is known for its know-how in terms of TIG hot wire welding, especially in the fields of narrow gap welding and cladding solutions. Polysoude is fully committed to this leading edge technology and has continued developing the TIG hot wire welding process in a large number of diverse applications in numerous industrial sectors, such as petro chemistry, offshore and onshore (generally covered by the term 'process piping'), power generation (conventional and nuclear) and many more. To introduce the benefits of the TIG hot wire process to a wider public, Polysoude has decided to tour the world in the true sense of the word in order to demonstrate these new applications to welding specialists. These demonstrations will take place in the United Kingdom, France, Scandinavia, Germany, Austria, Switzerland, Italy, the USA and Japan. You can look forward to e.g. presentations of the advantages of the TIG hot wire process compared to the TIG cold wire process, live welding demonstrations of carbon steel 168 x 12.5 mm in 5G position with open angle J and V, as well as stainless steel 355 x 90 mm in 2G position narrow gap.

Products

Temperature distribution film

"Thermex" is an economical thin film that can be used in virtually any application to monitor heated contacting surfaces from 200° to 300°F (93° to 149°C). It may be used alone or in conjunction with pressure indicating film from Sensor Products. Upon exposure to heat, "Thermex" (Fig. 1) changes colour instantaneously and permanently to reveal temperature distribution between any two contacting surfaces. The intensity of this colour change directly relates to the temperature it was exposed to enabling the film to reveal spot high or low temperature zones and minute surface variations. Invasive intolerant environments and interfaces that aren't easily accessed with traditional temperature indicators and infrared thermometers are among candidates for the distribution film. A sheet of "Thermex" is available in 14" by 17" (35.6 by 43.2 cm) format. It can be easily trimmed for smaller applications or custom cut to defined dimensions. Common applications include



Thermex® temperature distribution film enhanced by Topaq® Analysis

Fig. 1

heat sealing, lamination/press, flat web-type machines used in converting, ultrasonic welding, heat sinking and clutch/brake interfaces. Post processing analysis of "Thermex" is available for temperature fluctuations that need to be analysed with great precision. (Sensor Products Inc., 300 Madison Avenue, Madison/NJ 07940, USA; www.sensorprod.com)

Maximising inert gas retention

When welding stainless and other high alloy metals, it is important to completely displace oxygen in the weld zone with a noble gas and prevent additional air from entering. When surfaces are welded in the presence of oxygen, corrosion and other weld defects will result, causing unnecessary re-work. Now, oxidation can be minimised and even eliminated by welding the pipe joints with "EZ Purge" dams constructed with ZAPTM (Zero Air Permeability) technology. The patented "EZ Purge" is a pre-formed, water soluble and self adhesive purge dam. Similar to a mechanical purging device, "EZ Purge" is flat to allow equal distribution of gases across the body of the dam. Made of "Aquasol" water soluble paper combined with other water soluble polymeric composites, "EZ Purge" substantive body and ZAPTM technology prevents argon from exiting the dammed area. Made of sodium carboxy methyl cellulose and wooden pulp, the "EZ Purge" dam dissolves instantaneously and completely in most liquids and is 100% biodegradable. (Aquasol Corporation, 80 Thompson Street, North Tonawanda/NY 14120, USA; www.aquasolwelding.com)

Submerged arc welding flux production line for the international market

Gedik Welding has become the first company in Turkey which is able to produce

Fig. 2

and supply submerged arc welding flux for the Turkish and international market. The company is able to produce aluminate rutile, aluminate basic, fluorid basic and manganese silicate, for the hard facing sub arc wires and stainless steel sub arc wires fluxes with a capacity of 5,000 tons/year. By producing the fluxes, Gedik Welding is now able to provide "wire+flux" combination for various applications. The advantages of flux cored wire are high deposition rate, smoothness seam, easiest functionality in every position and less distortion and stress as compared to shielded metal arc welding. Flux cored wires are available for non alloyed and fine grained steels (Fig. 2), fine grained steels with high strength, creep resistant steels, weather resistant steels, high alloyed and stainless steels, hard facing, hard facing (cobalt based) and submerged arc welding flux cored wire, e.g. "Geka Subcor B 31 SC", "Geka Subcor B-1D 35 SC". The flux-cored wires are produced by the seamless production method. They are copper-coated and have a low level of hydrogen (H5) in them. (Gedik Holding Inc., Ankara Caddesi No:306 Seyhli Pendik 34913, Istanbul/Turkey; www.gedik.com)

Water jet technology for undersea operations

The waterjet manufacturer Jet Edge and its applications partner Chukar Waterjet have developed numerous water jetting tools for underwater operations, the workboat and shipyard industries, including undersea waterjetting equipment, portable water jet cutting machines, precision water jet cutting systems, ultra-high pressure water blasting tools, and electric and diesel-powered water jet intensifier pumps. Most recently, in emergency response to the Gulf oil spill, the two companies partnered to develop the first-known waterjet intensifier pump capable of operating at depths below 5,000 feet. BP used the subsea waterjetting system to blast away hydrates that were clogging a containment system. The tools are ideal for use in environmentally sensitive marine environments or potentially hazardous areas, including the Jet Edge "Hydraulic Versacutter" portable linear and pipe cutting system; "Gyra Jet LP" ultra-high pressure lance for surface preparation, coating and corrosion removal; "Ultra Deckblaster" walk-behind deck blasting system for removing coatings and corrosion; and the 80 hp 60,000 psi "iP60-80DS" diesel-powered portable water jet intensifier pump (Fig. 3). The pump is capable of producing up to 1.35 gpm (5.1 l/m) of ultra-

Fig. 3

high pressure water for mobile water jet cutting applications, and is especially suited for cold cutting in environments where heat and flames are restricted. The “iP60-80DS“ is powered by a reliable four-cylinder Cummins turbocharged diesel engine and is designed for portability and ease of maintenance. A 36,000 psi conversion kit is available. (Jet Edge, Inc., 12070 43rd Street N.E.,St. Michael, MN 55376-8427/USA; www.jetedge.com)

Integrated diode laser system

The release of a new integrated diode laser system based on fiber-coupled modules is available. Despite the extremely small dimensions of 336 mm x 144 mm, this high-power diode laser system delivers optical output powers of up to 50 W CW at 980 nm out of a 400 µm fiber and up to 35 W CW power out of a 200 µm fiber. Cooling is provided by Peltier elements and air flow. The system can either be controlled via an USB port using the supplied software or by conventional analog and 24 V signals. The “Mini“ (Fig. 4) is available as an easily integrable OEM version (without housing) or as a housed desktop version. A fiber optic cable of 5 m length and with SMA connector allows flexible beam guidance to the working area. Available accessories like processing heads of different focal spot sizes and working distances

Fig. 4

can be used in conjunction with the “Mini“ system. Furthermore, the integrated red pilot beam facilitates to adjust the laser to the work piece. The “Mini“ is used for a variety of applications in direct materials processing such as selective soldering and welding of plastics as well as for applications in illumination, analysis or research and development. For such applications, different wavelengths (630 nm to 2,000 nm) are available upon request. (Dilas Diodenlaser GmbH, Galileo-Galilei-Strasse 10, 55129 Mainz-Hechtsheim/Germany; www.dilas.com)

Electrode manipulation in the vertical-up position

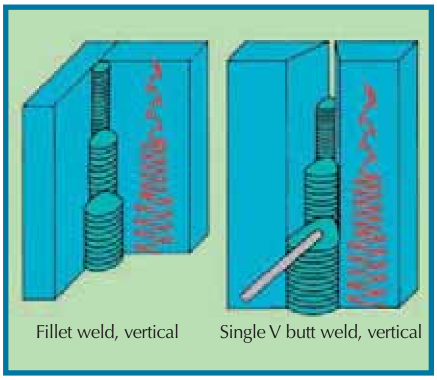


Fig. 1. The most important factor is the correct electrode manipulation.

The most important factor in the case of manual metal arc welding is the correct manipulation of the electrode (Fig. 1). This applies to every position and weld type. It must always be possible to control the molten pool in the vertical-up (PF) position and the molten pool must not run down. In the case of welds in the vertical-up position, the welder must work in the so-called „Christmas tree pattern". In this way, the previously deposited weld metal can solidify before the next step is "climbed".

Butt welds

In the event of incorrect electrode manipulation (Fig. 2a), the U shaped movement results in an extremely reinforced bead with deep undercuts. If a second layer is welded without machining off the reinforcement, this leads to slag inclusions in the notches. These defects can be prevented with the correct electrode manipulation (Fig. 2b). The slightly upward movement and the dwelling at the sides give rise to a flat bead. Notches and slag inclusions are avoided in this way. The arc can be kept short in this respect.

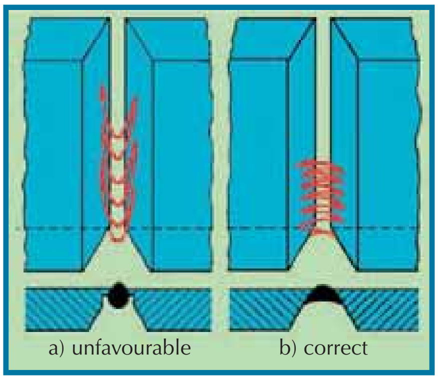


Fig. 2. Stick electrode manipulation during the vertical-up welding of butt welds.

Fillet welds

There are similar difficulties in the case of fillet welds as well. The incorrect electrode manipulation (Fig. 3a) leads to an extremely reinforced root layer. In vertical-up positions, the welding is therefore executed in the so-called "triangular weaving" (Fig. 3b). For the beginner, it is recommended to make the movements by counting 1 2 3 4 1 2… The stick electrode dwells at 3 and 4 in order to obtain good root penetration. In contrast, the 1 2 step sequence is carried out quickly in order to avoid heating the weld pool unnecessarily because the running-down of the pool would otherwise be favoured.

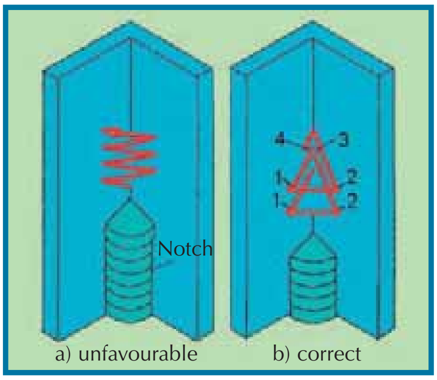


Fig. 3. Stick electrode manipulation during the vertical-up welding of fillet welds.

Heated tool butt welding of plastics

Not only metals can be welded. Thermoplastics can also be joined using various welding processes. Heated tool butt welding is one frequently utilised process. It has widespread applications in plastics processing from the skilled trades sector to automated series welding.

The utilisation fields encompass (for example) automobile construction, apparatus engineering, pipeline construction as well as the manufacture of windows. Fig. 1 shows an overview of the process: The joining regions of the plastic parts are pressed against a correspondingly tempered heated tool until enough material has been melted completely. The heated tool is removed and the plastified surfaces of the plastic parts are pressed together. The parts cool down under pressure or with displacement limitation until the melt has solidified once again. No welding filler materials are needed. Fig. 2 shows a compact welding machine for the heated tool butt welding of pipes. The following process steps must be complied with in order to produce a flawless joint: alignment, heating, changeover and joining. The heated tool temperature is 200 to 220°C for polyethylene (PE) and polypropylene (PP). In principle, it is true that the upper temperature must be striven for with smaller wall thicknesses and the lower temperature with large wall thicknesses. Fig. 3 illustrates the pressure course throughout the welding process.

Alignment

In this respect, the joining faces to be welded are pressed on to the heated tool

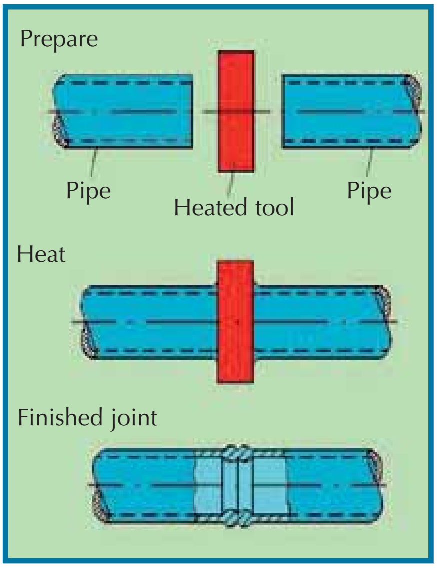


Fig. 1. Overview of the process.

Fig. 2. Pipe welding machine. (Photo: Widos GmbH)

until the entire faces are in contact with the heated tool with parallel planes. This can be recognised by the formation of the beads. The alignment is concluded when the bead heights have reached the stipulated values all around the pipe circumference or all over the top side of the plate. The bead heights are regarded as an indication of the fact that the entire areas of the joining faces are touching the heated tool. The alignment pressure of 0.10 N/mm² is effective throughout the alignment operation.

Heating

For the heating, the faces must be in contact with the heated tool at a low pressure. For this purpose, the pressure is lowered to nearly zero (under 0.01 N/mm²). During the heating, the heat penetrates into the welding zone via the contact faces and brings the welding zone to the welding temperature.

Changeover

After the heating, the joining faces must be detached from the heated tool. The heated tool must be taken out without damaging or soiling the heated joining faces. Thereafter, the joining faces must be moved together quickly until they are nearly touching. The changeover time should be kept as short as possible since the plastified faces would otherwise cool and the weld quality would deteriorate.

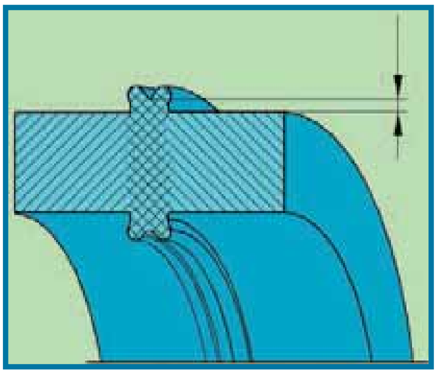


Fig. 4. Welding bead.

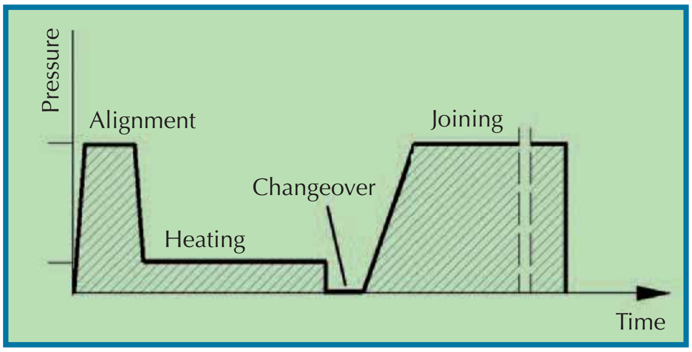


Fig. 3. Pressure course.

Joining

The faces to be welded should come together and touch at a speed of nearly zero. The required joining pressure is applied with a rise which is as linear as possible. The joining pressure is 0.10 ± 0.01 N/mm². After the joining, there must be a uniform double bead (Fig. 4). The bead formation gives an orientation about the uniformity of the welds. Various bead formations may be caused by different types of flow behaviour of the joined materials.

Pulsed arc

In the case of gas-shielded metal arc welding, a distinction is made between short, long, spray, intermediate short and pulsed arcs depending on the input heat quantity and the type of the droplet transfer. A background current which just keeps the electrode tip and the weld pool liquid is set in order to produce the pulsed arc. Current pulses which lead to the deposition of the droplets are superimposed on the background current. Since the level of the pulsed current and the pulse frequency can be adjusted exactly to the base material and the welding task, the droplets are transferred without any short circuits or spatter. The pulsed arc is utilised in the medium power range, for thin sheets and out of position.

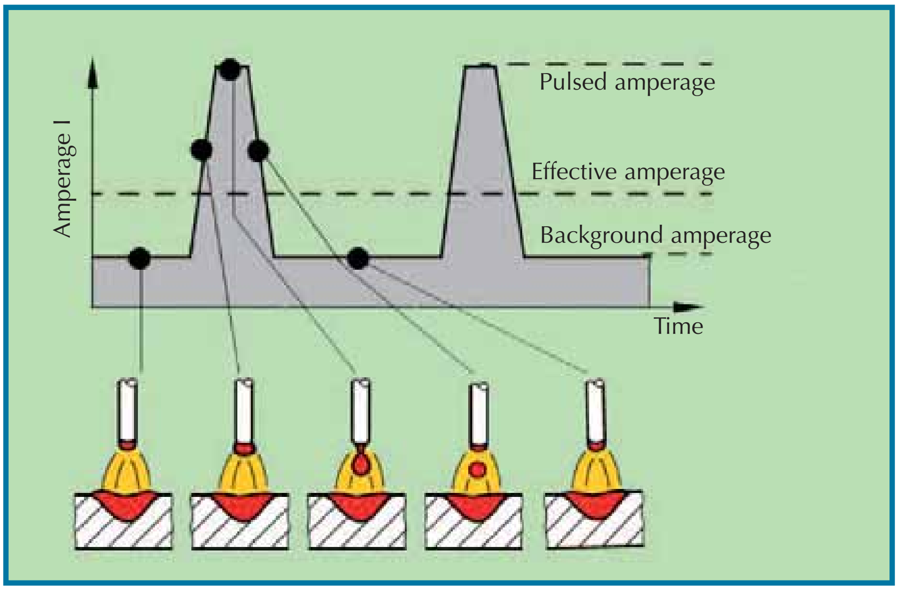


Fig. 1. Pulsed arc.

"Russia Essen Welding & Cutting" in May 2011 in Moscow

For the fourth time, suppliers from the fields of joining, cutting and coating will present their products and services to the trade public at "Russia Essen Welding & Cutting". On May 23 to 26, the fair will take place in the Krasnaya Presnya Expo-Centre Moscow. In parallel, fairs with related subject areas will be staged on the site: Wire Russia, Tube Russia, Metallurgy-Lithmash, Aluminium Non-Ferrous and Metalloobrabotka. Exhibitors and visitors will thus be offered the possibility of far-reaching contacts and high synergetic effects.

After the deep slump in 2009, the Russian economy is on course for recovery. A growth of 4 to 5% is expected for the year 2010 and should continue at this level in the following three years. In addition to the still dominant raw material sector, the growth will also be borne more and more by rising industrial production and increasing employment.

This dynamic market environment will offer outstanding chances for welding technology according to Western standards. There is a great need for modernisation in all the industrial sectors and with regard to the further development of the partly antiquated infrastructure in the fields of transport and logistics. This is where "Russia Essen Welding & Cutting" will take effect as the newest products and processes will be shown at the trade fair. At the same time, it will be the meeting place for established and intensifying business contacts.

Proven partnerships safeguard the success of "Russia Essen Welding & Cutting". From the Russian side, the "National Agency for Inspection and Welding" (NAKS) inputs its knowledge and its contacts in situ. Furthermore the DVS – German Welding Society has been assisting Messe Essen for over 50 years as a specialist partner and ideal sponsor of the "Essen Welding Fair". Messe Düsseldorf is the joint venture partner in the case of "Russia Essen Welding & Cutting". The appearance of German companies in Moscow will once again be supported by the Federal Ministry of Economic Affairs and Technology. That highlights the significance of the fair for the German companies.

The fair programme will be supplemented by the 4th conference entitled "Welding – A Look into the Future", jointly organised by NAKS and DVS. In the already proven form, experts will provide information about market trends and new developments. More information is available at www.schweissen-schneiden.com (According to press information from Messe Essen)

Good response for 2011 "Welding World" Exhibition

Since announcing the 2nd "Welding World" Exhibition, the Association of Welding Distribution (AWD) from Redditch, Worcestershire/UK is looking to considerably increase the number of exhibitors over the 2010 event. Companies already signed up to exhibit include Air Products, GYS Ltd, INE Spa, Weldability-SIF, Corewire Ltd, Nederman Ltd, JEI Solutions Limited and Prestige Industrial Pipework Equipment Ltd.

The 2nd "Welding World" Exhibition and the 37th Annual General Meeting and Conference of the AWD is being held at Crewe Hall, Crewe, Cheshire over the weekend 8 to 10 April 2011 (see "Welding and Cutting" issue 6/2010, page 335). The exhibition is a one day event taking place on Friday 8 April, where manufacturers and distributors will exhibit a wide range of welding and cutting equipment, welding consumables, health and safety equipment, process gases and other ancillary products. Last year was the first time this event has been held and was a pilot event to gauge reaction from the market.

Adrian Hawkins, AWD Vice Chairman said: "Last year was the first year of this exhibition and we are currently on line to increase the number of exhibitors at this year's event. As a result, we are extremely pleased with the level of interest shown in the event, especially the number of companies that did not attend last year putting their names forward to exhibit this year. This exhibition is the only event of its type in the UK market, where welding equipment and consumables manufacturers and distributors are able to exhibit their products under one roof at a one day event running alongside our AGM and Conference."

More information is available from the AWD Conference and Exhibition department, phone 01952 290036, e-mail secretariat@awd.org.uk (According to press information from AWD)

16th "Beijing Essen Welding" with a record number of participants

The 16th "Beijing Essen Welding & Cutting" fair will go to the starting line on 2 to 5 June 2011 with a record number of participants, i.e. around 1,000 exhibitors from 30 countries. The sister event of the "Essen Welding Fair" is the most important and largest welding trade fair in the Asian region. In seven fair halls at the SNIEC Expo-Centre in Shanghai, it will give an overview of the latest products, processes and solutions for everything to do with welding, cutting, joining and coating.

"Beijing Essen Welding & Cutting" is the meeting place of the Asian and international experts who obtain information here, prepare purchasing decisions or sign contracts. Companies from the international leader in the sector right down to the niche supplier use this platform in order to be exhibitors here. This highly specialised event is an outstanding opportunity to establish new business contacts, to intensify existing relationships and to make use of the diverse possibilities of the fair as a marketing instrument. In the comprehensive supporting programme with conferences and forums, they receive valuable information about new developments and the latest state of the art.

In addition to DVS – German Welding Society as a long-standing partner of Messe Essen, other renowned associations from all over the world are behind "Beijing Essen Welding", organise cooperative booths for the participants from their countries and input their knowledge. This year as well, the Federal Ministry of Economic Affairs and Technology will once again be involved with a cooperative booth. In the "German Pavilion" which has grown even further compared with the previous years, 26 German companies will show their newest trends and technologies and will use the fair in order to establish or intensify business relationships.

