WELDING & JOINING MATTERS

A journal of The Welding Institute

The Welding Institute
ESTABLISHED 1923

Issue 15
August 2026

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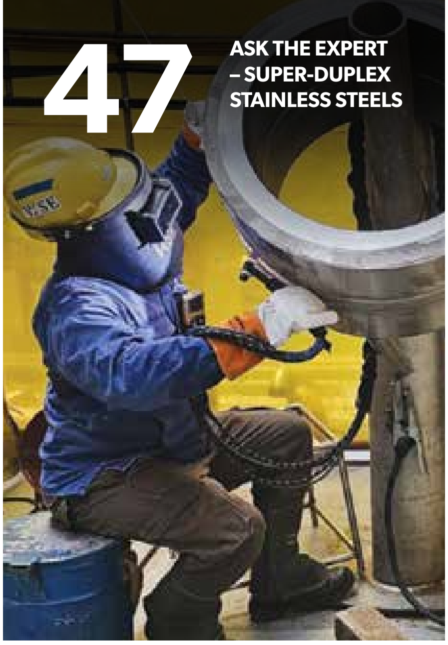

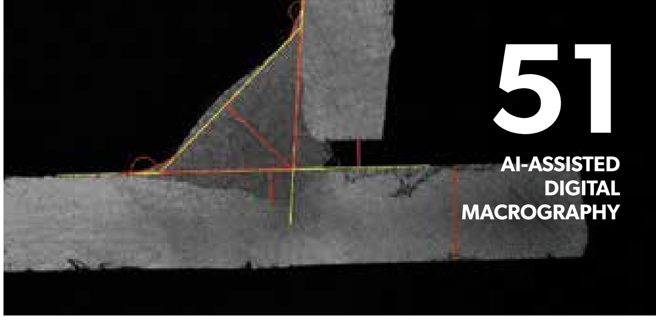

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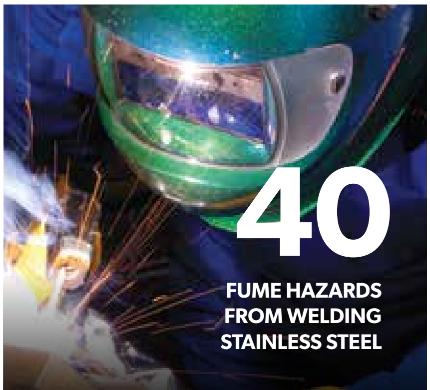

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Main cover picture: A stainless steel pressure vessel for the UK chemical industry. Image courtesy of Langfields.
Roundel image: Intergranular stress corrosion cracking. Image courtesy of R-TECH Group.

WELCOME TO THIS ISSUE OF WELDING AND JOINING MATTERS - BY ROB COOPER MANAGING DIRECTOR OF THE BRITISH STAINLESS STEEL ASSOCIATION

As the trade body representing the UK's stainless steel sector, the British Stainless Steel Association (BSSA) is delighted to contribute to Issue 15 and to strengthen our collaboration with the welding and fabrication community.

Welding is what brings stainless steel to life and it is fitting that this issue of *Welding and Joining Matters* gives prominence to this important family of construction materials, highlighting their versatility and the critical role welding plays in enabling their use.

Although stainless steels represent a relatively small share of the wider UK steel sector, their importance is large. They are the materials of choice for high integrity, long life applications across manufacturing, construction, energy, healthcare, transport and the food and beverage industries. Wherever durability, corrosion resistance and reliability are essential, stainless steels consistently deliver. However, stainless steels do not achieve their full potential by material selection alone. Their performance depends on how they are fabricated and welding is a critical enabling technology. Selecting the correct filler metal and gases, controlling heat input and performing the correct post-welding treatments are all essential for maintaining the stainless steel's integrity, corrosion resistance and surface condition. The expertise of welders and welding engineers is central to achieving successful results.

This issue of WJM provides an opportunity to recognise that expertise and reinforce the importance of sharing best practice. This is something the BSSA supports through guidance, technical resources and collaboration.

A pivotal moment: the UK Steel Strategy

The Government's UK Steel Strategy, published on 20 March 2026, sets out to secure the long-term future of UK steelmaking, strengthen resilience and position the UK as a leader in low carbon production.

The strategy includes a target to increase the proportion of steel used in the UK that is produced domestically, from around 30% to as much as 50%. It also introduces trade measures such as reduced import quotas and tariffs on out of quota steel while prioritising growth in sectors including clean energy, advanced manufacturing and defence. Although focused on carbon steel, the implications for the stainless steel industry are significant. Stainless steels are essential to many of the sectors highlighted, from nuclear energy to food production and pharmaceuticals. As the wider steel landscape evolves, stainless steel supply chains, availability and competitiveness will inevitably be affected.

What does this mean for the UK stainless steel market? The BSSA sees both opportunities and challenges emerging and recent investment signals growing confidence in the UK. Marcegaglia's £50 million investment in Sheffield, including a new electric arc furnace which will be coming online this year will significantly increase domestic melting capacity, and ensure stainless steel production in the UK has a long-term future.

Forthcoming changes to quotas and tariffs may influence steel flows into the UK. Since global supply chains are interconnected tighter import conditions may affect pricing and sourcing.

The Strategy's focus on clean steelmaking aligns closely with stainless steel's strengths. Produced largely via electric arc furnaces using recycled content, and offering long service life with full recyclability, stainless steel supports the objective of a circular economy. The success of products manufactured from the stainless steels depends on weld quality and critically on the people and skills employed. Continued investment in training and knowledge sharing will be essential for both conventional applications and for new developments, such as the application of new grades of duplex stainless steel and the use of advanced welding processes.