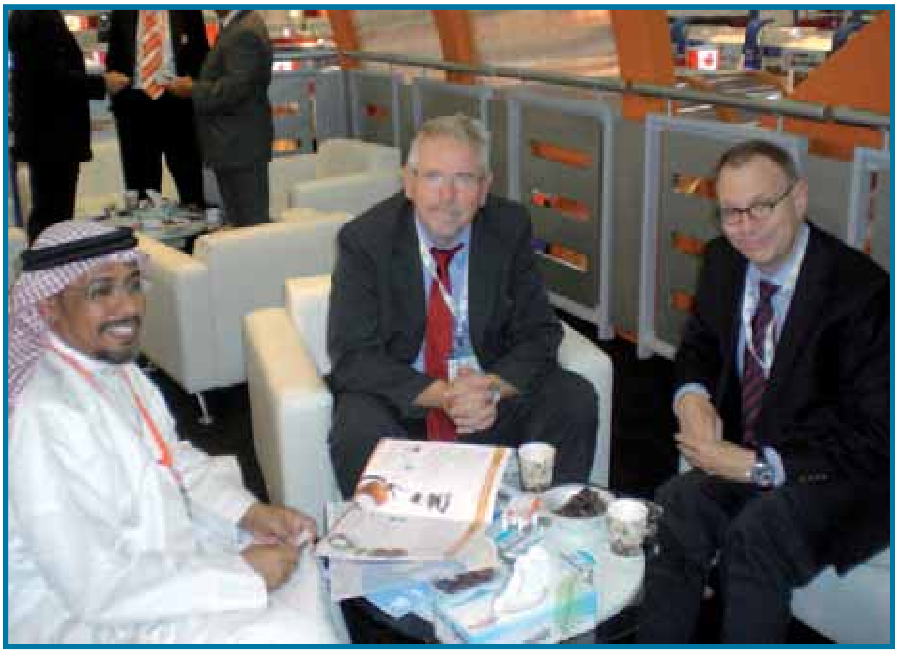
In this respect, "Beijing Essen Welding" profits from the know-how and success of the "Essen Welding Fair". The world's premier fair which is staged at Messe Essen in Essen/Germany every four years achieved one of the best results in its history in 2009 and will take place in Essen once more in 2013.

Apart from "Beijing Essen Welding" in China, the "Essen Welding Fair" has foreign offshoots in Russia, India and Brazil. The following events will take place this year: "Russia Essen Welding & Cutting 2011" in Moscow on 23 to 26 May as well as the premiere of the "Brazil Welding Show 2011": Together with the partner Aranda Eventos, it will be staged in São Paulo on 18 to 21 October 2011 parallel to the "Corte & Conformação de Metais" fair. In 2012, "India Essen Welding & Cutting" will once again take place in Mumbai on 29 to 31 October. (According to press information from Messe Essen)

DVS organised visit to Abu Dhabi

In November 2010, DVS undertook a visit to ADIPEC 2010 in Abu Dhabi. The trade exhibition is one of the largest fairs for oil and gas technology anywhere in the world. The objectives of the visit were to make German joining technology better-known and to create prerequisites for greater involvement of the sector in situ.

Discussions with representatives of the government, regional bodies and German companies with experience in the region show the great significance of long-term contacts for business success in Abu Dhabi. The crucial factors are a permanent presence on the spot, investments in the training of the specialists there as well as the willingness of the suppliers to render services. Short-term involvement is regarded as not very promising. The United Arab Emirates expect technological leadership from their partners. Germany has a very good reputation in this field.



Al Mashibi (Gulf Technical & Safety Training Centre, Abu Dhabi), Christian Ahrens (GSI – Gesellschaft für Schweißtechnik International GmbH) and Dr.-Ing. Klaus Middeldorf (DVS – German Welding Society) speaking about the possibilities of advanced joining technology training in Abu Dhabi (from left to right).

Excellent infrastructure and tax advantages

The free trade area is interesting for companies. It offers an excellent infrastructure as well as tax advantages. In any case, foreign firms need a lot of patience and continuous partnerships in order to obtain authorisation as a "registered company". One appropriate alternative is to found an independent company outside the free trade area. However, the 51% principle according to which foreign firms must cooperate with a national partner is still applicable to this at the moment. The German-Emirati Chamber of Industry and Commerce supports and advises companies which are planning to settle in the region.

DVS, GSI – Gesellschaft für Schweißtechnik International as well as the economic representatives in the delegation on the mission see a considerable business potential in the region. The German companies EWM Hightec Welding and Linde have already dared to take the step and have set up plants in Abu Dhabi. The participants in the mission from Carl Cloos Schweißtechnik and Putzier Oberflächentechnik are also showing great interest. DVS and Messe Es-

Meeting with the German Ambassador on the German cooperative booth at ADIPEC 2010: David Sutton (GDF Suez E&P Deutschland GmbH), Christian Ahrens (GSI – Gesellschaft für Schweißtechnik International mbH), Claus-Peter Regiani (Messe Essen GmbH), Klaus-Peter Brandes (Ambassador of the Federal Republic of Germany in Abu Dhabi), Dr.-Ing. Klaus Middeldorf (DVS – German Welding Society), Dr. Joachim Henneke (JHCS GmbH) and Jens Putzier (Putzier Oberflächentechnik GmbH) (from left to right).

sen therefore want to check further possibilities of taking part in a fair in the United Arab Emirates. The oil and gas industry is a sector with intensive joining technology activities. Until now, this aspect has not been very present at ADIPEC. In order to highlight the significance of joining technology, DVS sees the portrayal of the entire value added chain as a possible concept – from pipeline and apparatus construction right up to the repair of the installations.

94% of crucial oil and natural gas deposits in the UAE

Abu Dhabi possesses 94% of the crude oil and natural gas deposits of the United Arab Emirates. The complete economy of the country is based on the production and processing of these raw materials. At the same time, the country is preparing for the time "after the oil" and is currently opening up additional branches of the economy.

At the moment, Abu Dhabi's industry is completely characterised by workers from abroad. Not only management tasks but also commercial activities are performed by the so-called expatriates. As a rule, welding work is carried out by workers from countries such as India and Pakistan. Manual metal arc welding is utilised as the standard processes while gas-shielded metal arc welding is still largely unknown.

In any case, there is currently a trend amongst the natives to do something for their country and to get involved in the economy. Thus, vocational training has not played any role amongst the affluent population until now – this is changing slowly. Together with „Deutsche Gesellschaft für Technische Zusammenarbeit" (German Society for Technical Cooperation), the country is setting up vocational colleges at the moment in order to qualify "nationals" too.

Here, DVS and GSI can make a contribution to personnel qualification and can support companies in situ by offering practical training. Furthermore, GSI intends to check correspondence courses as well as lectures about joining technology at the universities. The basic training of joining technology specialists for the region continues to be carried out in the neighbouring countries.

One year of cooperative welding technology work in the Baltic region

In December 2010, the DVS Expert Group for the Baltic Region held its annual general meeting as well as an accompanying specialist seminar entitled "Mechanisation and automation in small and medium-sized enterprises". At the moment, the group has 50 members from Belarus, Russia, Lithuania, Latvia and Estonia. The objectives of the initiative are to promote the development of joining technology in the Baltic states and to incorporate the region into the DVS work.

In the first year, a few specialist events have already taken place in the Baltic region. For example, 80 participants from around 120 registered steel and metal construction companies in Estonia attended an event about the new DIN EN 1090 standard. Moreover, there was an initial exchange of experience with regard to welding technology training in Riga. The expert group has translated one issue of the DVS information sheet "Der Schweißer" (The Welder) into Russian and another issue is planned. Furthermore, the sales of the Russian-German technical dictionary from DVS Media are being supported and an independent Internet appearance within the framework of the DVS homepage is being planned.

The highlights in the year covered by the report included the ongoing training of welding shop foremen, instructors and supervisors at the DVS training establishment "Rigas 3. Arodskola". It was the third event according to the DVS 1154 guideline and took place with the support of the DVS federal state branch in Mecklenburg-Western Pomerania and SLV Mecklenburg-Vorpommern.

During the podium discussion, the Executive Committee and the speakers made themselves available to answer the questions asked by the participants.

Trends in global energy demands

Introduction

The energy consumption is steadily growing and it must be met by continuous expansion of power generation with careful consideration of the lowest possible negative impact on the environment. Welding, which is one of the most important manufacturing processes, must offer high and consistent quality and productivity in a safe working environment. There are several different energy sources to use but the renewables must have the highest priority such as hydro, wind, wave, geothermal, tidal, and solar and biomass. Green light has been given in several countries for expansion of the nuclear power, which will be asking for efficient and reliable manufacturing processes. Another area getting high attention from an environmental point of view is the automotive industry. The weight of cars must be lowered in order to reduce the fuel consumption and hence the CO_2- emission.

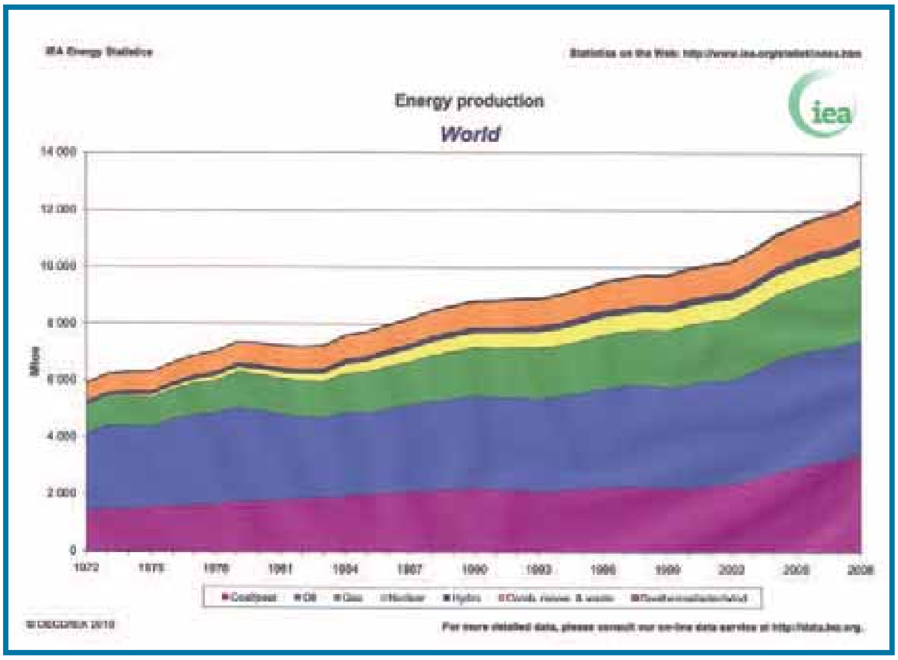


Fig. 1. *Global energy supply 1971-2007.*

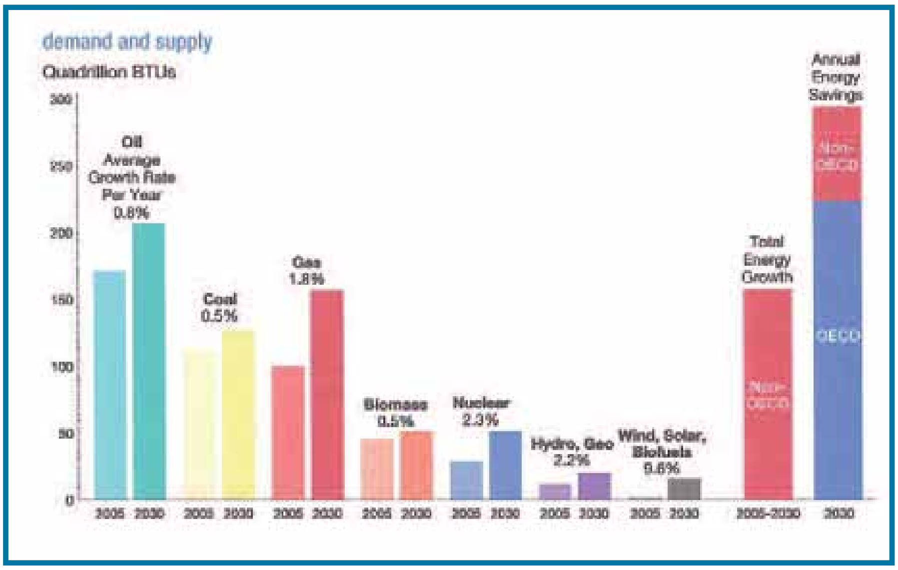


Fig. 2. *Annual increase in % for different energy sources and what savings are expected to be achieved by improved efficiency.*

Increased power consumption and supply

Coal, gas and oil are the main energy sources close to 85% while wind power supply 2007 was as low as 0.7% (Fig. 1). It can be compared with 5.9% for the nuclear energy. The energy consumption will have an annual increase with 1.2% or 35% higher in 2030 than in 2005. Coal, gas and oil will remain to be the main energy sources but one of the most important "fuels" will be saved through improved efficiency (Fig. 2), which is about twice the growth in global energy demand through 2030. Fig. 2 shows also that wind, solar and bio fuels will have the highest annual increase with 9.6%. The future of energy is directly linked to the future well-being and prosperity of the world's people.

Energy consumption is increasing annually with 1.2% or 35% higher in 2030 than in 2005. A BTU (British Thermal Unit) is a standard unit of energy that can be used to measure any type of energy source. We see a tremendous challenge: how to meet the world's growing energy needs while also reducing the impact of energy use on the environment.

No single fuel can meet our energy challenges. To satisfy projected increase in global energy demand to 2030 – and ensure reliable and affordable energy to help meet our interlocking social, economic and environmental challenges – we will need to expand all economic fuel sources through 2030. Technology will play a key role. Many do not realise the energy already is a high-tech industry. New innovations and improvements in energy technology continue to advance the potential for all sources of energy.

Oil and gas exploration and production

Oil and gas together with coal will remain to be the main energy sources. New sources both on-shore and off-shore are searched all over the world. There are many huge projects to meet the increasing demand of energy. In Europe we have three major gas pipeline projects: Southstream, Nabucco (Fig. 3) and Northstream. Russia is already supplying one fourth of EU gas import and is planning to increase this share by realising the Southstream project. This pipeline will avoid passing through risk

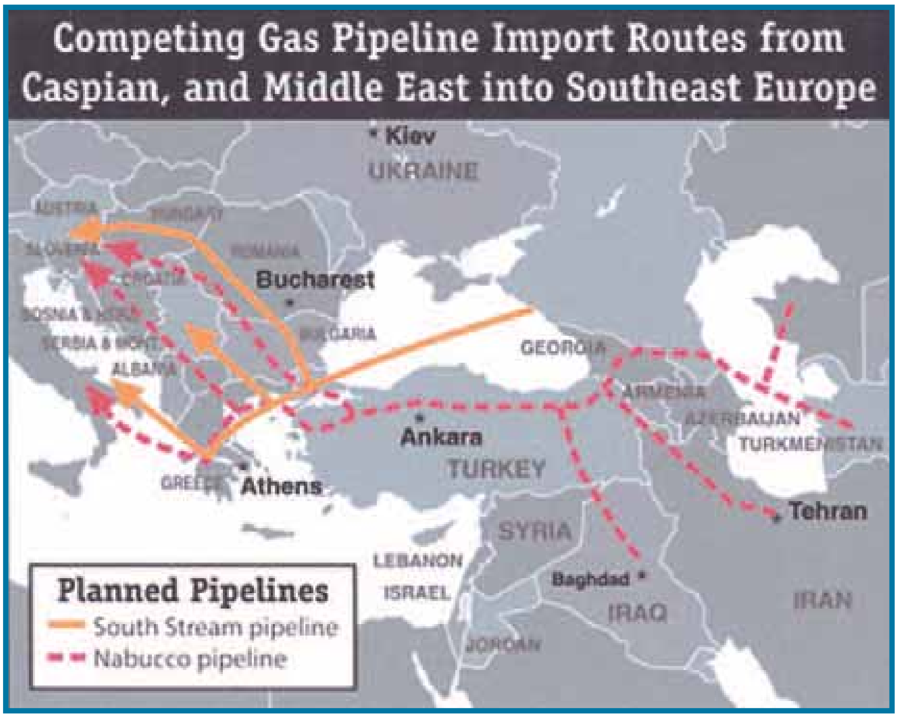


Fig. 3. Planned pipelines into southeast Europe.

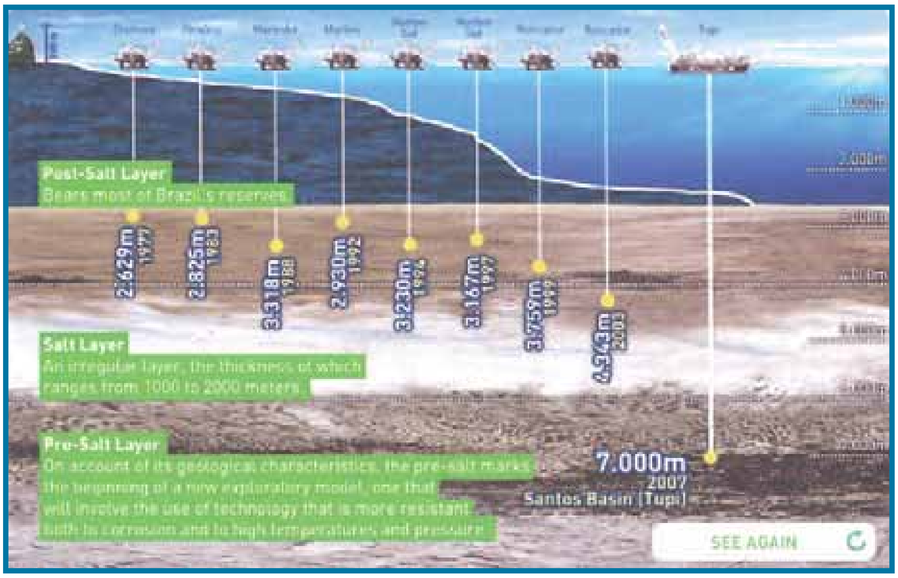


***Fig. 4.** Oil deposits and drilling depths in Brazil incl. the largest project Santos Basin (Tupi).*

countries Ukraine and Belarus. The Southstream and Nabucco projects are estimated to cost together162 billion SEK (approx. 18,4 billion Euro).

The Nabucco pipeline project is financially supported by EU in order to be less dependent on Russian gas supply. The controversial Northstream project covering two parallel gas pipelines 1,220 km under water from Viborg/Finland to Greifswald/Germany is just constructed. The cost for it is estimated to 8,5 billion Euro. Another impressing project in Santos Basin (Tupi) is running in the sea 300 km outside Rio de Janeiro, Brazil (Fig. 4). The drilling depth is close to 7,000 m. This is the largest oil deposit discovered by Petrobras in Brazil. It is planned to be in full operation in 2017.

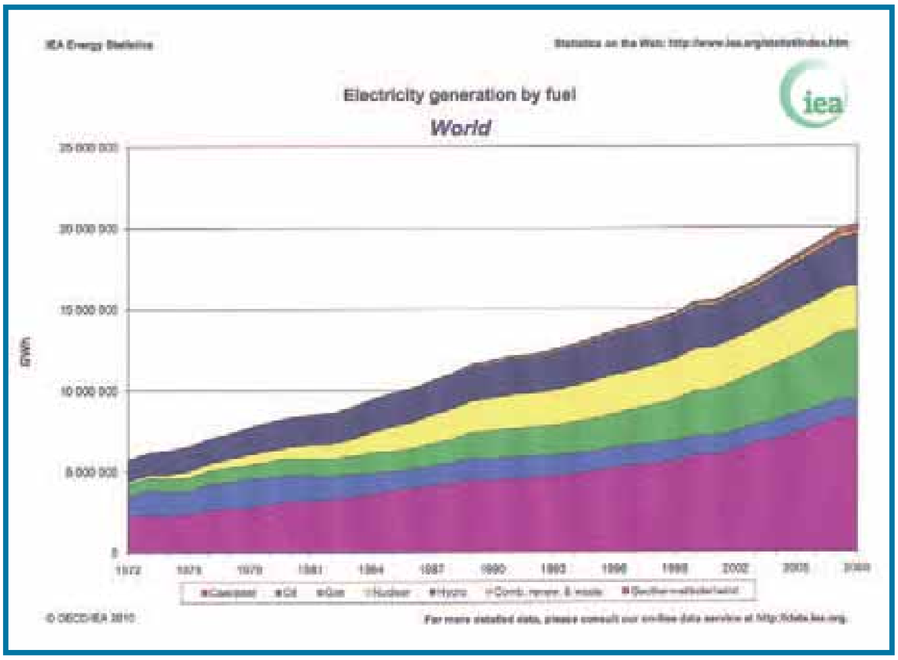


Fig. 5. Electricity generation by fuel.

Table 1. *Global distribution of wind power installations.*

Country	GW	%
US	35,159	22,3
Germany	25,777	16,3
China	25,104	15,9
Spain	19,149	12,1
India	10,926	6,9
Italy	4,85	3,1
France	4,492	2,8
UK	4,051	2,6
Portugal	3,535	2,2
Denmark	3,465	2,2
Sweden	1,560	1,0
Norway	0,431	0,3
Finland	0,146	0,1
Rest of the world	19,254	12,2
Total capacity	**158**	**100**

Electrical power capacity

Fig. 5 shows the electricity generation by fuel. Demand will be practically intense for electric power generation, which comprises 40% of the global energy need by 2030. It is fully understood when knowing that about 1,5 billion people – a quarter of the world's population – lack access to electricity.

Nuclear power

Nuclear power is produced mainly in USA, Europe and Japan. China (11) and India (18) have currently a few number of operating reactors. There are totally 439 reactors in operation in 30 countries. It represents about 14% about of the global electricity generation. Another 56 reactors are under construction, 136 planned and 299 proposed. China only stands for 25 to 35% all of these. The Finnish government decided in June 2010 that building of another two reactors can start with the objective to have these in operation by 2020. Some countries are very dependent on nuclear power, which is illustrated in Fig. 6.

The average age of European nuclear reactors is today about 25 years to be compared with the Swedish ones with 30 years. Methods are discussed to extend their lifetime to up to 60 years and at the same time increase the output power. Long-term planning for electrical power generation is extremely important as it takes 5 to 8 years to build a nuclear power reactor and other years to get construction permit and design it. The talking points for expansion of nuclear power are:

1. Environmental advantage – neglectable CO_2 emission and small environmental impact.
2. Safe supply – small amount of fuel, which is supplied from stable countries.
3. Cost efficiency – low and stable costs.
4. Possibility to restrict, legitimate demand and monitor.
5. Knowledge base and infrastructure is available.
6. There is a sustainable continuation to develop next generation IV.

There is somewhat of a contraction to the list above when reading other articles about the required materials. The future reactors will work with higher temperatures, have higher

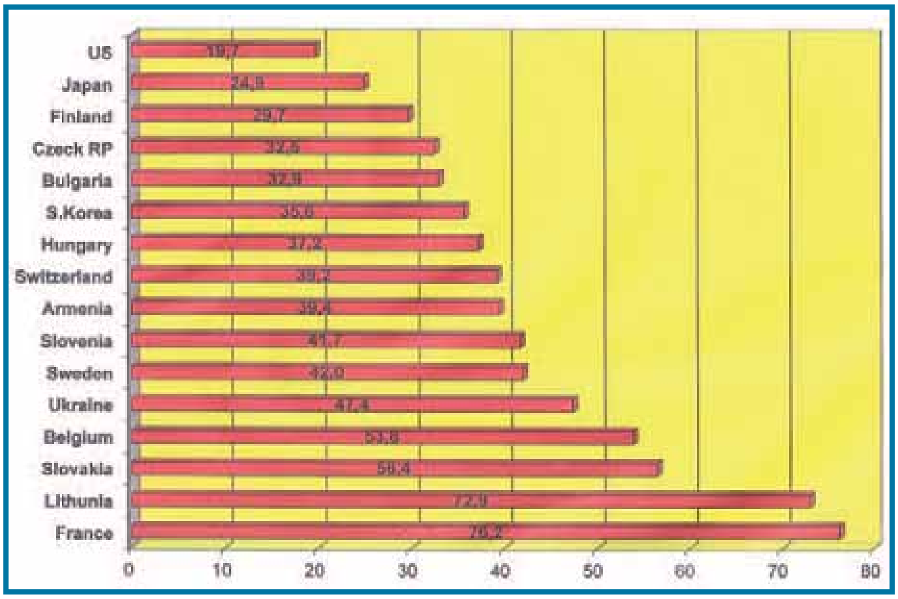


Fig. 6. countries are very dependent of nuclear power.