The broad view

The UK is the birthplace of stainless steel, first developed in Sheffield in 1913, and the sector is now entering a new period of change and opportunity. This issue of WJM highlights the technical landscape that defines stainless steel today. The UK Steel Strategy signals renewed commitment to metals manufacturing, and stainless steel will be central to delivering that ambition. The BSSA looks forward to sharing insights, highlighting best practice and supporting the welding community who are so important to our success. Together, we can ensure that the UK remains a centre of excellence for stainless steel innovation, engineering and fabrication.

Rob Cooper, Managing Director, British Stainless Steel Association (BSSA)

Rob has worked within the stainless steel industry for over 30 years in commercial and managerial roles. He has been an active board member of BSSA since 2015 and Managing Director since 2020.

Nuclear Energy

UK. Rolls-Royce Nuclear

An agreement has been reached between Rolls-Royce Nuclear and Siemens Energy for Siemens to supply their SST-8000 steam turbine-generator set as an intrinsic part of the RR-SMR power generation nuclear island. This will enable the provision of a complete, fully integrated SMR power generation package.

In addition, following a £2.5 bn partnership between R-R Nuclear and the UK government, Great British Energy-Nuclear has confirmed that the Wylfa site on Ynys Môn (Anglesey), North Wales, has been selected for the installation of three RR 470 MWe SMRs. RR are predicting that this will create 3000 jobs locally and an additional 5000 nationally. There is also a possibility of the site hosting an additional five SMRs to give a total generating capacity of over 1.4 GWe.

UK. Sizewell C

The UK's Department of Energy has awarded Mott Macdonald a 2-year contract of between £3.64 million and £4.84 million for the provision of technical consultancy during construction of the Sizewell C project. The project of two EPR reactors producing 3.2 GWe is planned to be similar to Hinckley Point C. It is anticipated that the experience gained at Hinckley Point will enable the Sizewell project to be completed more rapidly and at lower cost.

UK. The Odin microreactor

Atomworks of the UK and Mott MacDonald are collaborating on the development of the Cambridge Atomworks "Odin" microreactor, a self-contained package comprising a low-pressure, molten-salt cooled solid fuel fission reactor, electrical power generation and air-cooled cooling system, the entire unit being capable of transportation on a single low-loader. The intention is to have a prototype operational by 2030 with units becoming available to off-grid clients by the mid-2030s. Microreactors are classified as capable of generating up to 10 MWe.

Hungary

MVM Ltd (Hungarian Electricity Works Ltd) has signed a memorandum of understanding with the USA company Holtec International to investigate the deployment of Holtec's SMR-300, a 300 MWe PWR. The Hungarian company is considering the construction of up to 10 SMRs with a value approaching £15 billion ($20 billion).

China

At the San'ao nuclear power site in Zhejiang province, China, Unit 1, a Hualong One (HPR1000) pressurised water reactor, achieved a sustained chain reaction for the first time on 13th February 2026. The project was approved in September 2020 with the concrete for Unit 1 poured in December of that year and for Unit 2 a year later. The units are scheduled to be connected to the grid in 2026 and 2027 respectively with an additional four units planned for erection at the site. When complete the site will have an annual production capacity of 54 terawatt-hour (TWh), reducing annual coal consumption by some 50 million tonnes.

TWh, GWh, MWh and kWh, are measures of the energy capacity of a system; i.e. what that system delivers in one hour. A terawatt-hour (TWh) is one trillion watt-hours (10^{12} watt-hours). A gigawatt-hr (GWh) is one billion (10^9) watt-hours. A megawatt-hour (MWh) is equal to 1 million (10^6) watt-hours. A kilowatt-hour (kWh) is 1 thousand watt-hours. Example: a electrical fire is working at 2kW at any instant and hence in one hour will consume 2 kWh of electricity. Hinkley Point C will be capable of producing 3,200 MWe at any instant, with an annual expected production of about 25 TWh of electricity. SI units use the suffix e for the electrical output and t for the thermal output and each is a subscript. However these are frequently written without the subscript (as here) and for large power plant the abbreviation used is th rather than a t in many sources. Some sources do not specify whether they refer to electrical or thermal output.

Romania

Nuclearelectrica, the Romanian state-owned nuclear power corporation and the US based company NuScale signed an agreement in 2021 for the deployment of a fleet of the NuScale VOYGR-6 SMRs. The aim is to install six modules with a combined output of 462 MWe at the former coal fired plant at Doicesti near Bucharest with the first module in operation by 2033.

Bulgaria

A Bulgarian energy company, Blue Bird Energy, along with a European project developer, SGE SA, has signed a letter of intent for a joint venture (JV) that could build a fleet of as many as six small modular reactors (SMRs) in the country. It is planned for GE Vernova Hitachi to supply BWRX-300 SMRs, currently being manufactured in Ontario, Canada.

South Korea

X-Energy of Maryland, USA, has negotiated a binding supply chain agreement with Doosan Enerbility of South Korea for the manufacture of 16 Xe-100 SMRs, including the reactor pressure vessels, steam generators and other large steel structures. The Xe-100 is a high temperature (750 °C) gas cooled reactor producing 200 MWt. Doosan is intending to develop a dedicated SMR manufacturing facility in South Korea as part of the X-Energy programme for the production of a total of some 144 SMRs.

USA

The US Department of Defense and Energy and Valar Atomics of Hawthorne, California have transported one of Valar Atomics Ward 250 microreactors, without fuel, from California to the Utah San Rafael Energy Lab for testing. The Ward 250 is a 5 MWe high temperature gas-cooled reactor designed for deployment to military bases and remote locations, with commercial operation planned for 2028.