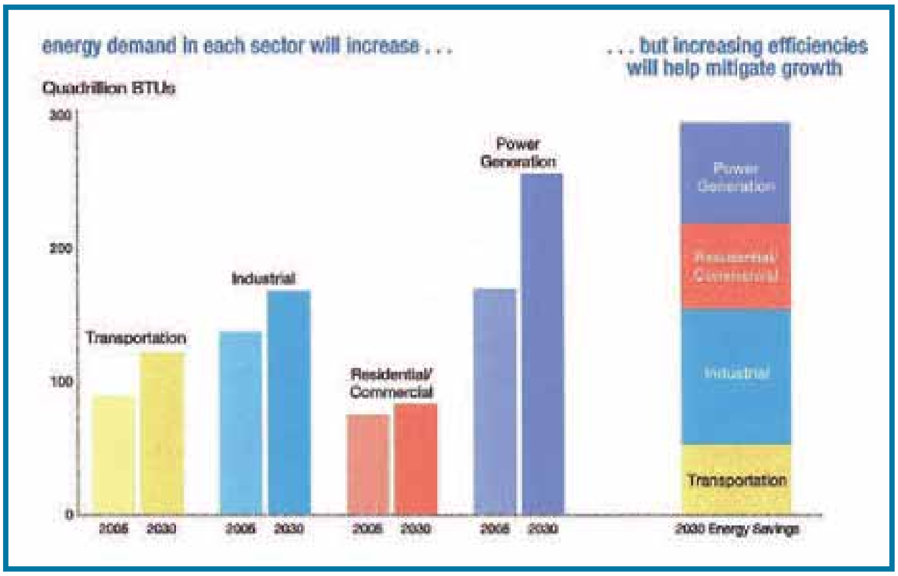


Fig. 7. Energy consumption in the four main end-use sectors.

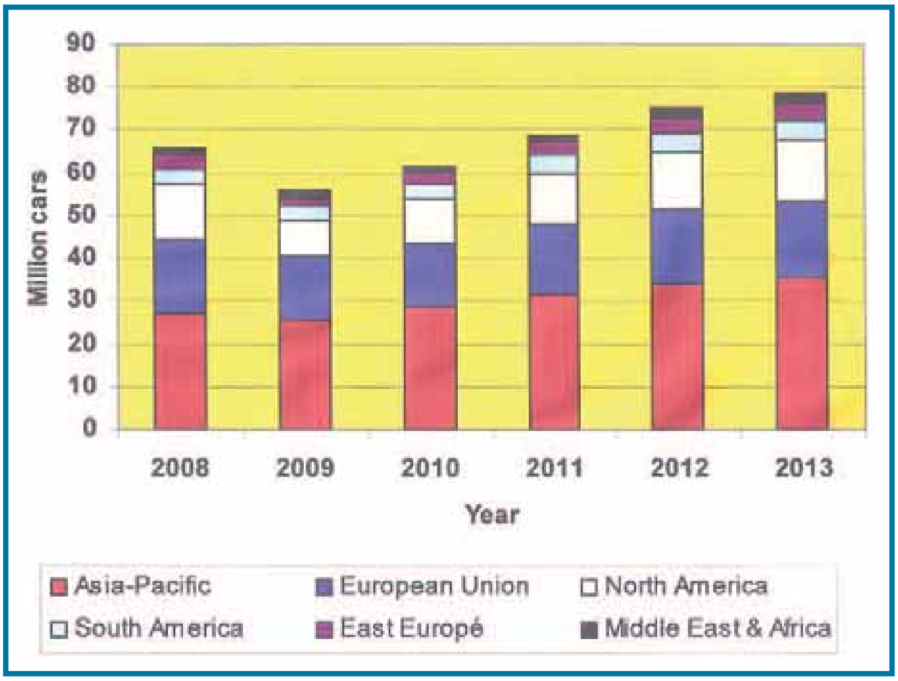


Fig. 8. Number of assembled cars in different regions.

radioactivity, be more corrosive, have more wear but still have longer lifetime. The future will show which statements are correct.

Wind power

Out of all energy sources the expansion of wind power generation has the highest growth (close to 10% p.a.) from a low level. Table 1 shows the global distribution of wind power installations.

2009 the wind power generation with 1,419 towers represented less than 2% of all electrical power in Sweden. The objective is 20% by the year 2030. The world's wind power capacity grew by 31% in 2009, adding 37,5 GW to bring total installations up to 158 GW. A third of these additions were made in China, which experiences yet another year of 100% growth.

Hydro power

There is no doubt hydropower can play a significant role in meeting many environmental goals, including climate change.

It is the world's most important source of renewable energy. In our increasingly carbon-constrained world, renewable energy forms, such as hydropower, have the potential to meet the sustainability criteria demanded of our times. World-wide, 18% of all electricity is generated by hydropower with an annual increase of 2,2%. Hydro power is the leading source of renewable energy. It provides more than 90% of all electricity generated by renewable sources. Other sources including solar, geothermal, wind and biomass account for less than 10% of renewable electricity production.

Other energy sources

Use of solar, geothermal, tidal and wave power will certainly grow but from almost a zero level. There are few pilot projects:

- ☐ This summer (2010) Europe's largest solar power station will be built for electricity supply to 17,000 households in Italy.
- ☐ In England there are plans to build the first geothermal power plant with a capacity of 3 MW corresponding to the needs of 5,000 homes.
- ☐ There is still only one large scale commercial tidal power station in the world – La Rance Tidal Power Plant in Brittany, France. This currently generates 240 MW of power and has been in operation for over 30 years without mechanical breakdown.
- ☐ The first commercial scale wave-power installation Pelamis has been successfully installed three miles off the northern coast of Portugal.

These energy sources are still in an emerging phase and will only be applied in niche markets.

Energy consumption in different sectors

Regarding the four main end-use sectors (Fig. 7), the biggest demand for energy comes from electric power generation – a fact that might surprise some people, who may think that transportation is the largest. By 2030 the power generation sector will account for about 40% of the total primary energy demand and its largest energy source will continue to be coal. In each sector, demand would be growing much faster without improvements in efficiency.

Car industry has major challenges

Stricter petrol mileage requirements may be a headache for car manufactures, but the aluminium industry views them as good news. In 2009, the aluminium content reached 8.6% of the average vehicle curb weight, continuing almost 40 years of uninterrupted growth. Over the next 10 years, the worldwide auto aluminum content is projected to grow 28 to 30 billion pounds per year – currently 16 to 17 billion pounds – not taking scrap and spare parts into account. For instance, the 2010 Chevrolet Corvette is a strong example of automotive work improving vehicle safety while delivering ultimate performance.

The steel industry is combating the aluminium use with high strength steel (AHSS). The use of AHSS in an average car is forecasted to grow from currently 68 kg to 204 kg by the year 2020. We are noting a similar trend for the use of plastic from 40 kg in Volvo 140 (1970) to 200 kg in Volvo V70 (2010). Another strong trend is the move of assembling and also manufacturing of cars to the growing market in Asia and specifically China. Fig. 8 shows the changes.

Number of assembled cars in different regions

The capacity today (2010) is about 89 million cars to be compared with the forecasted number of 61 million assembled. The large overcapacity will certainly end up with closures of factories in mature markets e.g. Western Europe and USA. This industry sector is extremely competitive. Hybrid electric vehicles (HEVs) are the new buzz in the car market, which is forcing car manufactures to make major investments in new technologies, often financially supported by state governments.

Challenging welding tasks

The welding operations in the energy sector are extremely demanding and in many cases 100% of all welds must carefully be non-destructive tested. Often all welding parameters must as well be registered and at the same time high productivity must be achieved. There are for instance narrow gap welding heads marketed for joining of thick walled pressure vessels e.g. for nuclear power stations. The head can accept an almost parallel joint ranging in width from 18 mm and in depth down to 350 mm. Welding of wind towers has currently a two digit annual growth and these applications are demanding high deposition rates and powerful manipulators.

In the automotive industry laser welding has become a common process and as important as robotised arc and resistance welding has been for years. Friction Stir Welding is today often applied in the aircraft industry, while the FSW process is judged to become important for joining of cars.

Summary

- ☐ The future of energy is directly linked to the future well-being and prosperity of the world's people.
- ☐ Expanding access to energy – and the opportunities it affords – should be a shared global goal.
- ☐ Our energy and environmental challenges are intertwined and their scale is enormous.
- ☐ Welding is an extremely important manufacturing process for the expansion of the energy supply.

Bertil Pekkari, Floda/Sweden

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WJS News

The Newsletter of the Professional Division of the Welding Institute · March/April 2011

Editorial

Career Management – whose job is it anyway?

Growing up in the East Midlands' coalfields, the vast majority of boys expected to work down the mines when they finished school and many of the girls expected to go into administrative jobs or work in local factories. We had a careers teacher but it only seemed to be a part-time responsibility; he was less enthusiastic about being at school than we were and he had little idea of career options beyond the obvious. I do remember having to complete a questionnaire that was used to feed a computer programme, which all sounded very impressive in the days when computers with less processing power than a modern notebook PC filled an entire room. However, the yard long printout listing possible careers based on an analysis of my preferences was less inspiring than the careers teacher.

At school, one of the people who influenced my choice of career was a visiting technical drawing teacher who brought real-world industrial applications into the classroom. More effective career guidance at school may have made my career progression more efficient but I remain eternally grateful to the inspirational people who nudged me in the right direction at the right time. Now, as then, youngsters' experience of work is mostly gained through the messages they receive from family, friends and teachers but the people they listen to most are their peer group. For the sake of our young people and for the sake of our industry, it is more important than ever that we help to provide them with the options and the information to enable them to choose a career that will be exciting and rewarding.

On your behalf, The Welding Institute supports and contributes to E4E (www.educationforengineering.org.uk), the mechanism through which the engineering profession offers coordinated and clear advice to UK Government and the devolved assemblies. In welcoming the proposal by John Hayes MP, Minister of State for Further Education, Skills and Lifelong Learning, for the formation of an all-age (13yrs+) independent careers service, E4E has also issued a policy statement that includes five recommendations to Government for improving the way careers education, advice and guidance is delivered and provided in schools and colleges:

- A statutory entitlement for young people in England to receive lessons in careers education as part of Personal, Social and Health Education.
- The need to demonstrate competence in the teaching of careers education as part of the professional standards for qualified teacher status.
- The use of real-life science and engineering examples in lessons with careers awareness embedded in the curriculum.
- Improved access to local and national labour market information for schools and colleges and closer links with employers.
- Specialist science, engineering and technology advisors in careers advisory agencies – echoing the recommendations of the careers profession taskforce.

Dick Olver FREng, Chairman of BAE Systems and Chair of E4E said, "Young people often do not make the connection between the mobile phones they use or the computer games console they play on a daily basis and the the engineers who created them." He continued, "We need to better inform our children and young adults about the value of engineering and the exciting career opportunities an engineering background can afford. Better careers education in schools and an improved, professional, independent careers service that advises young people of the many routes into engineering will improve this situation. We must make sure that young people are fully informed about the exciting opportunities afforded by a career in engineering, so that we will be able to meet the growing needs of our industries as we continue to re-balance the economy."

To supplement the efforts of the careers profession, The Welding Institute has an active engineering outreach programme that aims to deliver five major events for young people this year. We will be taking the 'Welding with Chocolate' experiment to Big Bang, the young scientists and engineers fair (www.thebigbangfair.co.uk) in March, and to the skills zone at WorldSkills 2011 in October, plus two other regional events. We are also firming up plans for an apprenticeship information day at TWI Cambridge, to be staged around the UK Finals of the BOC Apprentice Welder Competition. The Younger Members' Committee also has a programme of interaction with schools and colleges and a number of the committee members intend to become STEM Ambassadors this year. Your support is essential in all of these activities to ensure that the correct message is delivered in the best possible way, and that contacts are made that can support and guide school and college leavers into exciting careers.

What about career management after gaining employment? Ultimately, you are your own career manager but we all need support to find new opportunities, to be encouraged to take further qualifications or gain new skills, and to be coached and mentored to the point that we are ready to move up to our next position. The Welding Institute and the Welding and Joining Society provide a network of contacts with a keen interest in your industry sector and committed to furthering the profession and its personnel. Your engagement with the Institute, its members, and its events and activities can enable you to create and deliver a personal development plan that will turn your aspirations into a rewarding career. From role-specific CSWIP certification that will assure your competence to perform in your new role, through gaining recognition of your qualifications, skills and experience to become a registered Engineering Technician, Incorporated Engineer or Chartered Engineer, your professional development plan should be a route map to success.

And don't forget your commitment to lifelong learning. Continual Professional Development (CPD) is all of the learning that maintains, refreshes and extends your knowledge. Reading journals, attending seminars, contributing to committees all add to your knowledge and keep you up to date with developments. To retain your registration and renew your certification, it is essential that you record and submit evidence of your CPD (see http://www.twiprofessional.com/professional/index-development.jsp). You are your own career manager but we will do all we can to support you in achieving your aspirations.

If you would like to know more about career development, please visit www.twiprofessional.com or call The Welding Institute Porfessional Division via +44(0)1223 899000.

Eur Ing Chris Eady BSc(Hons), MSc, CEng, MRAeS, MWeldI

The Welding Institute sadly reports that Sir Bernard Crossland and John F Lancaster passed away in January 2011; both were eminent Honorary Fellows of the Institute.

Sir Bernard Crossland began his career as an engineering apprentice with Rolls-Royce and through part-time study gained his PhD from University of Bristol in 1953.
Sir Bernard was a former Pro-Vice-Chancellor of Queen's University, Belfast and had an international reputation as a research pioneer in high pressure engineering and explosive welding. He was perhaps best known for his role as an expert investigator of national accidents but was also a powerful advocate of strong integration between industry and education.
He served as an expert investigator of several tragic accidents, the most noteworthy of which was the King's Cross Underground Fire in 1987, for which he headed up the scientific committee that established the unique nature of the fire and made recommendations to prevent such a tragedy from occurring again. He also chaired the Public Hearing following the Bilsthorpe Colliery roof fall in 1993, and played an active role in investigation of the Ramsgate walkway collapse, the destruction of a major liquid gas plant in Qatar, the Southall high speed train crash and the Ladbroke Grove rail crash.
Sir Bernard lectured and published extensively throughout his career, and published his memoirs, "The Anatomy of an Engineer", in 2006. He also served on and chaired several government committees across the UK and received many awards in recognition of his service to his profession and to higher education.
As well as an Honorary Fellow of The Welding Institute, Sir Bernard was a Fellow of the Royal Society, a Fellow of the Royal Academy of Engineering, a member of the Royal Irish Academy and president of the Institution of Mechanical Engineers from 1986 to 1987. In 1987 he was made a Freeman of the City of London and in 1990 he was knighted for services to education and industry. In June 2009 Sir Bernard was awarded the Royal Academy of Engineering's Sustained Achievement Award.
John Frederick Lancaster's career in metallurgy spanned nearly fifty years. He had been a member since 1948 and was internationally acknowledged as one of the world's leading authorities in the field of materials and welding. His book 'The Metallurgy of Welding' serves as an invaluable reference for metallurgists, welding engineers and designers. It contains virtually all the information and guidelines engineers need to maximize the structural integrity and corrosion resistance of the full spectrum of welded materials and remains an indispensable hands-on reference and working companion for mechanical engineers and metallurgists.
John Lancaster had extensive industrial and academic experience in welding metallurgy. He worked at the APV Company on the welding of non-ferrous metals and stainless steel and later with M W Kellogg, where he was concerned with the fabrication of refinery and petrochemical plant using carbon and low alloy steel. He was Visiting Professor at Aston University from 1971 to 1976 and in 1980 was appointed Guest Professor at the University of Tientsin in China.
John served as TWI Vice President and President from 1967/68 and also served on Council, Professional Board and F&GP Committee.

Deceased

Name	Grade	Years in Membership
Dennis Lomer CBE	Hon Fellow	
Sir Bernard Crossland	Hon Fellow	
John Scott Allen	Fellow	60
N R Blount	Fellow	38
Prof. John Frederick Lancaster	Hon Fellow	63

Eastern Counties

Loyal Service Award presented to Ray G Butcher on the nineteenth of January 2011 at the Eastern Counties Branch AGM

Citation

In 1981 Ray came to a Branch meeting and was immediately seconded onto the committee. Since then he rarely missed a committee meeting and seldom a Branch event. When needed Ray would take the Chair our meetings.

Ray Butcher (left) receiving his Loyal service award from Eastern Counties branch Chairman Peter Brace

A loyal and working committee member, Ray has given good advice, useful suggestions and has taken on the organisation of numerous events. His contacts in the industry have been most useful in promoting Branch activities. When Air Products had a facility in the region Ray was instrumental in arranging a committee meeting venues with them.
More recently his input has been vital to the continuation and smooth operation of our annual golf tournament, that has, in this its 25th year, raised over £11,000 for the local Children's Hospices.
Ray has also been an active liaison officer with several of the local colleges where we have held events and provided awards.
Ray worked in the welding sales and support sector and to his clients throughout our region he always strongly promoted the Welding Institute and has been an excellent ambassador. We also recognise his work in the local community, particularly with youth football teams.

New members

NAME	STATUS	ENG C	BRANCH
Chin Sow Pang	Member	CEng	Overseas
Amites Sarma	Member	CEng	Overseas
Chiraz Ennanceur	Member	CEng	Eastern Counties
Chen Fun Wee	Member	CEng	Overseas
Richard Shepherd	Member	CEng	London
Lijuan Shang	Member	CEng	Eastern Counties
Carl Hauser	Member	CEng	Sheffield
Mario Celant	Member	CEng	Overseas
Guiseppe Di Crisco	Member	CEng	North Scottish
Paul Sidebotham	Member	IEng	Manchester
Lawrence Barboza	Graduate	Interim CEng	Manchester

Eastern Counties branch

The use of refractory metal tooling for friction stir welding of steel and non-ferrous metal
C E D Rowe (Cedar Metals Ltd) and Dr W M Thomas (TWI)
Wednesday 19 January 2011

David first outlined the principles of Friction Stir Welding (FSW), a technique invented at TWI in 1991 by Dr Thomas. It is now a well-established method for the solid state joining of aluminium and copper and has over 211 user licensees. However, the challenge is to FSW steels and titanium alloys.
When welding aluminium alloys FSW has a number of benefits, such as:
• Joining alloys which are difficult to fusion weld
• Distortion and shrinkage are low, even in long welds
• Mechanical properties and quality are excellent
• The process is energy efficient and there is no fume, porosity or spatter
The process has some limitations, for example:
• A backing bar is generally required
• A keyhole is left at the end of each weld
However, there are techniques for addressing each of these problems.
The tool, which the key to the operation of the process, must be:
• Strong and torque resistant at working temperature.
• Wear resistant and resistant to creep at welding temperatures.
• Of a material that can be machined/processed to complex profiles.
• A good friction couple with material being welded
These requirements lead to a list of desirable tool properties. These include:
• Good thermal conductivity (for heat removal from weld zone)
• Resistance to oxidation (to avoid the need for shielding gas)
• Be reasonably priced and readily available
• Be non-hazardous during production and use
• Material batch consistency to ensure consistent welding performance
• Resistant to cracking at ambient and welding temperatures
To FSW steels, which are harder and have higher melting and hence softening temperatures than the aluminium alloys, harder higher melting point tool materials are required. To address these issues Mr. Rowe reported on studies where refractory metals and their alloys were used to make FSW tools.
He discussed the use of:

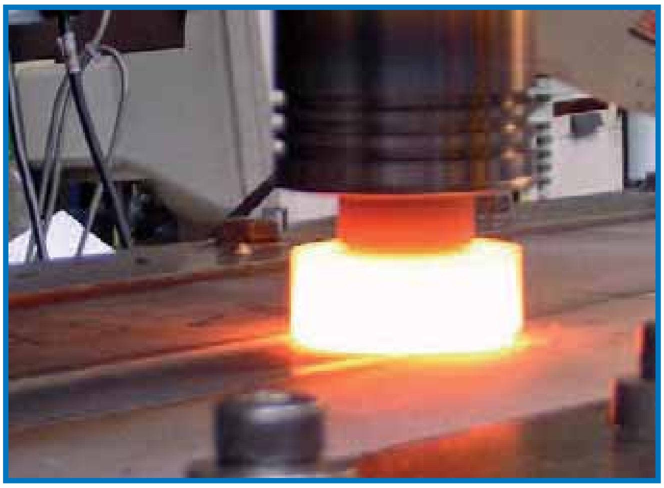
Molybdenum alloys, which proved not suitable for FSW of steels, but may be a cost-effective alternative to expensive tool steels currently used for welding aluminium alloys.

Tantalum alloys which gave some success. The Ta10W alloy may make a good shoulder material for the tool. While these alloys were suitable for aluminium welding, molybdenum is a cheaper alternative.
Tungsten alloys, proved to be the most suitable for the welding of 12% Cr stainless steels and some excellent samples were viewed.

Composite materials In general, these involved making the probe of one alloy and the shoulder of another. For example, a tool with a lanthanated tungsten body and probe together with a tantalum 10% tungsten alloy shoulder. Surface treatment of the tools by carburisation and/or nitriding or ruthenium plating also helped improve tool durability. Composite tools can be refurbished.

Ceramic tool materials
Polycrystalline Cubic Boron Nitride (PCBN), is being promoted in the USA by MegaStir Inc. The PCBN is pressed and sintered under high temperatures and pressures to near net shape followed by diamond grinding to finished profiles.
This ceramic appears to be the best for wear resistance and weld quality but the tools are of high cost and tend to be brittle. They also need precise set-up and process operating parameters to avoid damage. Once damaged, they cannot be refurbished. MegaStir Inc. has also developed a composite tool combining W-25Re for ductility strengthened with PCBN for wear resistance. It is reported to have increased tolerance to poor set-up and process parameters and offers a longer life compared to PCBN, W-Re or W alloys. This work is still at the development stage.

Future developments
Cedar Metals Ltd is promoting studies in various areas. With tungsten alloys, studies are examining ways of altering the crystal structure of the tungsten alloys to reduce the effect of recrystallisation embrittlement, which occurs as the alloys cool from welding temperatures. Also the addition of Hafnium Carbide (HfC), the hardest



carbide available, is being examined as a means of increasing wear resistance.
Always the aim is to produce reasonably priced tools to bring FSW of steel to general fabricators,
A lively question and discussion session followed this most interesting presentation.