ITER - France

The International Thermonuclear Experimental Reactor (ITER) in Cadarache, France has received the final components required to assemble the magnet designed to shape and control the superheated plasma. The central solenoid comprises six modules, each weighing 122.5 tonnes wound with 6 kilometres of niobium-tin wire that becomes superconducting when cooled to -269 °C. When assembled the solenoid measures 18 metres in height and 4.25 metres in diameter with a weight of some 735 tonnes.

Tangerine peel for recovery from radiation damage

In an interesting press release and perhaps of relevance to the nuclear industry, a research team at South Korea's Advanced Radiation Research Institute have isolated an antioxidant, hesperidin, from tangerine peel. This has been shown to restore liver, heart and kidney tissues damaged by radiation. In mice the hesperidin was determined to restore liver enzyme function by more than 90% and to have a prophylactic effect if taken prior to radiation exposure.

Carbon capture - UK

NZT Power (Net Zero Teesside Power) has announced a £4 billion project at the former Redcar steelworks for the construction of a gas fired power station with carbon capture, claimed to be a world first. The power station is planned for completion in 2028 with the carbon dioxide to be transported by pipeline for storage beneath the North Sea.

Renewables

UK

The construction of the Inch Cape wind farm, capable of generating 1.1 gigawatts and located 15 to 22 kilometres (9 to 13 miles) off the Angus coastline near Arbroath Scotland has commenced. Connection to the grid is expected to be achieved in 2027. The wind farm will comprise 72 Vestas V236 15 MW wind turbines positioned on monopile and jacket foundations in water depths ranging from 34 metres to 64 metres. The power will be transmitted by some 85 kilometres of subsea cables to a newly-built substation at the former coal-fired Cockenzie Power Station in East Lothian, Scotland.

On a less favourable note with regard to wind power, a report prepared by the energy analyst Montel has recorded a record loss in 2025 of 10 TWh of electricity resulting in a charge to UK billpayers of some £1.4 bn in curtailment costs, the costs paid to wind farm operators when they are required to switch off. The main reason for this loss is the inadequacy of the grid with too few lines.

To address this Ofgem has approved the expenditure of £90 bn by the National Grid, Scottish Power and SSE for the installation of new sub-stations and lines, although this programme is expected to take up to 5 years to complete.

EDF Power Solutions and the UK based Luminous Energy have received UK government permission to build the Springwell solar 800 MWe solar plant and battery energy storage system in North Kesteven, Lincolnshire. The solar farm is expected to cover some 594 hectares (1,468 acres). Also receiving government approval is a solar PV plant and battery storage system, generating 238 MWe, to be installed by Sussex based Boom Power at Fenwick near Doncaster UK.

Ukraine

The energy company DTEK Group of Ukraine has announced that it will invest €1.2 billion (£1.02 billion) in the construction of a 650 MWe wind farm with DTEK Renewables installing some 100 wind turbines at the Poltavska site in Poltova, central Ukraine.

Denmark

Alight Energy has commissioned a 253 hectare 215 MWe solar energy park at Rødby Harbour on Lolland, the second largest solar farm in Denmark. The park comprises 350,000 panels, half of which are trackers, designed to follow the sun. In addition, the solar park hosts some 1,700 sheep which are allowed to graze beneath the panels.

Japan

Located about 7 to 11 km off the coast, Japan's first floating offshore wind farm was connected to the grid in January 2026. The Goto 16.8 MWe offshore wind farm comprises eight Hitachi 2.1 MW turbines, each positioned on a ballasted vertical cylinder anchored to the seabed by three chain mooring at a depth of 120 to 135 metres and designed for sea conditions in the path of a typhoon.

Geo-thermal Energy

Canada

In a significant development in utilising geo-thermal energy Eavor Technologies, based in Calgary, Alberta, achieved a world first in providing electrical power to the grid in December 2025 at their Geretsried site in Bavaria, Germany, using their thermo-siphon closed loop geothermal system. The system uses horizontally drilled piping forming a completely sealed heat exchanger extracting heat from the surrounding rock and with no interaction with any surrounding fluid. The facility commenced providing 64 MW of heat and 8 MW of electrical power to the local community in December 2025.

UK

Picture courtesy of GEL Energy Ltd.

A somewhat similar development in Cornwall utilising geothermal energy has recently begun supplying power to the National Grid in a first for the UK. Geothermal Engineering Ltd (GEL) has commissioned a geothermal plant at their United Downs site near Redruth, capable of generating up to 3 MWe. The plant uses mineral rich hot water at a temperature of 190 °C pumped from granite rock at a depth of around 5275 m, to drive a steam turbine. An added significant bonus is that the hot water also contains lithium which is extracted before the water is re-injected via a shallower, 2393 m deep well.

CORINTH PIPE WORKS UK LTD – THE NEW NAME FOR THE HARTLEPOOL LSAW PIPE MILL

The longitudinal seam pipe manufacturing plant in Hartlepool, formerly owned by Liberty Pipes (Hartlepool) Ltd has been renamed Corinth Pipeworks UK Ltd following its acquisition on 4 March 2026 by Cenergy Holdings, based in Belgium. Hartlepool LSAW pipes facility was established in 1926 and boasts a rich legacy of supplying high-performance pipe to energy companies such as Shell, BP, Total and Equinor as well as leading subsea engineering firms. This facility is a significant asset for the UK, aligned with government priorities in infrastructure renewal, decarbonisation (through the use of hydrogen and carbon capture and storage), and national supply chain resilience.