John Weston

London branch

December 2010
A lifetime of advanced design and manufacturing technology - 1966-2009
Gerry Francis, Metallurgist and Materials Consultant

The meeting of 24 December was held at the offices of CB&I Ltd., 40, Eastbourne Terrace, London on the 9th of December 2010 and I am indebted to Charlie Barraclough for the following report.
Gerry was introduced by Geoff Clarkson of CB&I. His presentation included aerospace technology, including Concorde, communication satellites and guided weapons, oil and gas technology including refineries and chemical plants and offshore rngineering of natural gas production fields as well as innovations, process and chemical plant and hydrogen production
Gerry first discussed the materials and fabrication of the BAC Aerospatiale Concorde.
The aerospace structural materials were based mainly upon Aluminium alloys [AL –Cu] 2024 T6 strengthened by precipitation of non metallic particles during heat treatment. This meant that fusion welding could not be used for strength parts of a structure, therefore adhesive bonding with mechanical fastening was the primary means of construction. A cruise speed of Mach 2.0 produces kinetic heating of 1200C which allows aluminium to be used with the trade name RR58. Airframe skins were manufactured by both chemical and mechanical milling of plates and extrusions to produce parts of economic weight and thickness.
Quadrupling the oil price in 1972 proved that Concorde could only operate economically as a first class only mode of transport and the supersonic 'bang' proved to be an inhibitor for flying over land, therefore London to Australia flights were not allowed.
Take off noise was extensive and thunderous, with a low bypass ratio supersonic engine relying on reheat for power boost. The noise therefore could never match that emitted from the new generation of subsonic, high bypass ratio turbofan jet engines of the late 1960s.
Public confidence in Concorde suffered from the fatal crash at Paris. It necessitated extensive modifications to the fuel tanks to prevent any future incidence of debris penetration. There is not likely to be a successor to Concorde for at least 20 years.
The jumbo 747 and super jumbo Airbus's A380 have proved to be the future of passenger airplanes from 1975, rather than supersonic transport. These are manufactured from precipitation hardened aluminium alloys with both copper and lithium additions.
Today's latest high technology aeroplane is the Boeing 787 made extensively from carbon fibre to increase the power to weight ratio significantly by producing a lighter structure. However this plane is some three years late and not yet in passenger service. It will introduce a huge leap in advanced manufacturing technology but a large fuselage in composite material is highly controversial as its mechanical properties are not as easily defined as with metal structures.
The talk was followed by several questions including a discussion of the reasons for the Liverpool Bay pipeline failure (sulphide stress cracking). Joining processes in the aviation industry included riveting (40% of the time to build an aircraft) because the 2024 Aluminium alloy used lost strength when welded. Today friction stir welding permits aircraft panels to be welded for the first time. However, so many of the high technology processes in use today were developed in the 1960s; would today's austerity bring similar advances in decades to come?
A vote of thanks was given by Charlie Barraclough who had worked with Gerry on the Morecambe Bay node castings some 25 years previously; and several members of the audience found that they had trained in the aviation industry in Bristol at the same time, over 40 years ago.

January 2011

The January meeting of the London Branch of the Welding and Joining Society was held on 20 January 2011 at the Henry Holland, Duke Street, London. This was the Annual General Meeting of the Branch followed by a presentation.
Your correspondent was re-elected Chairman and gave thanks to Mike Lawrence, Dan Weeks and Eric Martin, who were re-elected to Programme Secretary, Secretary and Treasurer and whose hard work had contributed greatly to the success of the branch.
The presentation on the subject of TWI and the WJS was given by Lois Appleyard, Manager of the Professional Division of TWI ably assisted by Rachel Wall, Membership Officer and they were introduced by Mike Lawrence.
Amongst the items covered were the direction of TWI in the future; predominantly in reaching out to the young with SkillWeld and 'Welding with Chocolate'; the supply and delivery of services to members and the integration of the professional division with the training and the research sides of TWI.
The lively question and answer session showed the Branch to be particularly concerned with the education aspects of TWI and other organisations and their integration.
Altogether an enjoyable evening was held to mark the end of one successful year and hopefully another successful year to come.

Peter Jackson

Life membership

Name	Grade	Branch	Years in membership
R Loebner	FWeldI	London	43

East Midlands branch

24 November 2010
Joining in dental applications

A lecture by Dr Nigel Bubb, Fellow in Dental Materials, Leeds Dental Institute, The University of Leeds, was given at the Rolls-Royce Club, Derby.

The resumé that Nigel sent discussed the oral environment as being challenging for any material, especially a single material (phase). To be honest the world of engineering materials is pretty challenging, with materials that have to withstand temperatures in excess of 1300ºC and as low as -60ºC, with mechanical strength upwards of 1200MPa, dependant on application.

Given these extremes we wondered just how challenging dental applications could be compared to those in engineering? The lecture given by Dr Nigel Bubb soon exposed our lack of appreciation of the challenges faced in dentistry and the constant, relentless attack teeth are subjected to.

Most people at some time have suffered agonising pain when eating something cold like ice cream or drinking say a hot cup of tea. This pain is probably caused by fluid flow within holes, dentinal tubules, as small as 1µm in the dentine (Figure 1), providing a direct path to the nerve endings in the tooth's pulp.

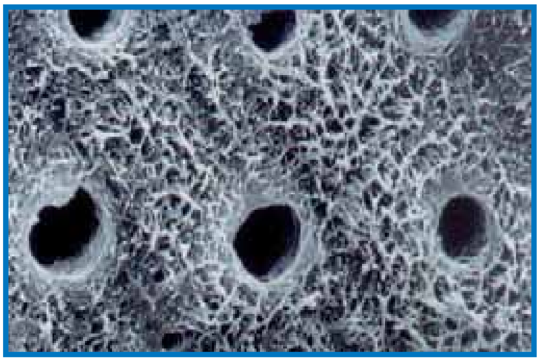


Figure 1 Showing typical holes in dentine, tubules in the order of 1µm in diameter (Courtesy - University of Leeds)

These tubules are exposed either as a result of the destruction of the protective enamel coating or as a result of receding gums (getting long in the tooth). One major destructive mechanism is the Stephen cycle, which describes the drop in pH in the mouth after eating and its subsequent recovery. Once the pH falls below about 4 then the mineral phase of the tooth starts to dissolve.

The Engineering challenges faced by dentistry

The environment	Mechanics
Wet	High forces
Temperature fluctuation	Wear
pH variations	Impact
Biological/disease.	Teeth become damaged or diseased Erosion Hardness.

What does nature do

Nature restricts the use of materials and provides a type of dental composite. Teeth, like bone, are formed from a mineral and organic composite. The mineral, being aptly named, apatite and the organic phase being collagen. Apatite is principally calcium and phosphorous arranged in a hexagonal structure with either OH- or F- at its centre.

During tooth formation, two distinct layers are laid down: enamel and dentine. The enamel is more highly mineralised and laid down in laminates, thus increasing its strength, wear resistance and toughness, trying to ensure that great lumps don't chip off during normal use. This is supported on the tooth by a less mineral dense layer, dentine.

The teeth are then set in bone via a kind of flexible bungee chord known as a periodontal ligament, which is formed from collagen. Teeth are therefore able to move slightly, and resist food becoming trapped and they also have self-repairing properties.

All this is bathed in saliva, which washes the teeth and transports a therapeutic cocktail of materials, which enables a complex self-repair process. It is this process that keeps in check the destruction caused during the Stephen cycle.

What have we done - Mechanical attachments

Historically repairs to teeth such as gold inlays, crowns and bridges have been carried out using a variety of relatively crude mechanical attachments such as pins and bands (basically gold rivets and straps). The earliest examples known are credited to the Etruscan's and date from 700BC, Figure 2. These examples took either human or animal teeth and mounted them in a gold band which was used to 'connect' to surviving teeth in order to bridge a gap caused by missing teeth. This technique was still being used well into the twentieth century, though synthetic teeth were deemed more acceptable.

Figure 2 - Etruscan bridge Science museum London

Again relatively crude, mechanical methods are used to join the restorative materials used for crowns and fillings. For crowns a simple taper of a few degrees is used (Figure 3), after the damaged tooth material is removed the remaining healthy tooth matrial is shaped to form the crown preparation.

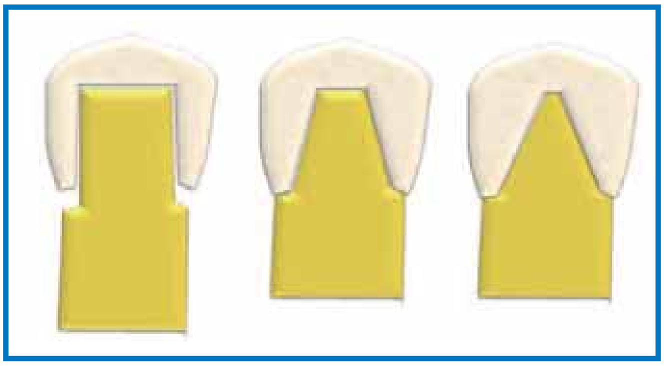


Figure 3 – Tapers - adapted from: Paul Franklin

If the preparation were to have parallel sides (or under cut), then the crown would not be able to be placed. If the angle were too obtuse then the crown would easily be knocked off.

Crowns are bonded to the tooth using thin weak lutting cement such as zinc phosphate.
This cement is rigid and does not provide a chemical Bond. A more modern cement such as zinc polycarboxylate is more compliant and forms a more resilient bond.
Whereas for fillings an undercut is required so as to form a dovetail joint.
The successful crown preparation should look something like that shown in Figure 4.


Figure 4 – Typical crown preparation (adapted from: Paul Franklin)

Some of the problems associated with crowns include:

- A sufficient gap around the tooth is required for bonding.
- The bonding cement itself (is forced out).
- Weakening of the tooth from producing a taper.
- Accesability around back of tooth when shaping.
- Cosmetic colour match

What do we do now?

Modern restorative techniques have developed with the improvement of materials and the realisation that sound tooth tissue should be retained. As such the modern era of dentistry is using bonded restorations. These make use of the latest generations of bonding agents which physically infiltrate the tooth structure.
In dentine, the material enters the tubules and wraps around any exposed collagen ends: in the enamel it enters the small voids between the crystals. This form of bonding is very effective, but only if moisture is controlled, as the materials are hydrophilic; hence in Figure 5 you can see a blue rubber dam, which keeps the area dry during placement of the restoration.


Figure 5 - Dental composite: (courtesy Paul Brunton)

Dental ceramics
Ceramics have been important in dentistry as a synthetic aesthetic tooth material. Historically, their use historically can be tracked with the development of fine tableware. Though due to deficiencies, mainly low fracture toughness, since the middle of the last century there has been significant independent development.

Lately this has led to interest in glass-ceramic materials, some having superior toughness. However, not all of these materials can easily be made in the numbers of tooth colours and shades needed to aesthetically restore teeth. As such there is a need to join conventional ascetic dental ceramic to these new materials making up a structure that in some crude way emulates the natural tooth structure.

What dentistry might do next

- A biomemetic approach
- Self-healing
- Tissue engineering

There are research programmes on each of these areas throughout the world with some leading work being carried out at the University of Leeds. The programmes seek to take natural processes, augment them and utilise them in regenerative applications.
The East Midlands Welding and Joining Society would like to thank Dr Nigel Bubb

Alan Caborn

An overview of some of the materials issues behind AGR nuclear reactor life extensions and PWR (Pressured Water Reactor) new build

A recent lecture was given by Chris Hamm of British Energy (now existing nuclear part of EDF Energy, London/UK), at Rolls Royce in Derby/UK. Chris started his lecture with an icebreaker or, to be more precise, a picture of the Russian ice breaker ship, "Kapitan Khlebnikov". This was used as an example to give us a stark warning of how global warming is shrinking the polar ice caps and with it the ice flows such as those along the North-West Passage from the Bering Strait to Greenland. This is where these ships operate and if global warming is unchecked icebreakers could be a thing of the past.

EDF, we were told, were playing their part in reducing global warming by looking to new nuclear future builds, other low carbon alternatives and sustainable energy sources. The perception of the UK public is that alternative energy sources such as nuclear power (Fig. 1), although generally accepted as being positive in terms of reducing global warming, are considered a risk.

Risk

To put risk into perspective, we were shown pictures of the well-known 1943 "Liberty" ship, the "Schenectady", which fractured in half just 24 hours out of harbour. Also shown were pictures of a less well known 1954 "World Concord" oil tanker that broke in two, however in this example both parts remained afloat until they collided together. Some risks, however, are perceived as acceptable. This was demonstrated by using the BMA guide to "Living with Risk" that showed the risk of an individual dying in any one-year from various common causes, such as (Table 1):

Fig. 1. Sizewell 'B' PWR (1988-1995). (All photos: courtesy of EDF Energy)

***Table 1.** Risk of an individual dying.*

	Risk
Smoking 10 cigarettes/ day	1 in 200
All natural causes, age 40	1 in 850
Influenza	1 in 5,000
Road accident	1 in 8,000
Playing soccer	1 in 25,000
Accident at work	1 in 43,500
Murder	1 in 100,000
Hit by lightning	1 in 10,000,000
Release of radiation from a nearby power station	1 in 10,000,000

(Source: BMA guide to „Living with risk")

Everyday risks were balanced against examples of radiological risks such as (Table 2):

***Table 2.** Radiological risks.*

	µSv
1 week in Cornwall	100
Dental X-Ray	20
Miner annual dose	1200
Brain scan	5000
135 g bag of brazil nuts	10
1 glass of mineral water daily for a year	65
Return flight to LA	140

1000 µSv = 1 in 25,000 risk of death, the same as playing soccer

(Source: BMA guide to "Living with Risk")

The risk of radon exposure and radon levels in England and Wales was discussed with the aid of a map. The widely publicised high radon levels in Cornwall are well known as being high, however what was surprising were the high radon levels in other areas such as the Midlands.

Overview of British Energy nuclear sites

The British Energy (part of EDF Energy) UK nuclear sites are shown in Fig. 2. Examples of each site were shown and discussed. An overview of British Energy is that they employ approx. 5,500 people and are the largest UK electricity generator, providing 20% of the UK's and 50% of Scotland's energy. The Advanced Gas Cooled Reactors (AGR) detailed on the map in Fig. 2 were constructed between 1958 and 1988.

An overview of the EPR that EDF Energy are intending to build was discussed and Fig. 3 shows Flamanville 3 under construction:

- ☐ Areva design,
- ☐ Pressurised water reactor,
- ☐ 1,650 MW (electrical),
- ☐ Under construction in Finland and France,
- ☐ approx. 350 operating staff.

Operating temperatures of the Advanced Gas Cooled Reactors (AGR)

The overall thermal efficiency of the old Magnox reactors was limited because of their low steam temperatures, see Table 3. There was therefore an incentive to change the reactor type to a higher temperature and more thermally efficient AGR.

The AGR steam pipes, turbines and ancillary plant have similar temperatures as for the coal plant, with 565°C steam. However, AGR's are limited to ~540°C steam and for comparison a PWR has ~285°C steam.

Structural integrity related safety cases

At all temperatures the structural integrity of the plant is critical. But what is structural integrity? Is it "Fit for Purpose"? We were given some examples of structural integrity, which included an early steam train boiler explosion, shown in Fig. 4.

Structural integrity can be defined in many ways, such as: "A structure's uncompromised ability to safely resist the required loads" or: "The science and technology of the margin between safety and disaster".

Failure tolerability of structural components

With the aid of Fig. 5 we were given an overview of the process used to demonstrate failure tolerability of structural components, using a multi legged integrity safety case.

Fig. 2. *EDF – UK nuclear sites.*

Fig. 3. *General view of Flamanville 3 being constructed October 2009.*

Table 3. *Comparison of thermal efficiency across different reactor types.*

Reactor Type	Magnox	AGR	PWR	BWR	CANDU	RBMK
Thermal Efficiency	31%	42%	32%	32%	30%	31%
Primary Coolant	CO_2	CO_2	H_2O	H_2O	D_2O	H_2O
Coolant Outlet Temp.	360°C	650°C	325°C	268°C	305°C	284°C

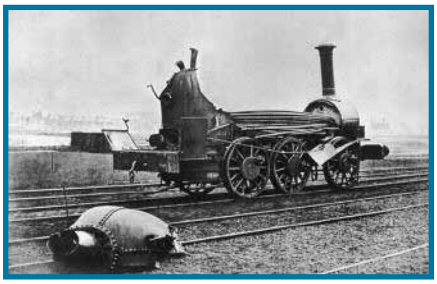


Fig. 4. *Early steam train boiler explosion.*

Structural integrity assessment

Chris explained that there were three main methodologies or codes used within British Energy (part of EDF Energy) for carrying out structural integrity assessments:

- ☐ R3 Impact Assessment Procedures,
- ☐ R6 Procedure – Assessment of the Integrity of Structures Containing Defects,
- ☐ R5 Procedure – Assessment of Structural Integrity at High Temperature.

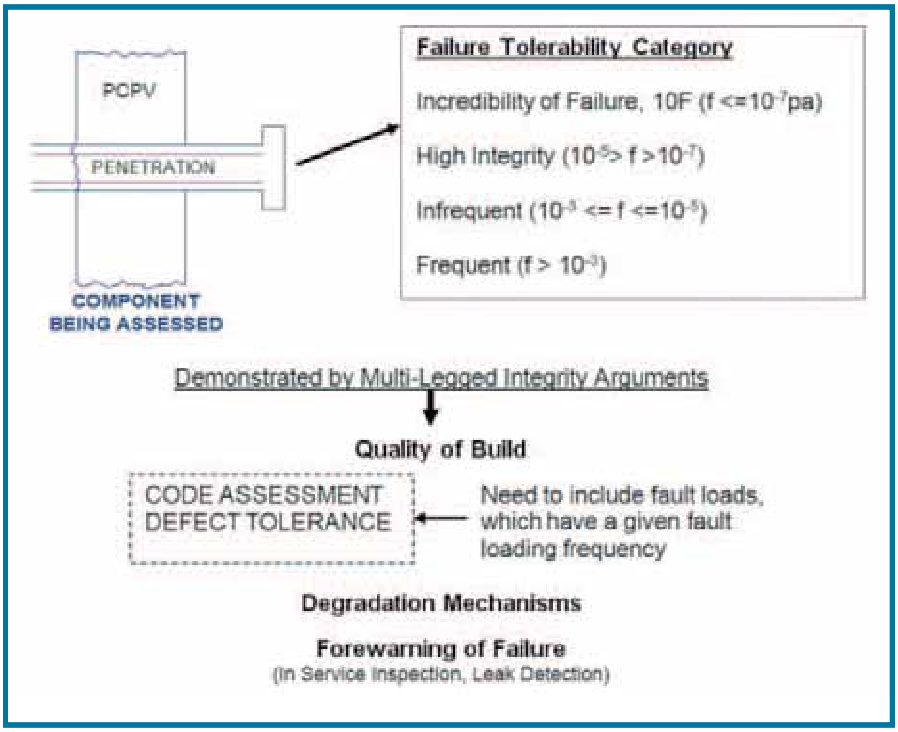


Fig. 5. *Failure tolerability.*

R6 Procedure Summary – This was discussed with the use of a failure assessment diagram that showed two distinct regions – safe and unsafe, with axes representing - crack tip fracture from crack growth and plastic collapse. The R6 procedure can be used for both low temperature and high temperature defect tolerance assessments.

R5 Procedure Summary – This is a high temperature assessment methodology whose inputs include materials properties, degradation mechanisms, defect sizes and service conditions such as load, temperature and geometry. The outputs from this procedure are defect tolerance and remaining life. R5 is the high temperature equivalent of R6 and as such is more complex. Similar methods to R5 and R6 are now covered in national standards such as:

- ☐ British Standard BS7910 (1999),
- ☐ French standard A16 approach,
- ☐ Japanese CRIEPI flaw assessment,
- ☐ US standard API579.

AGR degradation mechanisms

Degradation of the AGR plant also needs to be considered when carrying out structural integrity assessments, Fig. 6. Typical AGR plant degradation mechanisms were discussed in turn and several have been illustrated.

Thermal ageing – degradation mechanism

The effects of accelerated thermal ageing on the tensile properties of a type 347 stainless steel that has been aged to an equivalent service exposure of 650ºC to 675ºC, are shown in Fig. 7.

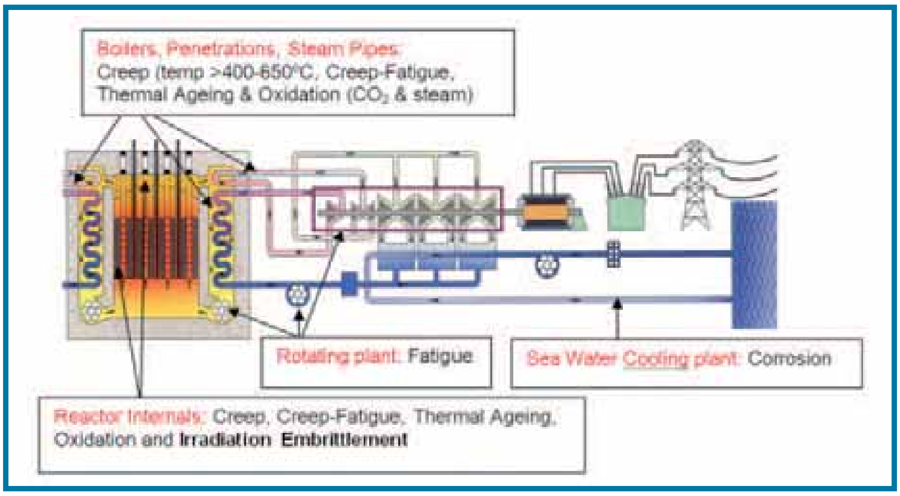


Fig. 6. Showing AGR degradation mechanisms.

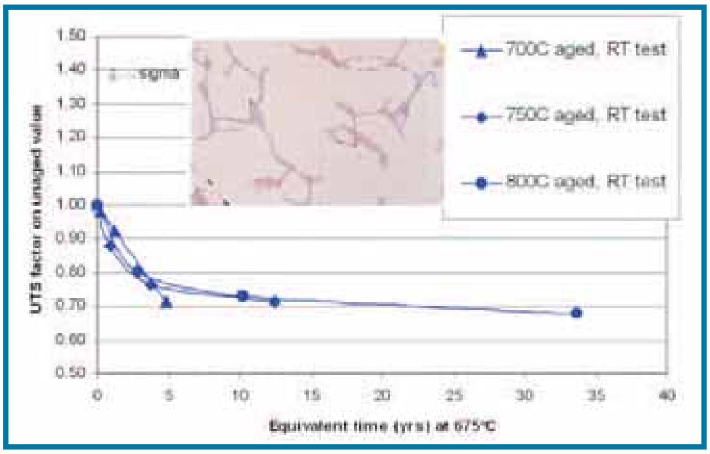


Fig. 7. Example of thermal ageing degradation.

Creep damage and cracking – degradation mechanism

Creep is the tendency of a solid material to deform permanently over time at elevated temperatures under the influence of stresses. Creep was never fully considered in the original design codes, but as can be seen from Fig. 8 it has resulted in a crack initiating. This is why integrity assessment codes such as R5 have been developed.