Ilias Bekiros, General Manager of Corinth Pipeworks, commented: *"Hartlepool LSAW facility's strategic acquisition intends to double CPW's LSAW capacity, enabling the company to undertake major projects worldwide. The move further strengthens CPW's position as a leading manufacturer of pipes for demanding deep offshore applications, supported by an exceptional track record in the industry."*

MILITARY-GRADE WELDING ACCREDITATION SECURED BY HOLLYGATE FABRICATIONS

Hollygate Fabrications, part of the Hyde Group, has achieved the DIN 2303 Q2 BK1 military grade welding accreditation, a milestone that positions the business to undertake highly critical defence and national infrastructure projects.

This accreditation recognises Hollygate Fabrications' ability to work under tightly controlled processes, manage complex documentation requirements and consistently deliver quality on safety critical components. Dan Spensley, Technical Director at Hollygate Fabrications, said: *"This accreditation … requires robust systems, a deep understanding of welding process control and a strong team culture. This has been a collective effort across the business and it reflects the standards we expect of ourselves when working on critical defence applications."*

Hollygate Fabrications operates a broad range of welding processes, including TIG, MIG, MAG, FCAW, MCAW, SAW and drawn-arc stud welding. Their facility is designed to handle large fabricated structures, with component capacities up to 20 metres in length and 6 metres in width. They operate a state-of-the-art dual collaborative robot welding system which, in combination with the advanced Lorch UK welding system, produces exceptional accuracy, consistency and efficiency. They work in carbon steel, stainless steel, duplex, super-duplex and aluminium alloys. Hollygate Fabrications also offer water-jet cutting, high accuracy profile cutting, heavy duty brake pressing, rolling capabilities and both vertical and horizontal sawing.

The combination of advanced welding capability, accredited quality systems including EN 1090 EXC4 and EN ISO 3834-2 and the attainment of the DIN 2303 Q2 BK1 accreditation together with group level support demonstrate the growth of Hollygate Fabrication and their position as a quality supplier to the defence industry.

ECITB DEVELOPS UPSKILL PROGRAMME FOR WELDERS

The Engineering Construction Industry Training Board (ECITB) predicts that the number of welders required in the Engineering Construction Industry could rise to more than 2,150 by 2030, up from 1,470 in 2025. To help tackle this shortfall ECITB has released a six-week programme designed to upskill individuals with limited or basic welding experience. Following a successful pilot, the ECITB is calling for training providers to deliver the Multi-position Fillet Welding (MMA) programme as part of a wider rollout across Great Britain. This programme has a particular focus on supporting workforce requirements within the nuclear sector, it also has strong cross-sector relevance and is suitable for a wide range of engineering construction environments.

The programme provides a structured pathway from foundational welding skills to multi-position MMA welding capability and technical test readiness. It blends theory and practical training. As well as those with limited experience, the programme is designed for learners seeking to transition into welding roles or those requiring structured development before formal welder testing to verify competence.

Learner progress is measured via the completion of a course workbook, a multiple-choice knowledge test and practical observation and assessment. Any training providers wishing to deliver the upskill welding programme should email programmeadmin@ecitb.org.uk

Find out more about the ECITB's welding training courses, tests and qualifications at https://www.ecitb.org.uk/professional-development/technical-and-trade/welding/

WALL COLMONOY LAUNCH THEIR SURFACING ALLOYS MICROSITE

Wall Colmonoy has announced the launch of its new Alloy Products Surfacing Alloys microsite, a dedicated digital resource designed to provide customers with easier access to product information and technical resources. The microsite provides access to Wall Colmonoy's Surfacing Alloys, including Colmonoy®, Wallex®, Colferoloy™, and WallCarb™ Tungsten Carbide and composite alloys. It also features the company's thermal spray equipment, including the Spraywelder™ System and Fusewelder™ Torch.

A key feature of the site is the Product Finder tool, which allows users to search for products by alloy type, hardness, industry, and application. This functionality makes it easier for customers to identify and compare products that align with specific operational needs, including wear resistance, corrosion protection, and overall performance requirements. The microsite is accessible on desktop and mobile.

Visit the new site at: surfacingalloys.wallcolmonoy.com

AN INTERNATIONAL SHORTFALL IN SKILLED WORKERS FOR THE ENERGY INDUSTRIES

The World Energy Employment report by Goldman Sachs Research and commissioned by the International Energy Agency (IEA), has determined that in the global energy sector (oil and gas, electricity) employment had reached some 76 million in 2024, increasing by more than 5 million since 2019. At the same time, the supply of newly qualified workers is not keeping pace with the sector's needs. Applied technical workers make up some 41 million of the energy workforce, with technicians, skilled workers and plant and machine operators and welders, pipefitters, electricians and solar PV workers making up the largest proportion.

Newly qualified entrants into the energy sector will need to increase by 40% to prevent the shortage of skilled workers from increasing further, this shortage of skilled workers having already become a major bottleneck in supply chains for many firms. The report states that an additional $2.6 billion (£1.92 billion) in training costs would be required to address this shortfall, representing less than 0.1% of global spending on education.

It is primarily the increasing demand for electricity from transport electrification, the burgeoning datacentre and AI industry and the nuclear engineering and renewables manufacturing industries that has resulted in this acute shortage of skilled, knowledgeable and experienced tradesmen, technicians and engineers. The electricity sector is now the largest energy employer with employment increasing by some 3.9 million jobs, overtaking the fossil fuel industries as the demand for electricity increases.

This 3.9 million jobs increase in the electricity generation, transmission, distribution, and storage sector has solar energy accounting for half of the job additions. In the transmission and electricity distribution sector alone, Goldman Sachs predicts that 65,000 apprenticeships are required in the forthcoming years just to satisfy the increased demand in skilled workers in this specific area. This figure does not include those needed to replace retiring workers nor the shortages in other industries.

Internationally, some 2.5 million additional positions for applied technical workers have been created since 2019, accounting for more than half of the increase in the energy workforce. Skilled workers such as electricians, pipefitters and welders, as well as plant operators and nuclear engineers are in particularly short supply.

The research has revealed that in the advanced economies an ageing energy workforce is increasing skill shortages with 2.4 workers approaching retirement for every worker below the age of 25 entering the energy industry; the ratio in the nuclear industry is 1.7:1. It is predicted that between now and 2035 two out of every three new workers will simply replace retirees. In the United Kingdom a shortfall of 1 million jobs is predicted as 20% of the engineering workforce retires within the next 15 years unless action is taken to encourage engineering focussed apprenticeships and reskilling of workers from other industries. Reskilling workers from the waning oil and gas industry for employment in offshore wind power and geothermal engineering may go some way to addressing this potential shortfall.

Copies of the full report can be obtained from https://www.iea.org/reports/world-energy-employment-2025.

ISSUES IN UK WELDING VOCATIONAL EDUCATION AND TRAINING – THE GAPS

Miles Goodwin. Wales Branch, The Welding Institute

Acknowledgements: The author wishes to thank Chris Smallbone; past-President of IIW, for his contribution to this report.

The UK welding education and training system is facing gaps in structure and capacity, and the attractiveness of the offering which, collectively prevent the training sector from producing the number of skilled welders required by industry. This article is an attempt to summarise the issues, to stimulate debate and the development of solutions.

Background

Severe constraints on training capacity

- Further education (FE) colleges struggle to recruit experienced welders as instructors, limiting the number of places they can offer.
- Although 91 colleges offer Level 3 fabricator/welder courses, only 231 trainees graduated in 2024, showing a major mismatch between provision and actual throughput.

Breakdown in the apprenticeship 'pipeline'

- The UK faces a shortage of 35,000+ welders due to retirements and insufficient new entrants.
- Employers report that apprenticeship wage costs have risen 66% (2023–2025), making it harder for SMEs to take on apprentices.
- Reduced employer capacity means colleges struggle to justify running welding programmes because fewer apprenticeship placements exist.

Weak educational engagement and poor career awareness

- Promotion and training in vocational and technical skills in schools and colleges is inadequate and there is no active promotion of welding as a career, thus dramatically limiting the number of young people entering the career.
- Welding still suffers from an outdated image as a "dirty job", rather than a high tech, high skill profession.

Lack of a co-ordinated National Training Strategy

- The UK has no structured, co-ordinated national programme to train welders. This is necessary to produces skilled staff in the volume required.
- Discussion centres on 'welders'. which shows a poor understanding of the range of skills in welding and welding technology which are necessary to meet modern industrial needs.
- Policy currently treats recruiting from overseas as a solution to the shortage, at a time when obtaining work permits is difficult. At best it is a short-term partial solution.
- Solutions promoted include very short, focussed training schemes lasting a few weeks. These have their place but will not meet the need for the breadth of skills and knowledge required for the majority of welding jobs in industry.

Instructor pay does not align with industry rates

- Further Education colleges cannot scale-up their courses because instructor pay does not compete with industry wages, making recruitment of qualified trainers extremely difficult.

Problems in the retention of welders after qualification

- The numbers who complete training in the construction trades are variable with suspected high drop-out rates.
- Retention after qualification is not incentivised.
- There is no data collation on retention of skills and remaining in the 'pool'. Without retention training more recruits alone cannot fix the shortage.

Uneven provision across the regions

As a result of the lack of a National Strategy training provision is uneven across the UK. Consequently industrial areas are taking local initiatives with some success but they would benefit from a coherent national strategy and funding.

Overall diagnosis

The UK welding education system is constrained by limited training capacity, insufficient apprenticeship opportunities, weak early stage engagement, and a lack of national coordination. Even where courses exist, instructor shortages, cost pressures, and poor retention undermine the process and limit success. The result is a widening gap between industry demand and the number of qualified welders entering the workforce.

Welding education gap matrix for the UK

This section examines the gaps in more detail.

Structural and system-level gaps

Gap	Root cause	Impact on FE providers	Impact on employers	Potential solutions
There is no national welding workforce strategy.	Fragmented responsibility across DfE, DLUHC, DESNZ and industry bodies.	Funding cycles are unpredictable. Colleges cannot plan multi year investment.	No stable pipeline of trained staff resulting in reliance on agency labour and overseas recruitment.	• National Welding Workforce Plan. •Multi year funding settlements. •Regional skills compacts.
Weak alignment between further education, employers, and standards bodies.	Inconsistent engagement between employers and FE. Standards are updated slowly.	Courses drift away from the needs of industry. Colleges have outdated equipment.	Apprentices arrive under-skilled. Retraining costs result.	Employer advisory boards. Mandatory industry input into curriculum planning.

Training capacity and infrastructure gaps

Gap	Root cause	Impact on FE providers	Impact on employers	Potential solutions
Instructor shortage.	FE salaries are 30% to 50% below industry rates.	Courses are capped or cancelled. Long waiting lists.	Fewer apprentices. Delayed project delivery.	Instructor salary uplift. Industry secondments. Dual professional routes.
Insufficient workshop capacity.	High CapEx for facilities: bays, extraction equipment, consumables.	Colleges limit cohort sizes and cannot scale up.	Employers forced to avoid training, recruit temporary staff or train in house.	Capital grants. Shared regional welding centres. Mobile welding training units.
Aging equipment.	Limited capital budgets for new modern equipment.	Students trained on obsolete equipment.	Trained skills do not match with modern processes (e.g., pulse MIG, automated welding).	Equipment leasing models. Equipment manufacturer/ college partnerships.