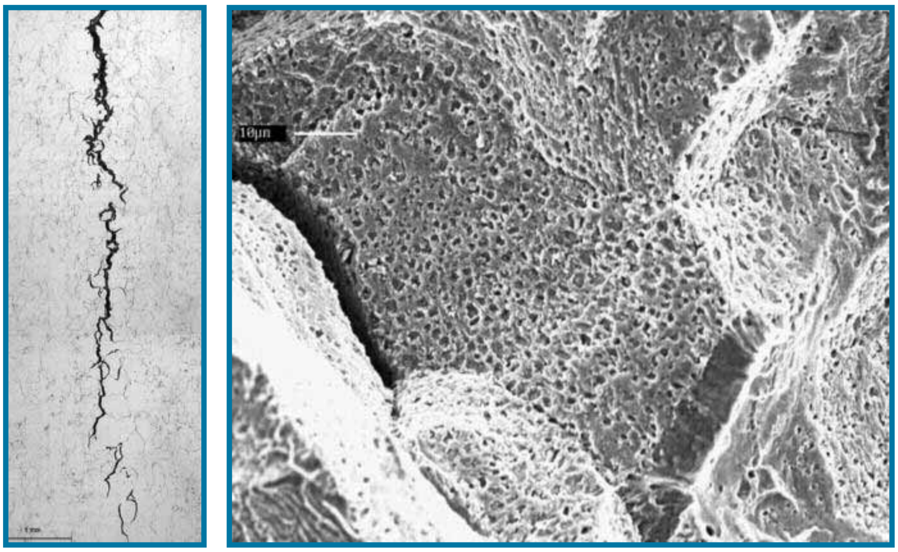


*Fig. 8. Creep cracking (**left**) and microscopic creep damage (**right**).*

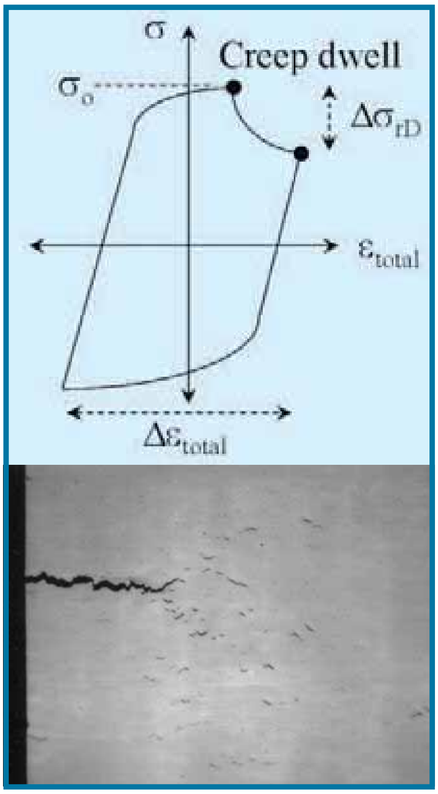


*Fig. 9. Showing creep dwell fatigue (**a, b**).*

Creep-fatigue crack initiation and growth – degradation mechanism

Cyclic plant operation (start-up, shutdown) with steady operation at elevated temperature can lead to both fatigue and creep components of degradation. Time at dwell can increase the crack growth rate and lead to creep fatigue interaction as shown in Fig. 9.

Reheat cracking – type 316H stainless steel

Reheat cracking can occur when the welded component is not subjected to post weld heat treatment, such as a stress relief heat treatment and has been subjected to high temperatures during service. This is a particular form of creep cracking that occurs during stress relaxation at operating temperatures.

Cracking is typically found in the coarse grained regions of the heat affected zone (HAZ) beneath the weld or in the coarse grained regions within the weld metal, as shown in Fig. 10. Stress concentration areas such as the weld toe are also susceptible to reheat cracking as are residual stresses in the steam header.

Reheat cracking experiment

Examples of a reheat cracking experiment using Borland test specimens made from segments of a type 316H ex-service steam header were shown.

Inspection of these Borland test pieces showed that cracking was due to heating only, without being influenced by external stress loads. Examples of the intergranular nature of the cracks were shown on as-welded specimens after 15,116 hours at 525ºC, 15,442 hours at 550ºC and a repaired Borland specimen after 11,810 hours at 575ºC.

A graph showing a comparison of predicted and observed creep damage was then shown to illustrate the positions of the cracks on node 1564.

Pictures showing typical weld types were shown, illustrating the parent microstructure, heat affected zone microstructure and the weld microstructure. This included a ferritic multipass weld, an austenitic 2-pass weld and an autogenous weld (no filler metal).

Primary Water Stress Corrosion Cracking (PWSCC) – degradation mechanism

Primary Water Stress Corrosion Cracking (PWSCC) is a source of degradation in the PWR system, as shown in Fig. 11.

In addition to service loads one of the key drivers in PWSCC crack growth are tensile weld residual stresses. These tensile stresses react with the water chemistry and temperature and can lead to crack growth.

Experience of operating nuclear power plants have underscored the need to re-examine the susceptibility of safety related components to PWSCC.

PWR service degradation has been observed on components such as control rod drive mechanism, pressuriser and dissimilar metal weldments. For instance the PWSCC of pressuriser alloy 82/182 nozzle to safe-end butt welds is now ranked highest of the ageing/degradation issues.

These observations have motivated the need to better understand PWSCC morphology especially in nickel base alloys and to assess the effectiveness of non-destructive examination (NDE) practices.

Non-destructive testing (NDT)

One of the improved NDT techniques has been the introduction at Sizewell B in 2009 of automated ultrasonic inspection of the pressuriser surge nozzle, as shown in Fig. 12.

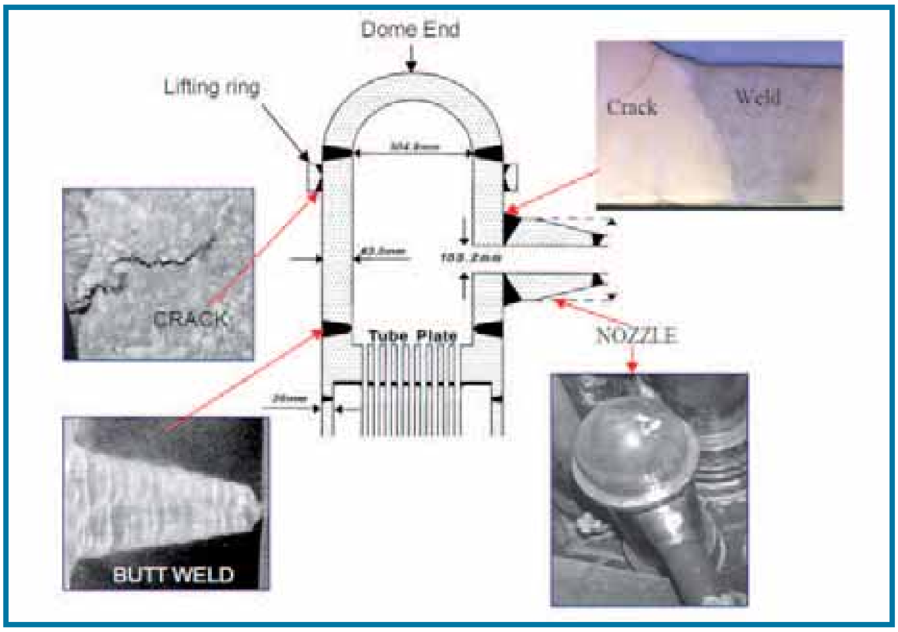


Fig. 10. *Showing reheat cracking in 316 stainless steel.*

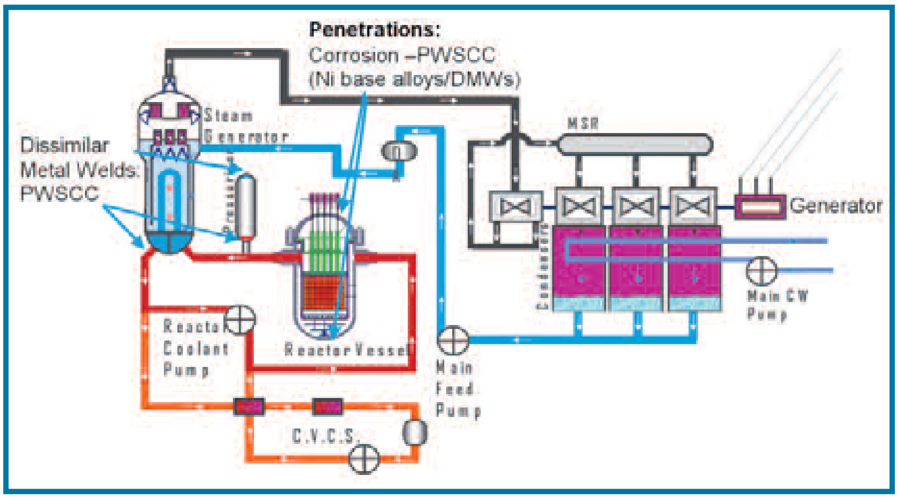


Fig. 11. *Showing typical degradation mechanisms PWR corrosion – PWSCC.*

Lessons for new build – A personal view

Don't assume everything will be alright – keep looking for degradation. Don't stop R&D activities – the data are essential and will probably save money in the long term!

The WJS East Midlands Branch would like to thank Chris Hamm of British Energy.

Alan Caborn,
WJS East Midlands Branch,
Derby/UK

Fig. 12. *Automated ultrasonic inspection.*

User software for the welding shop

Fig. 1. *Opening screen of the software "Weldassistant" with the new WPQR-administration module.*

Enhanced functions

First appearing in 2002, version 5 of the "Weldassistant" software will be available from end of March 2011. It can be had in the Basic and Professional editions which can be upgraded by means of free plug-ins.

Whilst the Basic version of the "Weldassistant" software from hsk-welding solutions GbR in Viernheim/Germany facilitates the creation of welding procedure specifications (WPS), the Professional version comes with the additional "welder administration", "cost calculation" and – completely new to version 5 – the "procedure qualification record" modules (PQR) (Fig. 1). The welder administration module enables the creation of welder test certification in accordance with EN 287-1. Comprehensive search functions for both the field of application as well as qualification data assist in rapidly finding the appropriate welder and/or drawing up new qualifications. Once stored, information on qualifications can be further utilised for extending the certification.

The new "procedure qualification record" (PQR) module facilitates the administration of PQRs and their areas of application. Comprehensive search functions for both the areas of application as well as the qualification data assist in finding the appropriate PQR for that special application. Because the areas of application can be manifold, it is possible to define several of these for one test weld (e.g. in accordance with DIN EN ISO 15614-1 and ASME Section IX).

Both the Basic and the Professional editions can be upgraded from version 4 via free plug-ins. At present, in addition to the filler materials and additives from ESAB (OK Handbook) these also include the shield and forming gases from the gas suppliers AirLiquide, Praxair, PanGas and Linde as well as the tungsten electrodes from the company Gesellschaft für Wolfram Industrie.

Example of a dual language welding procedure specification for nuclear power plant construction

Do you speak English? – Yes, sure

Following the introduction of the "Weldassistant" plug-ins, the advantage of "Weldassistant"'s multi-lingual software is now considerable. It even fulfils the high-level requirements for safety elements in a Chinese Nuclear Power Plant. This is illustrated, for example, in a welding procedure specification available in two languages.

On the new nuclear power plant construction, Taishan 1+2 in China, class 1 safety valves (highest nuclear engineering specifications) are necessary for safeguarding the main steam line. One of the challenges here was the creation of a "subject to approval" welding procedure specification (WPS) for welding the nozzle seam (arrow in Fig. 2) in accordance with:

- ☐ EN ISO 15609-1 Specification and qualification of welding procedures for metallic materials – Welding procedure specification - Part 1: Arc welding,
- ☐ RCC-M (French nuclear code),
- ☐ extensive customer specifications.

This concerns a link between the material M1112 (20MN5M) as per RCC-M and the fine grained steel P355QH (material number 1.0571). A single U groove preparation was designated for the 30 mm thick, 350 mm diameter nozzle seam. The root was to be tungsten inert gas welded. Manual arc welding was the process designated for the backing welds. The filler and capping runs were to be produced using submerged arc welding. Apart from the usual parameters for the welding, numerous further important specifications were required in the welding procedure specification. Among them:

- ☐ precise specification of the layer thickness per welding process deployed,
- ☐ specification of the welding current source and type,
- ☐ welding method (manual, mechanised or automatic),
- ☐ positional angle of the welding torch with tungsten inert gas welding,
- ☐ seam diagram with simulated repair welding,
- ☐ determination of the post-welding low hydrogen annealing (soaking) in addition to heat treatment.

English and German versions of the welding procedure specification made simple

Using the "Weldassistant" software, even precisely this most sophisticated type

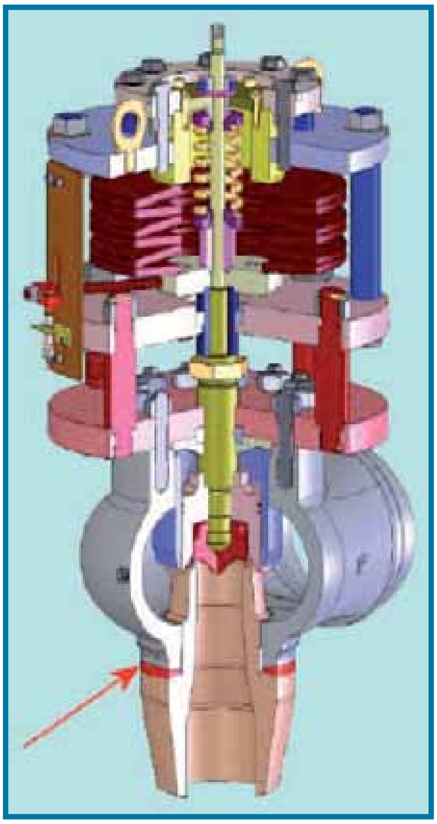


Fig. 2. *Main steam safety valve "Si9507" for the Chinese nuclear power plant Taishan 1+2 and position of the weld (red arrow).*

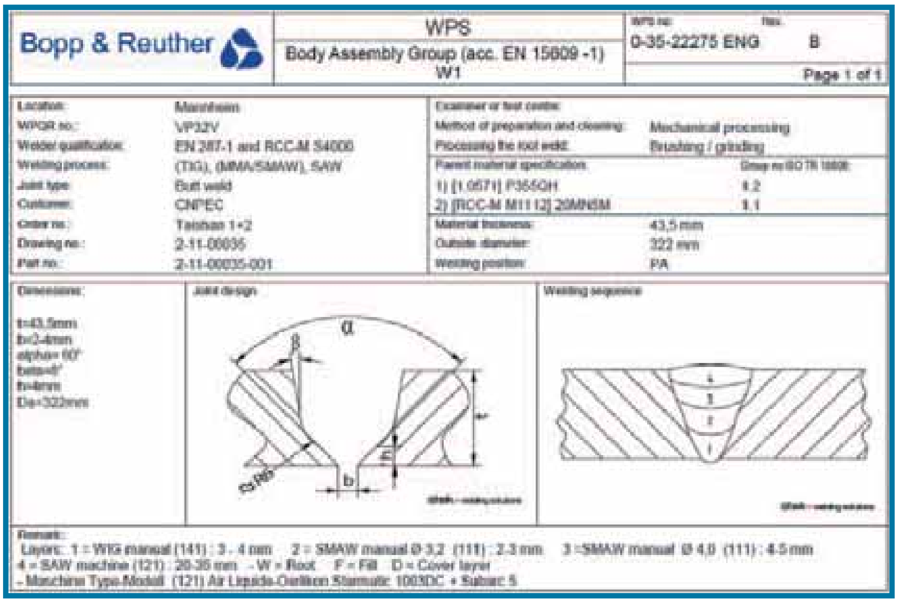


Fig. 3. Welding procedure specification (WPS) in accordance with EN ISO 15609 for the customer in English, prepared using "Weldassistant".

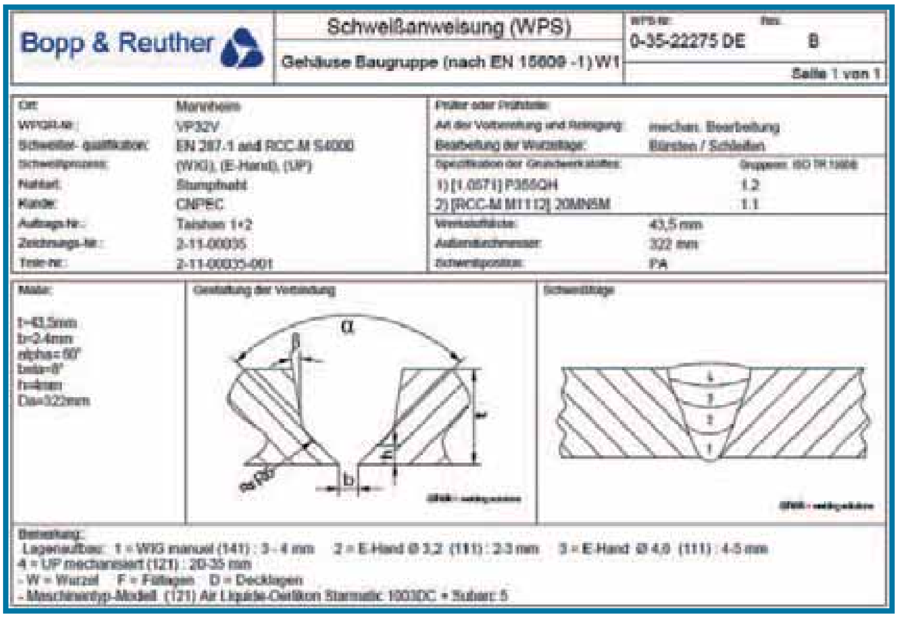


Fig. 4. After switching over the software language, the German version of the WPS is available after a few changes.

of welding procedure specification for class 1 weld seams in the nuclear branch can be implemented without problem. The compliance with the WPS schedule in accordance with EN 15609-1 and the possibility of integrating all statements in the customer specification into the WPS was, in the case of Bopp & Reuther, the decisive factor in selecting the software. The software was able to play to its multilingual strengths. The welding procedure specification submitted to the customer for approval had to be drafted in English (Fig. 3). But it could not be used in this form for the works in Germany. By switching over the software language, and with few changes, a WPS in German was created for the factory in Mannheim, Germany (Fig. 4).

The heat conduction during welding as well as the weld seam heat-treatment were further criteria which had to be illustrated in the welding procedure specification. With the "Weldassistant" software it is possible to enter format-independent parameters (Fig. 5, right) into the input boxes for the prompted keywords (Fig. 5, left).

Welding software should not only be a tool for filling out or creating forms (WPSs, WPQRs) – it also has to achieve the greatest possible benefit to the user. With the introduction of plug-ins, for the first time in welding software the manufacturers of welding filler materials, for instance, were incorporated into its further development which has considerably accelerated access to the necessary information. The new software version 5 demonstrates that its enhancements have still further improved the benefits to the user. With it, even the highest level of requirements in respect of the body of regulations and customer specifications in power station and nuclear technology can be fulfilled.

Klaus Hoffmann, Viernheim/Germany

The company Bopp & Reuther Sicherheits- und Regelarmaturen GmbH with its headquarters in Mannheim/Germany manufactures control fittings, safety and gate valves up to 10 tons in weight. It has applications in the petrochemical industry, in plant construction and both conventional and nuclear power plant. The applications range from low temperature, -196°C through to the latest generation of high temperature power plant valves for up to 725°C steam temperature. The variety of materials resulting from this, together with their sophisticated welding techniques, calls for a high number of correspondingly qualified welding processes. The requirements emanating from the body of regulations present welding technology, in particular WPS creation and the documentation, with very considerable challenges.

Weaving	String bead
Preheat temperature [°C]	≥ 220
Interpass temperature [°C]	220-280
Process	Stress relieffannealing
Heating method	Furnance from RT
Heating rate	3+/- 10% K/min
Holding temperatur	580-615°C
Holding time	90-120 min
Cooling	Furnance <300°C, rest calm air
Cooling rate	3+/- 10% K/min

Fig. 5. Specification for heat treatment.

Strength of block joints welded with large gaps

Dipl.-Ing. Sonja Zacke *studied civil engineering at the Leibniz University of Hanover/Germany. In 2006 she completed her diploma thesis on welding simulation and post-weld treatment. Since 2007 she has been a research assistant at the Institute of Ship Structural Design and Analysis at the Hamburg University of Technology (TUHH), currently working on her doctoral thesis with a focus on computational assessment of residual stresses and their influence on the strength of ship block joints.*

Prof. Dr.-Ing. Wolfgang Fricke *studied naval architecture at the Universities of Hanover and Hamburg/Germany. In 1985 he received his doctorship for a dissertation on linear and non-linear analysis of ship structures. From 1986 to 2000 he was employed by the Classification Society Germanischer Lloyd in Hamburg. In 2000 he became professor for ship structural design and analysis at the Hamburg University of Technology (TUHH).*

Dipl.-Ing. Sefika Elvin Eren *studied mechanical engineering at the Technical University of Munich/Germany. After two years of research activities at the GKSS Research Centre in Geesthacht/Germany, in 2009 she began with her PhD in component reliability at Imperial College London/UK.*

Dr.-Ing. Mustafa Kocak *studied mechanical engineering at Middle East Technical University, Gaziantep/Turkey. He then received his doctorship in 1982 at Bath University/UK. Until 1984 he worked as a researcher at Liverpool University. From 1984 to 2009 he was researcher and director of the Department of Joining and Assessment at the GKSS Research Center Geesthacht/Germany. Since November 2009 he has been General Manager of Gedik Holding in Istanbul/Turkey.*

The welding of block joints in shipbuilding often requires much effort because fabrication without margins sometimes leads to large gaps between blocks. The high stresses occurring due to constraints may be unfavourable. For this reason, a project was undertaken to investigate if butt joints welded with larger gaps fulfil the requirements. The objective was the proof of sufficient strength of welds fabricated with gap widths up to 30 mm.

Sonja Zacke, Wolfgang Fricke and Sefika Elvin Eren, Hamburg/Germany and Mustafa Kocak, Ankara/Turkey

Communication from the Institute for Ship Structural Design and Analysis of the Hamburg University of Technology, Hamburg/Germany.

1 Introduction

In shipbuilding the welding of large gaps at block joints is regulated by the classification societies with respect to the welding procedure. At present, the maximum permitted gap amounts to 25 mm. Apart from the welding technique also the strength of the welded structures becomes questionable with larger gaps. Unfavourable constraint conditions of the surrounding structure can also have negative effects. For this purpose, butt joints at 250 mm wide and 15 mm thick plates made of mild and higher-tensile steel, welded with different gaps under restraint conditions, were investigated with respect to their fatigue strength. The investigated parameters are:

- ☐ gap width (8 to 30 mm),
- ☐ welding technique (string-bead technique, weaving technique),
- ☐ steel grade (higher-tensile steel D36, mild steel A235),
- ☐ preloading and stress ratio R,
- ☐ welding position (horizontal PA and vertical position PF).

Altogether more than 60 specimens were welded; their geometry is presented in Fig. 1.

The 250 mm wide specimens were cut after cooling to obtain the fatigue specimens. For the fatigue tests a cross section of 40 mm × 15 mm was specified, so that four to five fatigue specimens were obtained from each welded plate. For statistical reasons of the fatigue evaluation at least eight specimens are needed, consequently 2 specimens must be welded for each joint variant.

2 Welding of the specimens

Welding was performed under definite constraints to take into account the structural ship stiffness. The constraint can be interpreted as the spring stiffness, which was obtained by several measurements on board within previous investigations [1]. For this purpose, a restraining welding set-up was designed. The arrangement as a closed system can show typical unfavourable constraints (Fig. 2).

The main properties of the investigated materials are summarised in Table 1. The welding procedure was the metal-active-gas (MAG) process; welding was done by an automatic system that is able to weave along the welding line.

A main indication of the differences between both welding techniques and the magnitude of the gap width is the energy input per unit length. Table 2 presents the averaged energy input for the passes and for better comparability (different number of passes per layer) also for the section. Furthermore the time needed for welding a 10 m long joint is given. As one can see, both techniques have a similar energy input per section welded in horizontal position (W, S). The energy increase for the large gap width corresponding to the higher number of layers needed is remarkable. As shown in the last column, the most time consuming technique is the 30 mm wide gap welded in vertical position, whereas for the horizontal welding position the difference can hardly be noticed for both welding techniques. These times do not include cooling times, responding to the fact that the joint has cooled down after the welder has finished the 10 m long layer and started with the next one.

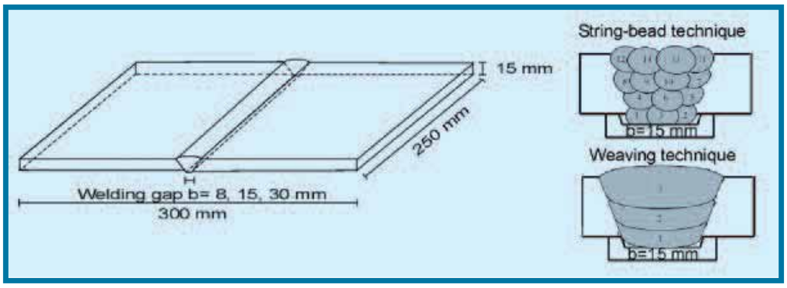


Fig. 1. *Geometry of the specimens (left) and welding technique (right).*

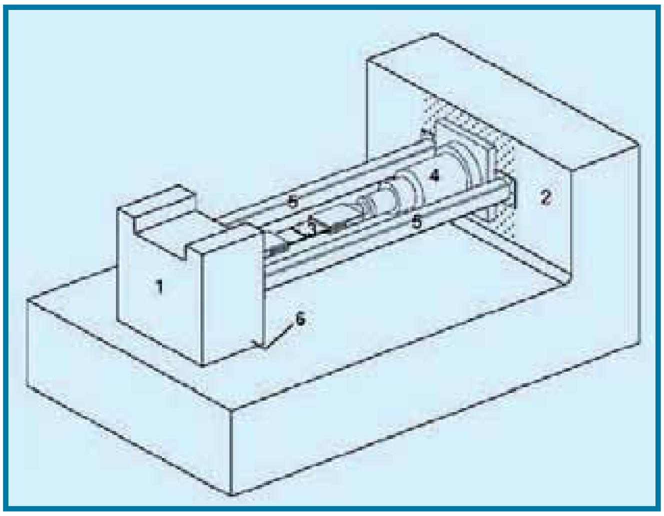


Fig. 2. *Restraining welding set-up.*

Table 1. *Material properties.*

	Base material		Filler material
Steel grade	D36	A235	FILARC PZ 6113
Yield stress f_y [MPa]	355	235	For protective gas MISON 18: 460
Actual yield stress [MPa]	390	290	
Tensile stress [MPa]	520	410	For protective gas MISON 18: 460
Ultimate tensile strain [%]	29	22	Min. 22
Welding procedure	Automatic MAG		

Table 2. *Comparison of energy heat input and welding time (W weaving technique, S string-bead technique, WS weaving technique welded in vertical position)*

Gap width	Test variant	Energy input per pass	Energy input per cross section	Welding time for a 10 m long joint
		[kJ/mm]	[kJ/mm]	[h]
8 mm	W	2.5	9.8	6.5
	S	1.1	9.9	5.8
	WS	2.6	10.6	8.2
30 mm	W	4.4	22.1	13.6
	S	1.3	28.9	14.4
	WS	6.1	24.5	17.4

3 Measurement of the reaction forces

It is assumed that the shrinkage stress of both welding techniques is very different due to the high heat input per layer for the weaving technique. The energy input per section indicates a similar behaviour but the energy input per layer is decisive regarding the shrinkage behaviour. Therefore, the reaction force transverse to the welding direction was additionally measured during and after welding. This load becomes part of the fatigue tests as a preload or mean stress.

Fig. 3 shows the reaction force Fy, which ranges between 250 and 700 kN. The upper three curves characterise the weaving technique, the broken lines represent the results for mild steel. Generally, the curves of the string-bead technique are below those of the weaving technique. All curves depend on the gap width. Although the gradient is steeper for the weaving technique, overall it is relatively small.

Furthermore, the reaction moments were measured about the axis in the welding direction as well as in the thickness direction. It turned out that the weaving technique specimens barely showed remarkable moments during welding and after cooling, while the string-bead specimens showed significant moments about both axes, which, moreover, increase with the gap width.

4 Material characterisation

In the context of the fracture evaluation performed by GKSS Hamburg, extended material property investigations were done. The characterisation of the base and the weld material was performed with hardness measurements, chemical analysis, evaluation of micrographs and extensive fracture toughness measurements.

The hardness measurements presented in Table 3 do not indicate any abnormalities and fulfil the requirements of the classification societies. The comparison shows an increased hardness for the string-bead specimens by 25HV-30HV.

It can be seen that there is a decreasing trend of hardness with increasing gap width. Furthermore, the root layer has higher values than the top layer, which results from the multiple heating of the root according to the number of passes. This is also the reason for the decreased hardness for the large gap width, because the number of passes needed increases with the gap width and, therefore, the root layer is warmed up more often.

The base and the weld material were examined within the scope of the chemical investigation. Upon comparison of the carbon content of the weld for both welding techniques, it was noticed that the string-bead technique specimens have a higher mass content of carbon than the weaving technique specimens. This confirms the results of the hardness measurements, since a higher proportion of carbon explains the higher hardness values of the string-bead technique specimens. Overall, the requirements for the material com-

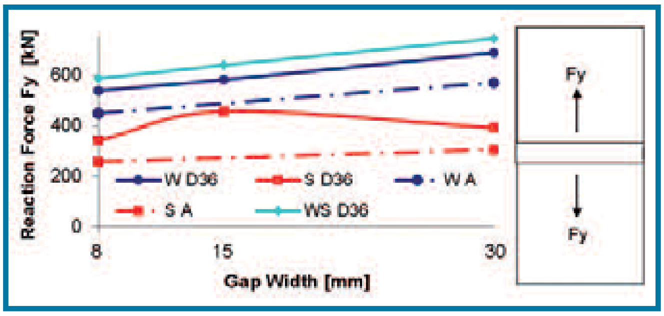


Fig. 3. *Reaction force Fy measured after cooling.*

Table 3. *Comparison of hardness measurement results HV10.*

Gap width	8 mm		30 mm	
	Weld	HAZ	Weld	HAZ
Weaving (top)	200	178	176	165
String-bead (top)	222	205	207	211
Weaving (root)	180	172	149	157
String-bead (root)	205	201	171	186

position of Germanischer Lloyd [2] are fulfilled for all specimens.

The micrographs (Fig. 4) show significant differences in the welding technique comparisons. The microstructure of the weaving technique specimens is finer and more homogeneous; that of the specimens welded with the string-bead technique is coarser according to the higher hardness values.

The fine-grained microstructure results from a diffusion-controlled phase transformation during cooling, where large quantities of austenite are transformed. A very homogeneous microstructure can be seen in the root layer especially for the 30 mm wide gap specimens welded with the weaving technique, which resulted from the high heat input per unit length of the weld due to the large weaving amplitude. The straight-line movement of the string-bead technique, however, causes a continuous heat input for every pass with faster cooling rates. This is why the rough phase austenite is not totally transformed.

As a part of the determination of the fracture parameters three-point bending tests were performed using small specimens (cross section 15 mm × 15 mm). The fracture toughness value CTOD (crack tip opening displacement) was measured with σ_5-clips [3]. The test set-up is presented in Fig. 5.

The CTOD values can be interpreted as the displacement of the surfaces of a crack normal to the original (undeformed) crack plane at the tip of the fatigue precrack. After precracking a static load is applied resulting in a stable crack growth. As third and last part of the procedure a post-fatigue load follows. The pre- and post-fatigue parts are the most time-consuming steps of the testing procedure. However, these steps are essential to assure stable fracture.

This approach ensures a sufficient data quantity for stable crack propagation. As a result of the investigations it was found that the base material has the highest fracture toughness CTOD-values within a scatter band of 0.85 to 1.05 mm (Fig. 6).

The fracture resistance of the filler material welded with the weaving technique is in the range of about 0.7 mm; the CTOD-values of the string-bead technique are shown in the lower part of Fig. 6 as separate columns for the various gap widths. On average, these specimens only reach half the fracture resistance of those welded with the weaving technique. The result of 0.251 mm for steel grade D36 with the 8 mm wide gap is even critical. Within the chemical analysis a martensite portion was found only in the structure of this series of specimens. Martensite is a very brittle structure and may be the reason for the low fracture toughness of these specimens.

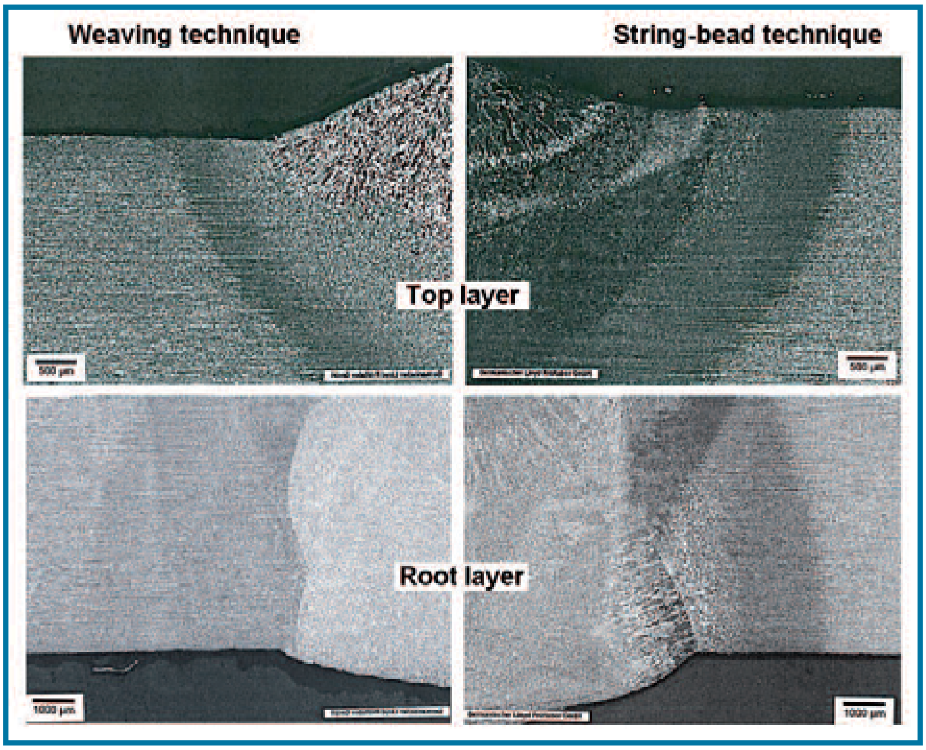


Fig. 4. *Micrographs of specimens with 30 mm wide gaps.*

5 Fracture safety assessment

Fracture analysis is rarely applied in ship structural design. However, there are special cases where a strength assessment should be based on this analysis type. The recently developed European Fitness for Service (FFS) procedure FITNET [4] offers possibilities in this respect and has a hierarchy of methods, designated Option 0 to 5. In general, the assessment becomes less conservative and more accurate with increasing option number, under the condition that the user must provide increasingly accurate material data and/or carry out a more detailed analysis. This hierar-

Fig. 5. *Three-point bending set-up, CTOD determination.*

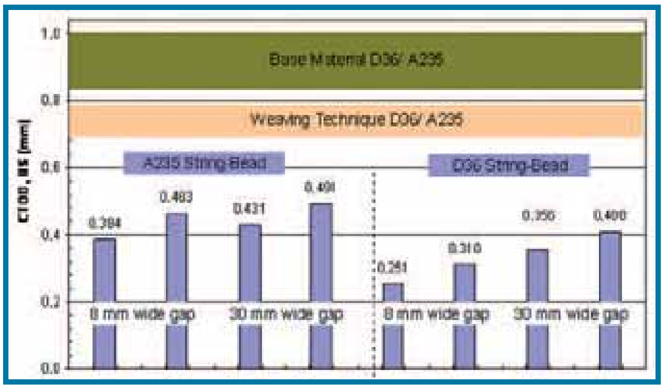


Fig. 6. *Maximum CTOD values of A235 and D36 steels welded by the string-bead and weaving technique.*

chical approach to analysis is a feature of all major fracture assessment procedures, including ASME/API 579, British Standard 7910 and R6.

5.1 Residual strength tests

Residual strength tests of the welded plates with centre cracks (M-(T)-panels) were carried out on 250 mm wide plates instead of the small specimens used for the fracture toughness tests. These tests are intended for a comparison and thus a verification of the critical load that leads to failure determined by FITNET assessment. For this purpose, the specimens were dynamically precracked until remarkable crack edges were visible. At these edges σ_5-clips were installed. The test set-up and the measurement arrangement are shown on the left-hand side of Fig. 7.

During the experiments eight signals were recorded; the most important parameter is the ultimate load leading to failure. This was subsequently compared with the failure load predicted by FITNET.

5.2 Structural integrity assessment using FITNET

The FITNET Fracture Module used in this project is based on fracture mechanics principles and is applicable to the assessment of metallic structures (with or without welds) containing actual or postulated flaws. The purpose of the analysis is to determine the significance, in terms of fracture and plastic collapse, of flaws postulated or present in metallic structures and components.

The procedure is based on the principle that failure is deemed to occur when the applied driving force acting to extend a crack (the crack driving force) exceeds the material's ability to resist the extension of that crack. This material 'property' is the material's fracture toughness or fracture resistance. Two approaches for determining the integrity of cracked structures and components have been selected for the FITNET procedure. The first uses the concept of a failure assessment diagram (FAD) and the second a diagram that uses a crack driving force (CDF) curve. Both approaches are based on the same scientific principles and give identical results when the input data are treated identically. In this project, FAD was preferred to CDF due to its simplicity in representing results. Within the FAD approach, the analysis is based on the position of one evaluation point of the investigated structure relative to a failure curve that is independent of the structure. The following figures show the respective FAD diagram with the corresponding maximum force and the failure points of the residual strength tests. The evaluation with FITNET offers various conservative approaches for the calculation, which depends on the available input data. The options are ascendingly less conservative and have been included in the investigations for Options 1 to 3.

Fig. 8 shows the results of the FITNET analysis for a specimen having a 30 mm wide gap and the base material D36 welded with the weaving technique. Kr can be interpreted as a geometry and

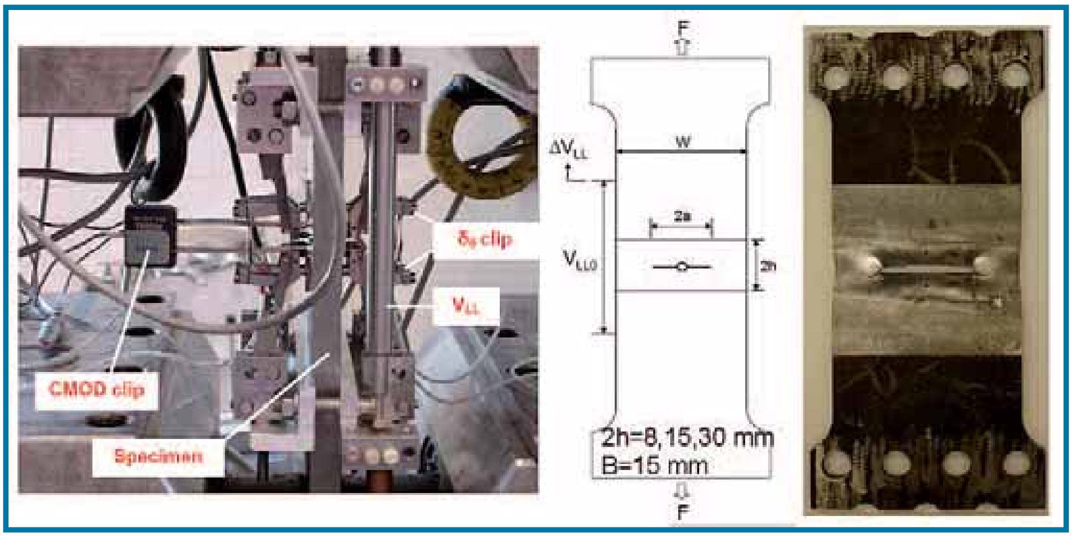


Fig. 7. *Experimental set-up for testing M(T) panels and geometry of the specimens for the residual strength tests.*

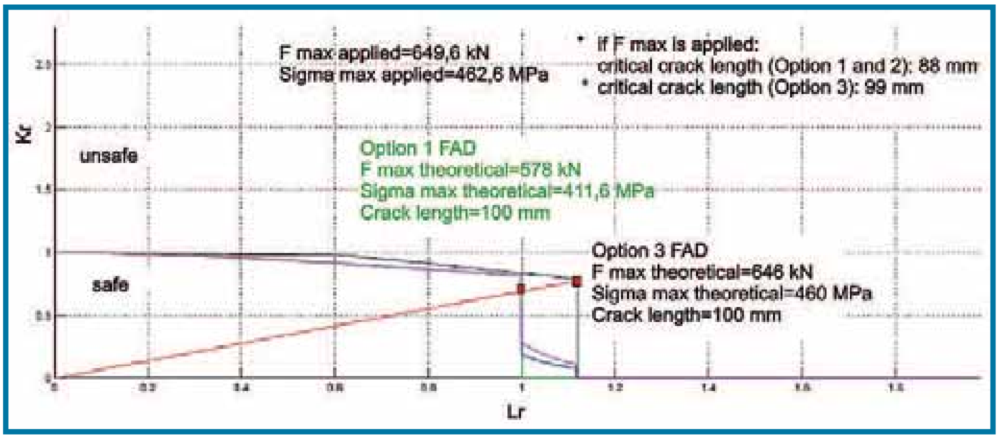


Fig. 8. *Assessment of D36 steel welded by the weaving technique using Options 1, 2 and 3; 2H = 30 mm.*

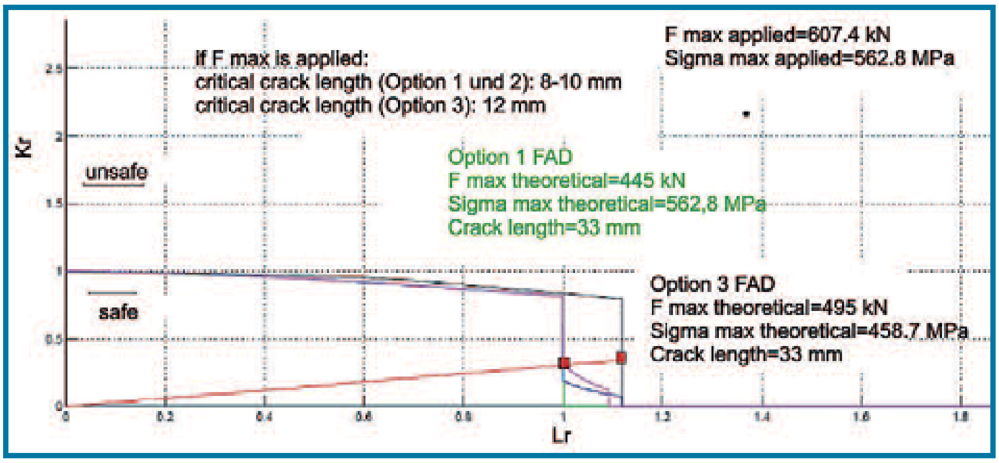


Fig. 9. *Assessment of D36 steel welded by the string-bead technique using Options 1, 2 and 3; 2H = 30 mm.*

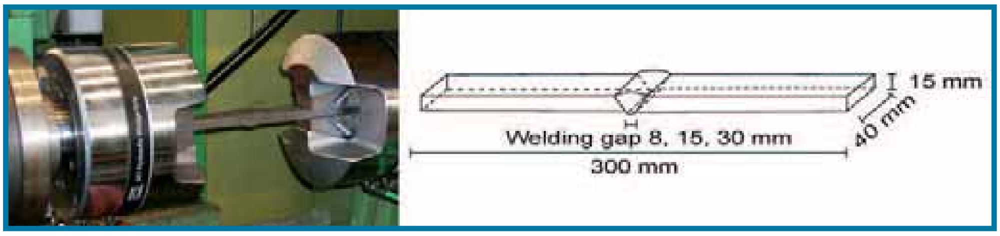
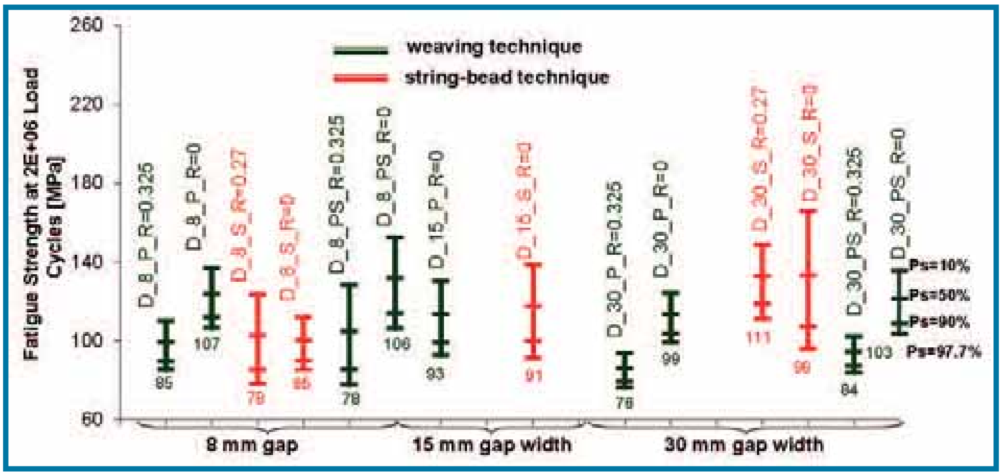


Fig. 10. *Testing set-up and geometry of the specimens.*



load dependent (crack driving) parameter including the fracture toughness values CTOD. Lr is defined as the ratio of external load F and the plastic limit load Fp. The three options are compared with each other: For option 1 a maximum stress of 412 MPa is reached and for Option 3 460 MPa is achieved. The residual strength tests showed a maximum stress of 463 MPa. The critical crack length is 88 mm for Option 1 and 99 mm for Option 3. The critical crack length is the entire length of the crack when the specimen fails if the maximum load of the experiment is assumed. This calculated crack length was taken as the starting crack length for the residual strength tests. For the series of the weaving technique welded specimens with a 30 mm wide gap (steel grade D36) the critical crack length calculated with FITNET is almost 100 mm, the crack length 2a within the residual strength tests is also 100 mm.

The critical stress of 460 MPa is in the range of the yield stress of the base and the weld material for this series of specimen. The critical crack lengths are quite large as a result of the good CTOD values.

The corresponding diagram for the specimens welded with the string-bead technique is presented in Fig. 9. For Option 3 the same critical stress of 460 MPa can be seen. The crack length for the residual strength tests, however, was only 33 mm and the corresponding maximum stress was 563 MPa. In this case, the test results reached a higher critical stress than those calculated with FITNET. This is to be considered with caution because of the different critical crack lengths, which are very short compared to the series of specimens discussed above.