Apprenticeship pipeline gaps

Gap	Root cause	Impact on FE providers	Impact on employers	Potential solutions
Falling apprenticeship starts.	Wage inflation. SME cost pressures. Levy underspend.	Colleges cannot run full courses.	A lack of entry level labour.	Wage subsidies. Levy flexibility. Shared apprenticeship schemes.
Inconsistent workplace mentoring.	SMEs lack trained mentors.	Apprentices fail End Point Assessment (EPA) or drop out.	Lost investment in trainees. Low productivity. Rework.	National mentor training. Employer incentives.
Slow EPA throughput.	Limited EPA organisation capacity. Scheduling delays.	Qualification bottlenecks.	Delayed deployment of trained welders.	Expand EPA organisation network. Digital EPA options.

Curriculum and qualification gaps

Gap	Root cause	Impact on FE providers	Impact on employers	Potential solutions
Limited coverage of advanced processes.	Curriculum focuses on MMA/MIG/TIG basics.	FE providers are not geared up for FCAW, orbital, mechanised automatic welding and advanced processes (e.g. laser combination processes).	Employers must upskill new hires.	Modular training units. Training in partnership with equipment manufacturers (OEMs).
Insufficient awareness of shop floor welding controls.	Lack of training in specification requirements and welding procedures.	Lack of time or resource to teach these topics and students are unaware of key shop floor welding controls.	Welders require shop floor training. Token adherence to procedures.	Training modules in fundamental welding control requirements.
Insufficient awareness of inspection and NDT.	Siloed qualifications. Lack of basic training in inspection and NDT.	Lack of resource to teach these topics and students are unaware of inspection and NDT practices.	Lack of inspectors with welding experience. Employers struggle to fill inspection roles.	Embed inspection and NDT fundamentals in Level 2/Level 3.
Weak digital/ automation content.	Slow adoption of welding simulators, robotics.	Lack of resource to teach welding simulation or run courses in robotics. Students lack digital readiness.	Industry automation plans slowed.	Introduce VR/ AR simulator for manual welding. Introduce training courses with modules in automated and robotic welding.

Learner recruitment and retention gaps

Gap	Root cause	Impact on FE providers	Impact on employers	Potential solutions
Low awareness of welding careers.	Schools prioritise academic routes.	Small applicant pools.	Fewer young entrants.	National careers campaign. School outreach.
Poor retention in Level 2 to Level 3 pathways.	Low early wages. Cost of PPE and travel.	High dropout rates.	Fewer qualified welders.	Bursaries. Employer sponsorship. Travel support.
Under representation of women.	Cultural perceptions. Lack of role models.	Missed recruitment potential.	Smaller talent pool.	Targeted outreach and women in welding programmes.

Regional and sector-specific gaps

Region/Sector	Gap	Impact	Solutions
Humber, Teesside, South Wales (heavy industry).	Demand far exceeds training capacity.	Project delays in energy, shipbuilding, general fabrication.	Regional welding academies. Employer funded training provision.
Rural regions (e.g., Herefordshire, Cumbria).	Sparse provision. Travel barriers.	Learners drop out due to logistics.	Mobile training units, hybrid delivery.
Nuclear and defence sectors.	High spec welder training/qualifications not delivered widely.	Long lead times for coded welders.	Specialist academies. Sector specific funding and training provision.

Industry readiness and transition gaps

Gap	Root cause	Impact	Solutions
Slow transition to welding skills for 'green' technologies.	Limited training on dominant welding processes used for renewables, hydrogen etc.	Workforce lacking in process skills for new energy projects.	Training modules in 'green' welding. Partnerships with welding equipment manufacturers.
Lack of structured CPD for qualified welders.	No national CPD framework.	Skills stagnation. Uncertain/poor career progression.	National CPD passport. Modular upskilling.
Weak recognition of International Qualifications Framework (IQF).	Complex equivalence processes.	Migrant welders under utilised.	Streamlined recognition pathways.

Summary

UK welding education is constrained by seven systemic gaps:

1. There is no national strategy addressing future welding needs. This gives rise to a fragmented training provision and an unstable supply of welders.
2. There is a shortage of instructors. This gives rise to limits on the available courses, the numbers which can be trained and cancelled courses.
3. The apprenticeship pipeline is weak in available places and throughput. This is both a consequence and a cause of insufficient capacity for prospective employers.
4. There is a curriculum lag; a mismatch between the types of training available and the current and future needs of employers. This is a consequence of limited training provision in automated welding, advanced welding process systems and training in robotics.
5. There are systemic recruitment and retention issues due to the limited and inconsistent inflow of students, trainees and apprentices.
6. There are great regional disparities in demand and responses to the demand in terms of training initiatives and provision. The constant factor are that there are local shortages of all levels of welding skill in the UK's industrial areas.
7. There is a limited understanding of the future welding skills needed for the 'green' industries particularly in respect of automation.

The overall conclusion is that the UK cannot meet industry demand for a wide range of welding skills unless it scales-up its training capacity, modernises the curriculum and the breath of skills being trained, supports employers by providing a consistent framework of training options and capacity and develops a co-ordinated national strategy.

MILLER ELECTRIC'S HERCULES HIGH DEPOSITION WELDING PROCESS

Matt Kramer. Hercules product specialist. Miller Electric and Jeff Zook. General Manager. Gullco USA

Matt Kramer. Hercules product specialist. Miller Electric.