Fig. 11. *Scatter bands of the fatigue strength of all test series of D36 steel.*

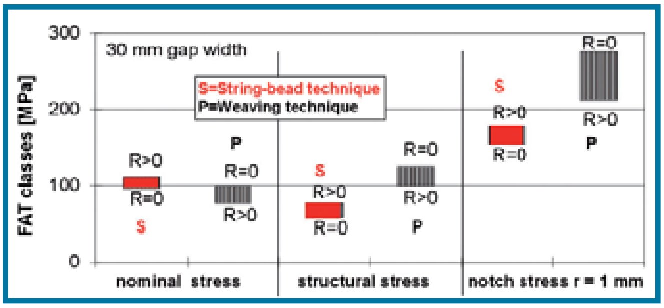


Fig. 12. Comparison of FAT classes derived from nominal and local stress approaches.

The only significant difference in the results of both welding techniques can be seen in the crack lengths. The specimens welded with the string-bead technique reach their critical crack lengths at 30% of those of the weaving technique welded specimens. This means a remarkably small fracture safety or damage tolerance.

6 Fatigue tests

Butt welds having a width of 250 mm were cut to a width of 40 mm, Fig.10. Altogether about 200 specimens were tested; they were separated into different test groups for the welding technique, steel grade, gap width and preload. The testing set-up is also shown in Fig. 10.

The upper and lower stress was defined according to the steel grade, the upper stress was set to 80 to 90% of the nominal yield stress and 70% of the real yield stress. This way a comparability of results was obtained.

For each test series with constant parameters at least eight specimens are needed to obtain statistical coverage. To investigate the influence of the residual stresses, a part of the specimens was tested with a preload. Generally it is assumed that the level of the residual stresses including the reaction forces reaches the yielding point of the material. If a construction is subjected to high residual stresses, further loading leads to stress redistribution, whereby the original residual stress state is changed. The investigation of the influence of residual stress should also take into account this aspect.

For the evaluation the nominal stress as well as two local stress approaches were used [5][6], furthermore the fatigue resistance against crack propagation was calculated for two specimens.

The evaluation based on the nominal stress approach is independent of the local weld geometry and the imperfections of the specimens; the result only refers to the applied load and the number of cycles to failure. Therefore all local effects affecting the failure of the specimens are implicitly included in this procedure. When extrapolating the fatigue strength for the survival probabilities P_s=10%, 50%, 90% and 97.7% with a slope exponent m=3 to $2{\cdot}10^6$ load cycles, the scatter bands shown in Fig. 11 are obtained. The scatter bands of the specimens are very different and for the string-bead technique specimens they are relatively large. Therefore the P_s=50% values as averaged fatigue strengths are more reliable, since they give a comparable estimation of the influences of the investigated variations.

The fatigue strength of the weaving technique specimens decreases with increasing stress ratio R. For these test series the mean values show a remarkable change, while the specimens welded with the string-bead technique have a relatively constant level regarding the stress ratio. Because of the different scatter bands the characteristic values and also the detail categories have other tendencies than the mean values. This means that the 97.7%-values for the stress range are more uncertain than the average due to the small number of specimens. Generally, for small gaps the weaving technique seems to be adequate; for larger gaps the string-bead technique is better.

The structural stress and the notch stress approaches were also applied. To quantify the effects of the weld geometry and the welding deformations on the life time, two finite element calculations were performed for each specimen. The structural stress and the notch stress were used as parameter for the S-N curve, where the corresponding FAT classes were obtained with the slope exponent m=3 for $N=2{\cdot}10^6$ load cycles. Figure 12 compares the resulting FAT classes from the nominal and local stress approaches. For the three concepts it can be stated that the results of the weaving technique fulfil the requirements. For the string-bead technique specimens, however, only the evaluation with the nominal stress approach corresponds to the required values; the local approaches show significantly lower fatigue strengths than necessary. The results achieved with the structural approach are especially remarkable. The reason for this is a low stress level at the crack initiation point due to angular misalignment and the weld geometry leading to correspondingly lower fatigue strength. Important is that the numerical structural and notch stress models did not correspond to the real crack location.

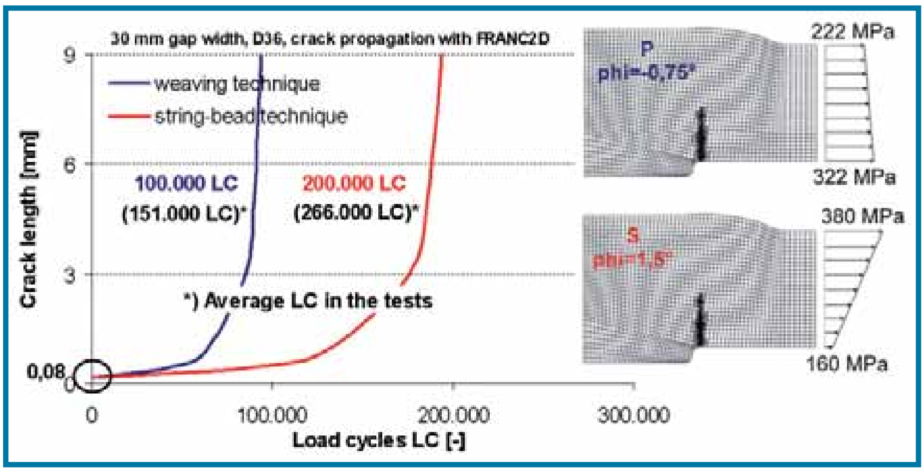


Fig. 13. Endured load cycles of the specimens with 30 mm wide gap calculated with FRANC2D.

Altogether, the comparison shows that the weaving technique fulfils the requirements with the nominal and the local stress approaches. The string-bead technique, however, achieves the required fatigue strength only with the nominal stress approach. This means that these specimens endured much more stress cycles in the tests than the local approaches predicted.

To clarify the unusual results for the local concepts and the higher number of cycles endured in the tests, a crack propagation analysis was performed. This concept has been successfully applied to fatigue assessment of welded joints in the past. This concept showed good accordance with test results especially for welded joints with high notch effects or imperfections and the resulting short crack initiation lives.

For the calculation the two-dimensional finite element program FRANC2D [7] is used. Only two specimens with the base material D36 and 30 mm gap width are investigated. Both specimens are based on the same numerical model regarding the geometry and the material data. The discretisation of the initial model is very fine with an element length of 0.5 mm. During crack propagation the mesh is modified around the crack tip by the program.

The main difference between both models is the load distribution. From the structural stress calculation, the bending stresses resulting from angular misalignment were determined and used as load for the crack propagation. As shown on the right-hand side of Fig. 13, the weaving technique specimen (P) is bent downwards due to negative angular misalignment phi=–0.75°, while the string-bead technique specimen (S) is bent upwards due to positive angular misalignment phi=1.5°. As stated before, the crack initiated at the root side even in the string-bead technique specimen although the lower stress is only 40% of the upper one.

The result of the crack propagation calculation is shown in Fig. 13. The lifetimes of both welded joints are very different. The curve of the weaving technique specimen is steeper compared to that of the string-bead technique specimen and reaches about 100,000 load cycles for a crack length of about 10 mm. The string-bead technique specimen achieves a lifetime twice as large. The values in brackets are the number of cycles to failure reached in the tests. A comparison of both values shows the same trend, which means that the test results are well reflected by the crack propagation analysis. Thus, this concept, in contrast to the local approaches, is able to predict the endured load cycles of the tests conservatively. The reason for this is the stress gradient of the structural bending stress in the specimens, which is considered in the crack propagation analysis, leading to a shorter life time for the string-bead technique.

7 Conclusions

The aim of the investigation was to evaluate the fatigue strength of butt joints welded with the weaving technique in comparison to the string-bead technique as well as the applicability of both welding techniques for large gap widths welded with unfavourable constraints.

Despite a small decrease in the fatigue strength, the results for the weaving technique agree with the existing fatigue class. As expected, the reaction forces showed an appreciable influence on the fatigue strength, which is considered by increasing the stress ratio R. Welding by the string-bead technique also leads to the usual fatigue class when based on the nominal stress approach. However it leads to a relatively low fatigue class when assessed with local approaches. This is due to the unexpected crack initiation at the weld root where decreased stresses occur due to downwards oriented angular distortion. Material effects or effects of the local weld geometry as well as unfavourable residual stresses may cause root cracks. The measurements of the transversal reaction force showed high shrinkage forces. In [8] a continuative welding simulation for both welding techniques is presented and shows that the residual strains in the root are different for the various specimens. Welding with the weaving technique leads to compressive strains, while the string-bead technique leads to tensile strains that may be responsible for the bad fatigue results of this technique.

Generally, the fatigue investigations indicate a clear influence of the welding technique on the fatigue strength of a weld.

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Helium additions to MIG shielding gas – an economic option?

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Dr. Norman McPherson *graduated BSc, PhD in metallurgy from the University of Strathclyde, Glasgow/UK. From 1973 to 1986 he was employed by British Steel at the Ravenscraig Works, specialising in the development of the continuous casting of steel slabs. He was awarded the Sidney Thomas Gilchrist Medal by the Metals Society for his work in this area in 1982. In 1987 he became Technical Manager of Thor Ceramics and in 1990 he moved to the position of Quality Manager of Kvaerner Govan in Glasgow, in the shipbuilding sector. Between 1990 and 2000 he held various positions including Deputy Production Director. When BAE Systems took over the he was appointed Welding Engineering Manager for BAE Systems – Naval Ships. He is into a second term as Visiting Professor within the Department of Mechanical Engineering at the University of Strathclyde and along with Dr. Alex Galloway is building up a research portfolio on MIG shielding gases. He has published over 100 journal and conference papers and is the co-author of three books on continuous casting.*

An investigation has been carried out to establish the technical and economic benefits of adding two levels of helium to a normal shielding gas. Technically no adverse issues were established using the two levels of helium, and the most significant positive one was the highly beneficial effects on travel speed increase and heat input decrease. Although helium gas carries a significant cost premium, the economic evaluation showed that overall this was a beneficial approach as the man-hour reduction associated with the welding process dominated the process cost effects.

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1 Introduction

There is an ongoing requirement to reduce rework related to heat induced distortion on thin plate structures. The most evident area for this is currently in the shipbuilding industry where there is a drive to reduce weight by using higher strength steels. This has resulted in the extensive use of 4 and 5 mm thick plate, especially in naval vessels, particularly Lloyds DH36 grade steel. The top side of destroyers, Fig. 1, has been the focus of this for some time and landing craft units (LCU), Fig. 2, are relatively light weight structures overall. In the case of the LCU much of the thin steel plate was Lloyds EH32 grade steel.

Whilst hybrid laser welding is seen as a possible option to control the distortion, there can be significant capital costs incurred depending on individual build yard configuration. In addition, many factors contribute to thin plate distortion, but reducing heat input has a dramatic effect, hence the interest in hybrid laser welding. However, there is still scope within the accepted arc welding processes to reduce heat input. Increasing the welding speed has a significant effect, but only if it can be achieved without compromising the weld quality in any way.

Fig. 1. *A Type 45 destroyer with a top side containing a significant proportion of 4 and 5 mm thick plate.*

Fig. 2. *A Landing Craft Unit (LCU) which contains significant quantities of 4 mm thick plate.*

Table 1. All weld metal chemical analysis of metal cored wire.

% C	% Si	% Mn	% P	% S
0.06	0.5	1.5	<0.015	<0.015

It has been recognised that helium additions to shielding gases can have beneficial effects, particularly by increasing the weld penetration. This is mainly related to the good thermal conductivity of the gas and its ability to improve the heat transfer from the arc to the component. Much of this was founded on tungsten inert gas (TIG) welding research carried out on steel some time ago [1, 2] and also for welding aluminium [3].

There is also evidence [4] that helium additions to twin wire automated metal inert gas (MIG) systems appear to generate some benefits too. The outcome of that work could be transmitted to single wire MIG welding of carbon steel plate by aiming for the same penetration with the helium containing shielding gases, by increasing the welding speed.

On the basis of this, a series of trials was set up to establish the technical and economic feasibility of using helium additions to a standard shielding gas.

Three shielding gases were used to produce 4 mm thick butt welds in DH36 steel with a 1 mm diameter metal cored wire at constant gas flow of 15 l/min. The all weld metal composition of the cored wire is shown in Table 1. 4 mm thick plate was selected as it would accentuate any distortion effects.

The base case gas was argon / 20% carbon dioxide, and the two helium-bearing gases were:

- ☐ Argon/10% helium/14% carbon dioxide and
- ☐ Argon/20% helium/14% carbon dioxide

Welding was carried out on a welding jig which held the plate rigid as it travelled beneath the fixed welding nozzle. This allowed the jig to be used to carry out distortion measurements before and after welding, with a laser scanner. It was important also to capture thermal data from the plates during and after welding, and this was achieved by having an array of thermocouples at right angles to the weld, 10, 20 and 30 mm from the weld centreline. This was validated using thermal imaging equipment.

All welding was monitored using a PAMS unit, to be able to quantify parameters in the location of the thermocouples.

2 Bead-on-plate welds

The initial welds were bead-on-plate produced using 500 mm × 500 mm × 4 mm pieces. This allowed basic parameters to be set for the butt welds, but also contributed useful data on weld and heat affected zone (HAZ) dimensions. In addition, travel speed optimisation was established in this part of the work.

The data shown in Table 2 summarises the findings. Basically the two gases containing helium showed benefits in terms of reducing HAZ width and increasing depth/width ratio.

Every 1% increase in helium content produced a 0.2mm/sec increase in travel speed, on average. Each 10% addition of helium to the shielding gas created a 20% increase in welding speed, which was linked to about a 4% decrease in voltage, and 21% decrease in HAZ width. Therefore these data were viewed as being highly encouraging in terms of the subsequent butt welding.

It was also evident that as the helium content increased, the depth/width ratio of the weld also increased, which is in line with the findings of Mills [1] on TIG welds, although in that work the effects were more marked due to the much higher helium contents involved.

3 Butt welds

The butt welds were created from 500 mm × 250 mm × 4 mm plates with 35° weld preps and a 1 mm face. As before thermocouples were attached to the plates, but only to one of the plates as it was considered that the heat flow would be symmetrical.

A ceramic backing tile was fitted to the root side of each weld prep. Apart from that, the same format was followed as for the bead on plate welds, with the exception that the weld was left to cool for 10 minutes, while thermocouple data were collected.

For each case the material distorted in the same manner i.e. with a saddle shape shown in Fig. 3 , which was the base case (argon/20% carbon dioxide).

The maximum distortion for each case was as follows:

- ☐ Argon/20% carbon dioxide –7.28 mm
- ☐ Argon/10% helium/14% carbon dioxide –6.34 mm
- ☐ Argon/20% helium/14% carbon dioxide –6.69 mm

The increased helium content did not have a beneficial effect on distortion over the 10% helium-bearing shielding gas.

The welding parameters for each weld are shown in Table 3 and show a reduction in heat input (which is based on an arc efficiency of 0.8) with increase in the helium content. It should be noted that this is related to an increase in travel speed too. Thermal measurements showed there was little difference between the peak temperatures of the two helium-bearing gases (~

Table 2. Welding parameters and related data for bead-on-plate welds.

Argon (%)	Carbon dioxide (%)	Helium (%)	Travel speed (mm/s)	Wire feed speed (mm/s)	Voltage (volts)	Heat input (kJ/mm)	Maximum temperature (°C)
80	20	0	10	7	27.5	9.53	480
76	14	10	12	7	26.5	7.52	360
66	14	20	14	7	26.5	5.89	365

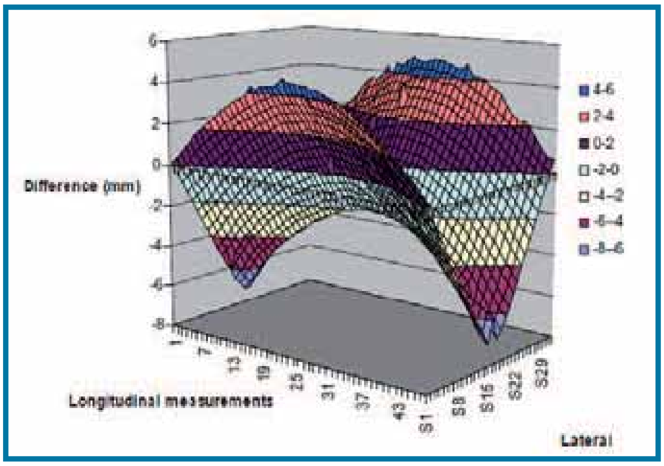

Fig. 3. Distortion induced in 4 mm thick plate when welding with argon/20% carbon dioxide.

360°C at 10 mm from weld centreline). This was confirmed from the thermal imaging measurements.

4 Weld physical attributes

The macrosections of each weld are shown in Fig. 4a-c. The asymmetric roots in the helium bearing shielding gas welds were due to having to fit the ceramic backing bar in the vicinity of the thermocouples. The smallest weld metal volume was found in the 20% helium welds. In addition there is a need to refine the cross sectional root profile in areas such as undercut on the cap, and the root profile. This is particularly the case in the 20% helium weld.

The weld width data is shown below:

- ☐ Argon/20% carbon dioxide 11.7 mm
- ☐ Argon/10% helium/14% carbon dioxide 9.5mm
- ☐ Argon/20% helium/14% carbon dioxide 7.2mm

The hardness data were expected to indicate that as the helium and travel speed increase the weld metal hardness should increase due to the higher cooling rate. Micro and macro hardness measurements (Vickers) were taken and found to be in broad agreement, with the micro data being slightly higher than the macro data. The maximum weld metal hardnesses are shown below:

Table 3. Welding parameters for butt welded plates.

Argon (%)	Carbon dioxide (%)	Helium (%)	Travel speed (mm/s)	Voltage (volts)	Current (amps)	Heat input (kJ/mm)
80	20	0	10	26.5	258	0.54
76	14	10	12	25.1	285	0.47
66	14	20	14	25.3	272	0.395

	Macro HV_{10}	Micro HV_{10}
☐ Argon/20% carbon dioxide	202	215
☐ Argon/10% helium/14% carbon dioxide	216	235
☐ Argon/20% helium/14% carbon dioxide	208	231
☐ Parent plate	165	175

The differences in hardness from each shielding gas are not considered significant, although there is a slight rise with the helium enhanced gases. With this grade of steel and its weld metal there is a tentative relationship between hardness and toughness, i.e. as the hardness increases the toughness decreases. As a result, it can be inferred from this data that there would not be a weld metal toughness problem.

The porosity contained in each weld was assessed from a number of images of each weld and the average volumetric porosity is as follows:

- ☐ Argon/20% carbon dioxide 0.41%
- ☐ Argon/10% helium/14% carbon dioxide 0.09%
- ☐ Argon/20% helium/14% carbon dioxide 0.035%

It is not particularly evident why the helium addition should influence the porosity within the weld metal, but even at the worst level there is not a cause for concern, in typical circumstances. A further positive benefit has been identified from Miklos' work [4] where there is significantly less top leg undercut on fillet welds and a very smooth transition from weld to plate when helium is present in the shielding gas. It was also evident that as the helium content increased, the depth/width ratio of the weld increased.

The technical evaluation has implied that the shielding gas could be used with a 10 or 20% helium addition without adversely affecting the weld metal properties, and in most cases it has improved the overall weld and heat affected zone.

5 Economic evaluation

It is pointless to add a component to the process unless it is going to generate value to the process. For this reason an economic evaluation was carried out to supplement the technical evaluation. The cost has been based on figures available at a particular point in time for gas costs and labour costs. All the data has been tabulated in Table 4. Although the gas cost per metre rises with increase in helium content, it is not particularly significant in terms of differentials. The dominant cost factor/metre is the labour cost. As a result of the increase in speed developed from the use of the helium gas, there is an overall increase in productivity which results in a reduction in the cost/metre of the welded length.

Indications from the practical situation means that leaks will probably be present in the supply system. Taking a scenario where the leak rate is the same as the gas usage rate/metre, the last row in Table 4 shows that this has an almost insignificant effect on the total cost per metre.

Some factors have been omitted from this evaluation:

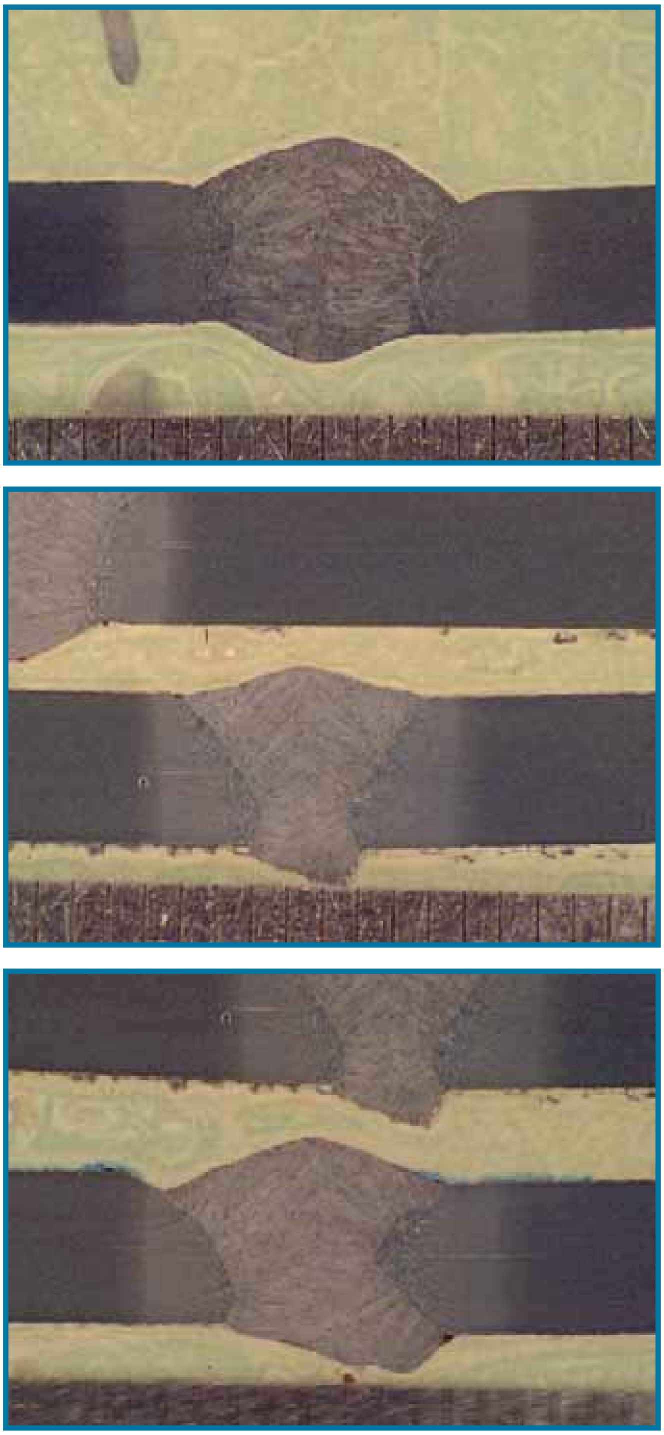

Fig. 4. *Weld macro cross sections:* ***a)*** *Argon / 20% carbon dioxide,* ***b)*** *Argon / 14% carbon dioxide / 10% helium,* ***c)*** *Argon / 14% carbon dioxide / 20% helium.*

- ☐ Power cost: will be lower with helium added gases due to increased welding speed.
- ☐ Consumable cost: will be lower due to increased welding speed at constant wire feed speed.
- ☐ Distortion rework: A reduction in the man hours associated with heat line straightening.