Jeff Zook, General Manager, Gullco USA.

Introduction to Hercules

Miller Electric introduced Hercules high deposition welding to the market commercially in 2022. Hercules features a novel approach that eliminates an often-overlooked variable which occurs with traditional single wire GMAW methods; the position where the welding wire picks up the current wanders within the contact tip. Hercules introduces a secondary contact upstream of the arc initiating contact within the welding torch which has a dedicated power supply. This energy raises the temperature of the filler metal via resistance heating and effectively maintains this at a constant value and then the primary power supply initiates the arc and executes the weld. The reduction in variability of power and resistance heating allows Hercules to achieve dramatically higher deposition rates over other single wire GMAW process variants.

The difference between Hercules and traditional single wire GMAW

With traditional single wire GMAW the distance from the point of contact to the arc is continuously changing and the amount of resistance heating that occurs in the filler metal changes with it. Figure 1 illustrates the variability of the distance from contact point to the tip of the wire which can vary by as much as 400 to 500%. The change in the amount of resistance heating in the electrode is not readily controlled by the power supply, challenging its ability to maintain arc stability. Hercules removes the variation in resistance heating, thus allowing the same power supply to hold a stable arc at much higher wire feed speeds and torch travel speeds and provides the welder with greater control.

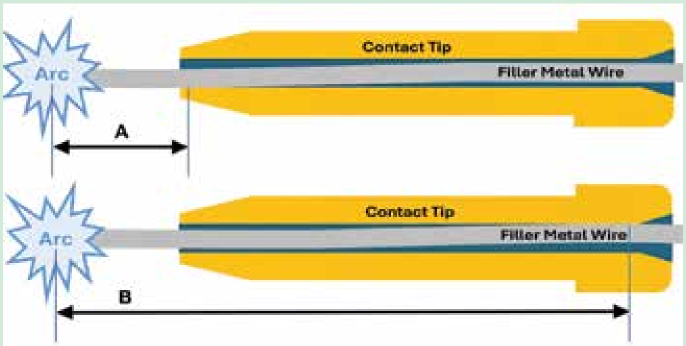

Figure 1: Potential variability in resistance heating length for traditional GMAW.

Equipment development

Hercules accomplishes the controlled resistance heating length by introducing a secondary upstream contact within a unique to Hercules liquid cooled welding torch developed by Tregaskiss. Introducing energy into the filler metal at an earlier point upstream of the arc challenges traditional filler metals which can cause drag on the wire. Hobart engineers have developed a new wire formulation that eliminates this issue. A unique wire drive by Miller accommodates the higher range of wire feed speed required for Hercules. Finally, two Miller power supplies are used. The Miller XMT furnishes the power to pre-heat the filler metal and the Miller Auto-Continuum executes the welding arc. Figure 2.

Figure 2: The Hercules system components by Hobart, Miller, and Tregaskiss.

With higher wire-feed speeds and faster torch travel speeds Hercules delivers a weld deposition rate which can be higher by 30% or more relative to convention GMAW (measured in lb/hr or kg/hr of deposited weld metal). Often Hercules does not require buying a new robot and modifying existing robot cells installed in your factory can provide that increase in deposited weld metal. If the welding cell is the bottleneck in your current manufacturing sequence then this increase can unlock under-utilised capacity in upstream and downstream operations resulting in an overall gain in productivity.

Deposition rate improvement realised in industry

Hercules is proving itself in a variety of applications across the welding industry in North America. The following YouTube file shows a tank application, with butt, lap, and groove joints that are straight, cylindrical, and a saddle: https://www.youtube.com/watch?v=c181GD_4Jyg. The video shows on split screen a 'race' in which Hercules finished a straight seam in 1 minute and 14 seconds, while traditional solid single wire GMAW took 3 minutes and 31 seconds to finish. Comparative results will, of course, vary based on the different welding situations under evaluation (e.g. solid wire, cored wire, type of joint, type of gas, transfer mode) however this dramatic improvement is of the same order of magnitude as results reported by Miller's customers across many applications.

Figure 3 shows comparisons in time between Hercules and traditional GMA welding for the different configurations on the tank application. The configurations include different weld types, with and without corners as shown in the video. It is evident that time to weld with Hercules versus an optimised solid wire GMA weld varies with the weld configuration but in each example there are productivity gains which are from 38% to 78%. Hercules shows its main productivity advantages for the long straight welds and sometimes in a program Hercules will get turned off in favour of a more traditional GMAW process in order to navigate tighter corners and complex joint geometries.

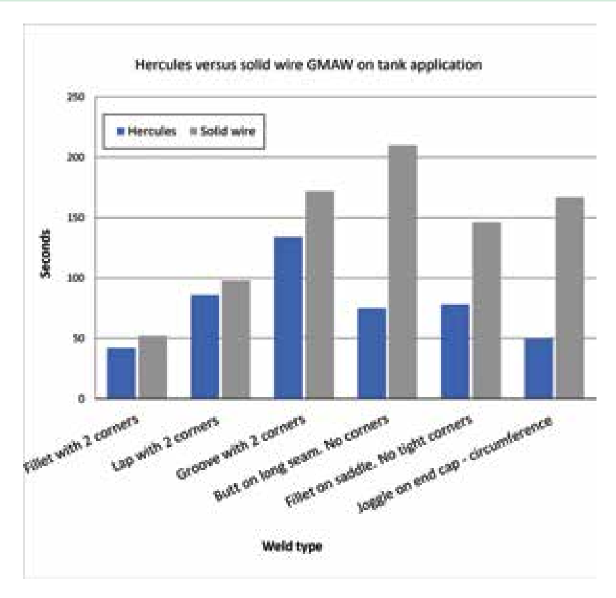

Figure 3: Hercules reduction in time to weld charted over 12 weld joints on the tank application.