Table 4. *Financial assessment of helium additions to MIG shielding gases.*

	Argon 20% CO_2	Argon 10% helium 14% CO_2	Argon 20% helium 14% CO_2
Travel speed	10 mm/sec	12 mm/sec	14 mm/sec
Weld time	50 secs	41.67 secs	35.714 secs
Gas volume used	$0.0125m^3$	$0.01042m^3$	$0.00893m^3$
Actual gas cost/ 500 mm	£ 0.01566	£ 0.01930	£ 0.0235
Actual gas cost/m	£ 0.03132	£ 0.0386	£ 0.0470
Actual labour cost/m	£ 1.25	£ 1.0417	£ 0.8929
Total cost/m	£ 1.281	£ 1.0803	£0.94
Gas cost as percentage of total cost	2.44%	3.56%	5.00%

Overall there is at least a 27% and a 16% cost benefit in adding 20% and 10% helium respectively to the base case shielding gas. This could potentially create a very high level of saving in a high throughput shipyard.

6 Concluding comments

Despite the apparent increased cost of adding helium to shielding gases, it has been shown to be technically and economically a sound proposal. The only outstanding piece of work is to where to introduce the helium into the shielding gas delivery system. The most significant benefits would be seen in automated welding systems as the manual process creates a number of variables. The small reduction in the carbon dioxide content of the shielding gas will create a positive impact on the carbon foot print.

The support of the EPSRC for one of the authors (AG) is gratefully acknowledged, as is permission from BAE Systems Surface Ships to publish this work. In addition the involvement of BOC was most valued in the supply of gases, and also the technical interaction with Dr. Chris Birch.

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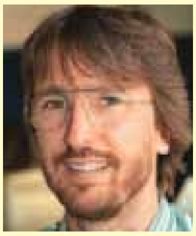
Optimisation of the projection geometry for the resistance welding on newly developed advanced high-strength to ultrahigh-strength steel materials



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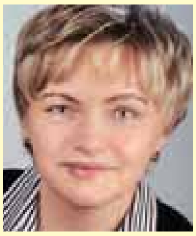

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In series and mass fabrication, resistance projection welding is a very economically viable joining process because of its short fabrication times. One decisive advantage of the process technology lies in the fact that several joints can be manufactured in one operation [1...5]. However, the resistance projection welding on the advanced high-strength to ultrahigh-strength sheets which have been introduced into fabrication in the meantime [6] is leading to great difficulties at the moment, amongst other reasons, because the projection geometry is not optimum. The strength of the joints is frequently lower than in the case of conventional soft deep-drawing steels and also exhibits a wide scatter. Moreover, fractures in the joining plane (shear fracture) occur very frequently. In the research project entitled "Optimisation of the geometry of embossed projections for the resistance projection welding on advanced high-strength to ultrahigh-strength steel materials" which is being promoted by AiF, investigations into the optimised designing of the projection geometries were conducted at SLV München and were compared with the projections according to DIN EN 28167. Results with the HCT690TD and HCT780TD TRIP steels, with the HCT780CD complex-phase steel as well as with the DX54D+Z100 soft deep-drawing steel (all sheet thicknesses: 1.5 mm) are presented within the framework of this publication. The welding was carried out with identical materials and in various mixed combinations. The welds were executed on a medium-frequency projection welding machine from Dalex, model: PMS 32-5 MF.

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1 Experiments

A suitable embossing tool has been manufactured for the embossing of the projections. It consists of a column structure which is provided with a pneumatic cylinder on the top side. The upper and lower dies are easy to replace and the projection heights can be altered with stops. A holding-down device is used in order to prevent the sheet from plunging during the embossing operation. In addition, there is the possibility of recording force and displacement courses with suitable sensors. The geometries of the upper and lower dies suggested according to DIN EN 28167 [7] were used and investigations were conducted into optimised variants with an altered upper die geometry and lower forming die.

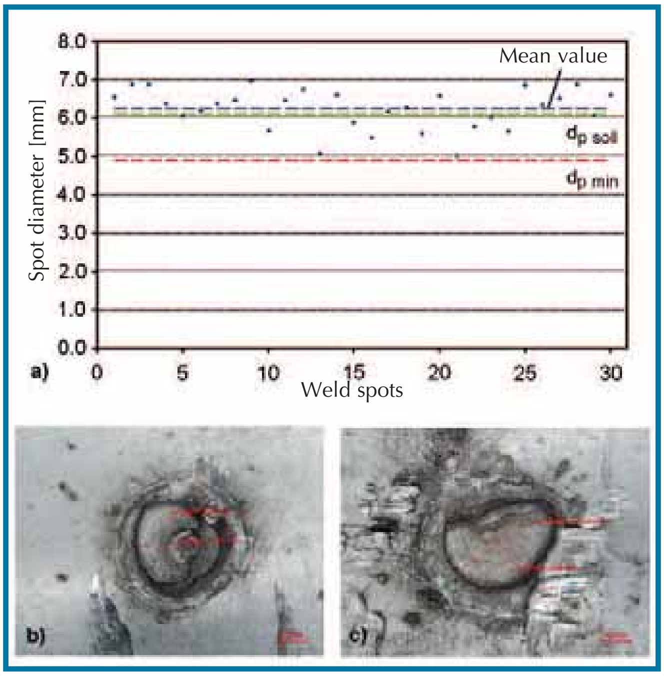


Fig. 1. *Series welds (material: HCT780TD, sheet thickness t_{Bl} = 1.5 mm; electrode force F_E = 3 kN, welding time t_S = 200 ms, welding current I_S = 13.0 kA);* ***a)*** *graphic representation of the evaluation,* ***b)*** *fracture pattern of a weld at t_S = 100 ms, I_S = 15 kA and ($d_{p\ min}$),* ***c)*** *fracture pattern of a weld at t_S = 200 ms and I_S = 13 kA.*

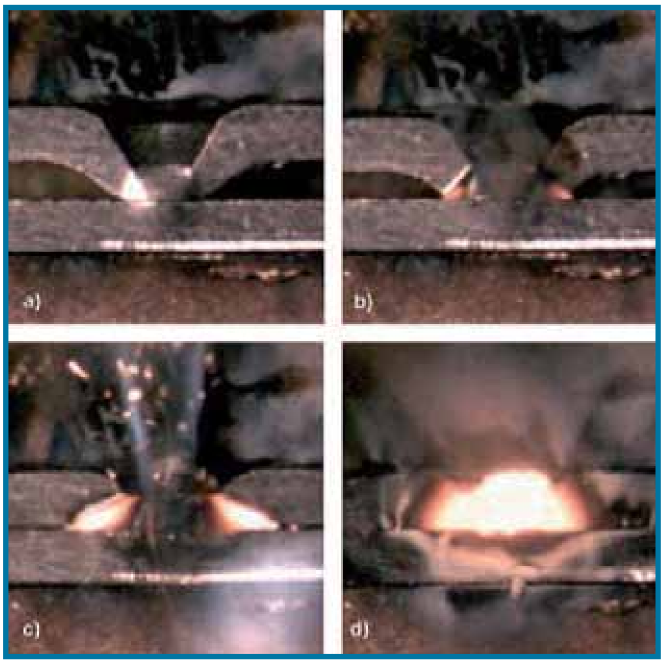


Fig. 2. Heating of the ISO projection and deformation behaviour during the welding; ***a)*** welding time t_S = 0 ms, the electrode force is applied, ***b)*** t_S = 60 ms, beginning of the heating at the sides of the projection at the smallest cross-section, ***c)*** t_S = 100 ms, „breaking-through" of the projection in the centre - slight heating in the bottom sheet, ***d)*** t_S = 200 ms, complete melting of the projection greater in the top sheet.

2 Results

2.1 Welding tests with ISO projections

The ISO projections were fabricated according to the stipulations in DIN EN 28167. The projections are divided into the various Groups A to C. In this respect, provision is made for the projections in Group C for applications with stringent strength requirements. Group C is recommended for high-strength materials as well. The utilised tapered upper die has a 60° taper angle (with varying cone frustum diameters) and embosses the projection in a lower hole die. Within the framework of the project, the investigations concentrated on the sheet thickness of 1.5 mm, i.e. the projection diameter of 5.0 mm is used with a projection height of 1.25 mm.

Influence of the welding time

In interplay with the electrode force and the welding current, the choice of the welding time has a strong influence on the inclination to spatter in the case of the resistance projection welding of high-strength materials. With a welding time of 100 ms (current rise: 20 ms, short-time welding) for the projection diameter of 5.0 mm (geometry: ISO C5 projection), the high-strength sheet materials in particular have a greater inclination to welding spatter because of the higher welding currents required (e.g. I_S = 15 kA at F_E = 3 kN). At the beginning of the resistance heating, the current density is too high and local overheating phenomena arise in the contact region between the projection and the sheet surface. Even if the current rise time is extended to 40 ms, this does not lead to any distinct reduction in the inclination to spatter. The fracture pattern very frequently exhibits unsymmetrical mixed-mode fractures in the joining plane. Often, spot diameters of just 4.0 to 5.0 mm are achieved.

If the welding time is extended to 200 ms, this results in a reduction in the inclination to spatter in comparison with the short-time welding especially at the beginning of the resistance heating due to the simultaneous reduction in the welding current (13 kA). Larger spot diameters up to 7.0 mm are achieved but the fracture pattern exhibits an unsymmetrical welded joint more frequently. The relatively wide scatter of the spot diameters is also recognisable when 30 resistance projection welds are tested, Fig. 1. A low Cpk factor (process capability index: [$d_{p\ mean}$ – $d_{p\ min}$] / [3 × standard deviation]) of 0.8 is reached there. In series fabrication, the Cpk factor should be min. 1.67.

The cause of the relatively wide variation in the spot diameters and of the greater inclination to spatter is shown by the evaluation of the high-speed photographs, Fig. 2. In this respect, the sheets were cut in the centre of the projection and the heating in the cutting plane was viewed with a high-speed camera. It is easily recognisable that the projection breaks through in the region of the side of the projection with an extreme reduction in the sheet thickness at the beginning of the welding and that the heating is carried out only insufficiently in the contact area between the projection and the sheet. The breakthrough of the projection can also be recognised in the metallographic specimen, Fig. 3, by the cracks in the top sheet.

Fig. 3 shows the evaluation of the tensile shear and cross-tension tests (ten specimens in each case) on the projection welds with ISO C5 projections, material: HCT690TD. The established data was used in order to calculate the respective mean values and to determine the coefficients of variation. The ISO C5 projections reach a mean tensile shear force of 21.2 kN and a relatively high coefficient of variation of 13.9%. The specimens exhibit an irregular fracture pattern. Similar results are achieved in the case of the HCT780CD complex-phase steel (tensile shear force: 20.7 kN, variance: 12.8%).

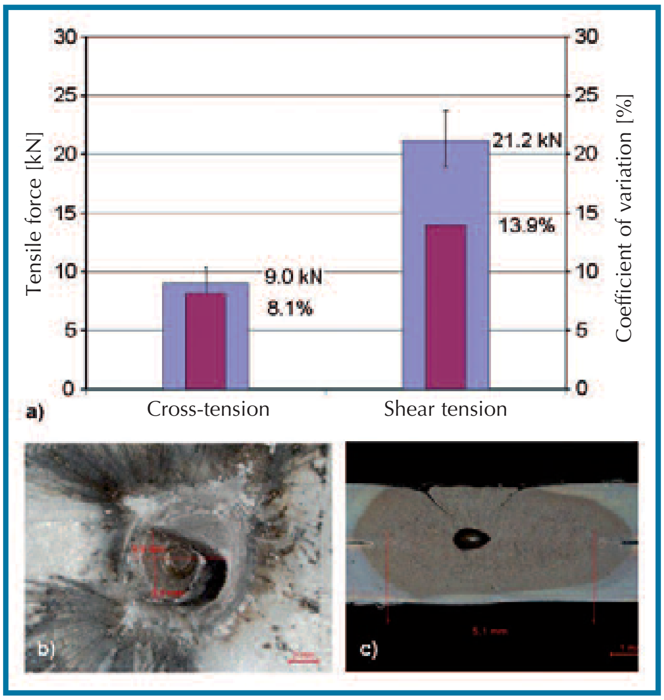
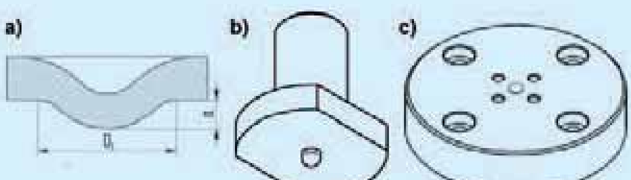


Fig. 3. Resistance projection welds with ISO projections (material: HCT690TD, sheet thickness t_{Bl} = 1.5 mm; projection: ISO C5; electrode force F_E = 3 kN, welding time t_S = 200 ms, welding current I_S = 13.0 kA); ***a)*** cross-tension and tensile shear forces, ***b)*** fracture pattern: unsymmetrical with spatter, ***c)*** metallographic specimen: cracks in the region of the embossing, pore or shrinkage cavity.



Sheet thickness mm	Lower die diameter mm	Spherical diameter mm	Projection height mm
0.8 ... 1.0	4.5	3	1,0 ... 1,1
1.0 ... 1.25	5.0	3	1.1 ... 1.2
1.25 ... 1.5	5.5	3	1.2 ... 1.3
1.5 ... 1.75	6.0	3	1.3 ... 1.4
1.75 ... 2.0	6.5	3	1.6 ... 1.7

Fig. 4. *Schematic representation of the optimised projection geometry* ***(a)*** *with a spherical upper die* ***(b)*** *and a lower forming die* ***(c)*** *as well as recommended dimensions according to the table.*

The test results show that the ISO projections are suitable for the advanced high-strength sheets to a limited extent only. The inclination to spatter is high and the unsymmetrical fracture pattern and the relatively wide scatters of the results suggest that the geometry must be optimised.

2.2 Optimisation of the geometry

A suitable geometry with the following criteria is necessary in order to exploit the economic advantages of resistance projection welding:

- ☐ uniform sheet thickness in the formed region,
- ☐ uniform strain hardening,
- ☐ no sharp edges,
- ☐ high stiffness,
- ☐ no cylindrical lug at the edge of the projection,
- ☐ embossing into a lower forming die.

One projection geometry in order to attain these objectives is portrayed schematically on Fig. 4. The welding projections are obtained using a spherical upper die (diameter: 3.0 mm) and spherical lower dies with different diameters.

In this respect, particular attention is paid to homogeneous interfaces between the various regions of the welding projection (side of the projection). The embossing of the projection in a negative form yields the advantages that the material is formed in a more defined way in the lower die and also that the cracking at sharp edges is prevented. The forming is carried out gently and the interfaces are smooth. The lower die diameter was stipulated at the nominal diameter of $5 \cdot \sqrt{t}$. For the suitable projection height, reference was made to DIN EN 28167. Fig. 5 shows a selection of various diameters and heights which can be manufactured with varying upper die penetration. For the indicated shapes, it is true that the forming proceeds very harmoniously in the region of the side of the projection and that reductions in the sheet thickness are hardly recognisable.

The embossing forces for the manufacture of these geometries are approx. 4.0 to 11.0 kN depending on the required projection diameters and heights. No cracks caused by the forming process were detected in the case of the investigated polyphase steels.

2.3 Welding tests with optimised projections

High-speed photographs were also taken in order to illustrate the advantages of the optimised projection geometry during the resistance heating. The individual photographs at various welding times are portrayed on Fig. 6. It becomes recognisable that the initial heating takes place in the contact region between the projection and the sheet. In comparison with this, welds with ISO projections have an inclination to the burning-through of the projection. The resistance heating in the optimised projection tends to be stronger in the sheet base material. This leads to an additional reduction in the inclination to cracking at the embossed projection.

As can be seen on the individual photographs, the optimised projection can be heated in a considerably more favourable way than the ISO projection. The highest heat concentration arises, as desired, directly at the apex of the projection (in the contact area between the sheets to be welded together). The projection geometry is retained almost until the end and does not collapse abruptly. The more positive welding behaviour is also shown when the cross-tension and tensile shear forces are established, Fig. 7.

It is to be recommended to increase the amperage and the electrode force in comparison with the ISO projection (i.e. by 1 kA and 1 kN respectively) in order to achieve high tensile forces and uniform spot diameters. Approx. 20% higher tensile shear forces are obtained than in the case of the ISO projection with a simultaneous reduction in the variance to 5% (ISO projection: 13%). In the cross-tension test, the rises in the tensile force turn

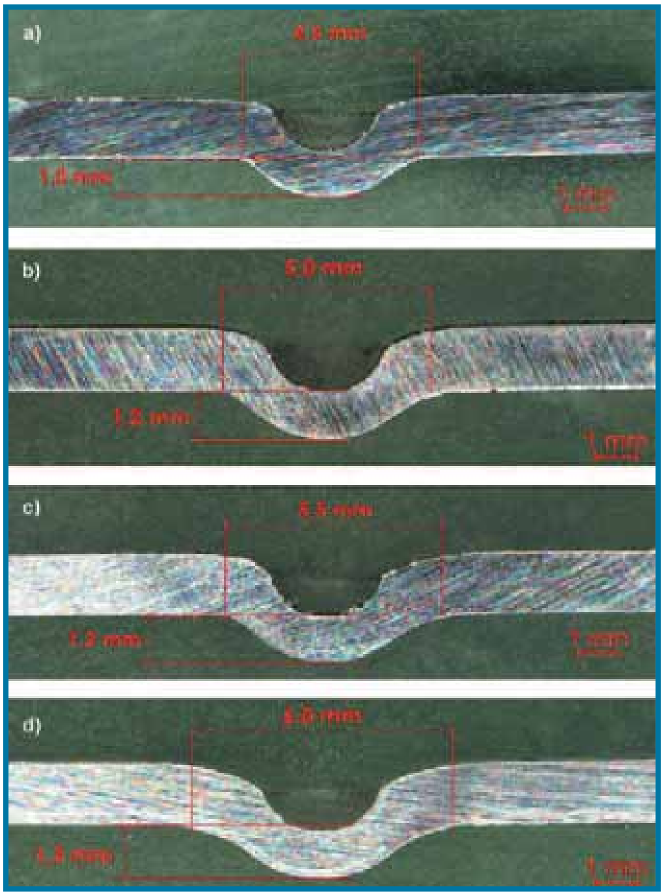


Fig. 5. *Examples of projection geometries which can be manufactured with different diameters;* ***a)*** *projection diameter: 4.5 mm,* ***b)*** *projection diameter: 5.0 mm,* ***c)*** *projection diameter: 5.5 mm,* ***d)*** *projection diameter: 6.0 mm.*

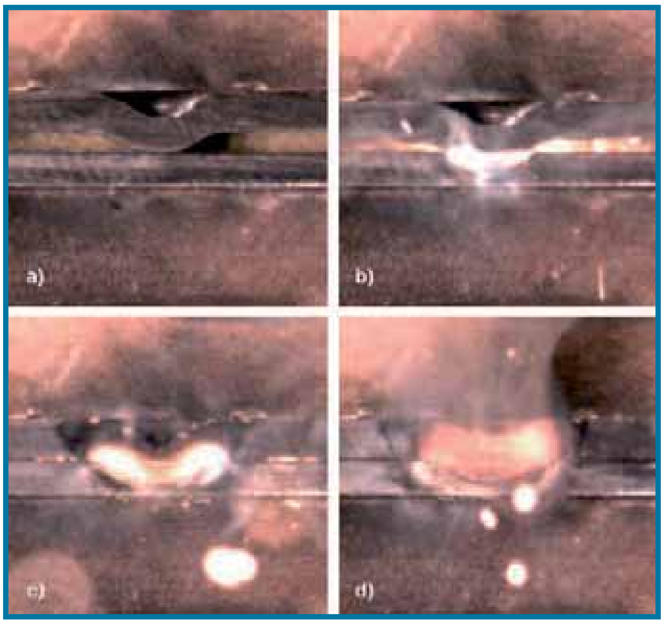


Fig. 6. Heating of the optimised projection and deformation behaviour during the welding; ***a)*** *welding time t_S = 0 ms, the electrode force is applied,* ***b)*** *t_S = 60 ms, beginning of the heating at the contact position between the projection and the sheet,* ***c)*** *t_S = 100 ms, further heating with drifting of the resistance heating outwards,* ***d)*** *t_S = 200 ms, complete melting of the projection with better complete melting of the base sheet.*

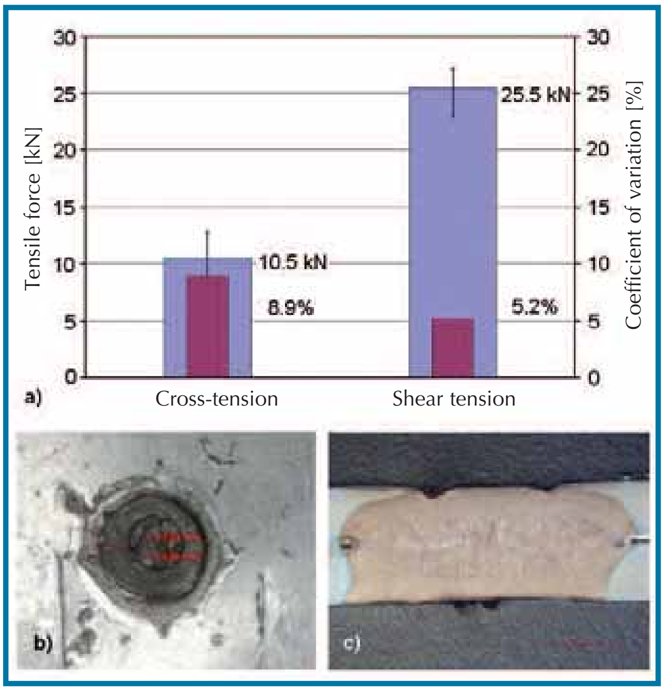


Fig. 7. *Resistance projection welds with optimised projections (material: HCT690TD, sheet thickness t_{Bl} = 1.5 mm; optimised projection with diameter: 5.5 mm, height: 1.2 mm; electrode force F_E = 4 kN, welding time t_S = 200 ms, welding current I_S = 15.0 kA);* ***a)*** *cross-tension and tensile shear forces,* ***b)*** *fracture pattern: detachment fracture,* ***c)*** *metallographic specimen: defect-free joint.*

out to be smaller due to the loading since the notch effect exerts a great influence on the attainable tensile force there. The cross-tension forces increase by approx. 15% to 10.5 kN.

The investigations on mixed joints (e.g. between DX54 and HCT690TD) also explain that very uniform and high tensile shear forces can be achieved with the optimised geometry. As shown by the results, the new geometry is also suitable for soft deep-drawing steels. Above all, the variance in the established tensile shear forces (10 kN) is very small at 3%. The penetration behaviour into the base sheet is very good.

3 Concluding remarks

The resistance projection welding of advanced high-strength embossed sheets is possible with good process reliability if the projection geometries satisfy more stringent requirements. Corresponding to the higher strengths, the new geometry should not exhibit any reductions in the sheet thickness in the region of the upper embossing die. A spherical upper die which makes provision for smooth interfaces at the side is suitable for advanced high-strength materials. Because of the high material strength and strain hardening resulting from the forming process, the stiffness is reduced only insignificantly. It was possible to demonstrate that the utilisation of the optimised projection geometries led to an improvement in the strength and, in part, in the coefficient of variation too.

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