Control of deposition rate

Welders have long known that increased deposition rate by itself does always result in an improvement in productivity. That increased amount of weld metal may be more than is required by design and hence is just over-welding. When using a high deposition rate process you need to match your travel speed to the higher wire feed speed to achieve the desired penetration and weld size whilst simultaneously ensuring that the heat input is appropriate for the welding procedure. Demonstrating this generally means running trial welds where wire-feed speeds and travel speeds are increased whilst monitoring arc stability. If this is done Hercules will deliver higher wire feed speeds and increased travel speeds, while achieving targeted heat input, weld size and penetration without over-welding. Miller's engineers can provide guidance on starting parameters for any specific application.

Another way to think about Hercules is that as travel speeds increase the *residence time* to complete a cross section of weld reduces. This, in turn reduces the time and hence the opportunity for variation in heat input to be introduced, making any potential variation easier to control. Feedback from industry is that Hercules introduces less heat to accomplish the same desired penetration and there are also reported benefits of elimination of internal stress and reducing leaks in vessels. This process, with its increase in deposition rate can be compared with other traditional methods of doing this using twin-wire and tandem-arc welding, however those methods have two filler wires feeding two welding arcs with their added complexity of control.

The benefit of controlled resistance heating of the welding wire

There is a relatively long history of using resistance pre-heating of the electrode or filler to improve deposition in a variety of weld processes. Examples are:

(1) stick welders reported that when using oven-dried rods (of certain types) there were residual benefits in being able to run them at higher temperatures.

(2) The use of 'hot wire' to improve deposition in TIG welding.

(3) The use of 'hot wire' filler in laser welding.

In GMAW various kinds of contact tip designs have been proposed to increase the effective length over which resistance heating occurs. One proposal was to lengthen the contact tip to increase the distance between the point where the welding wire makes electrical contact and the arc. A more recent proposal has been to fix the point where the wire makes electrical contact within the contact tip by using a spring-loaded element, thus avoiding the contact point from moving up and down the length of the contact tube.

Achieving high productivity using Hercules

Figure 4: Hercules GMAW process running on a Gullco SAM Carriage.

Miller introduced Hercules on robotic welding applications through its automation group and field experience demonstrated that the target market would be for applications which consisted of long straight welds. Today, Miller is cooperating with Gullco to apply Hercules on fixed automated installations such as long seams in the fabrication of beams, or applications involving girth welding, and other applications where Gullco has a long history of providing industry standard, best in class solutions.

Figure 5 shows the welding parameters and deposition rate for Hercules with 1.4 mm FabCOR wire. A deposition rate of 13 kg/hr can be easily achieved, using only one wire and this is much higher than any single wire GMAW solution available. Since the process requires only one wire it is much simpler to operate and maintain when compared to other high deposition GMAW processes.

TYPICAL OPERATING PARAMETERS*:

Diameter Inches	Diameter (mm)	Weld Position	Amps	Volts	Wire Feed Speed in/min	Wire Feed Speed (m/min)	Deposition Rate lbs/hr	Deposition Rate (kg/hr)	Contact Tip to Work Distance Inches	Contact Tip to Work Distance (mm)
0.052	(1.4)	Flat & Horizontal	225	25	300	(7.6)	10.3	(4.7)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	340	26	500	(12.7)	17.0	(7.7)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	365	28	600	(15.2)	20.4	(9.2)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	400	30	700	(17.8)	23.8	(10.8)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	420	32	800	(20.3)	27.2	(12.3)	3/4	(19)
0.052	(1.4)	Flat & Horizontal	430	34	900	(22.9)	30.5	(13.9)	3/4	(19)

Figure 5: Deposition rates for 1.4 mm Hobart FabCOR Hercules wire when using the Hercules GMAW process.

Summary

Arc welding is mature technology and major advances are hard to come by. Miller Hercules achieves a step-change in productivity by developing from known physical principles, coupled with Miller arc control technology.

Hercules delivers a similar or better deposition rate to submerged arc welding or twin arc welding without the limitations or added complexity of those processes. It is increasingly recognised in the North American marketplace as providing a new benchmark for higher deposition rate welding with a process which is simple to apply and easy to control.

LASER CLEANING FOR METAL: PRINCIPLES, APPLICATIONS, AND INDUSTRIAL ADVANTAGES

Steve Purnell. Business Development Manager.
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Laser cleaning is an advanced surface treatment technology used to remove contaminants, coatings, rust, oxides, oil, and residues from metal surfaces without damaging the underlying substrate. Unlike abrasive blasting, chemical cleaning, or mechanical grinding, laser cleaning uses highly controlled laser energy to selectively vaporise or dislodge unwanted material.

Fundamentals of laser cleaning

The process

Laser cleaning operates by directing a high-intensity laser beam onto a contaminated metal surface. The contaminant layer absorbs laser energy more efficiently than the base metal. As energy accumulates, the contamination undergoes thermal expansion, vaporisation, sublimation, shockwave detachment and plasma-induced removal. The base metal remains largely unaffected when process parameters are correctly configured.

The types of lasers used

Fibre lasers are the most common industrial choice due to their high electrical efficiency, compact design, and excellent beam quality. Typically they work at a wavelength of 1064 nm with power ranges up to 3 kW. They are particularly suited to rust removal, paint stripping, and surface preparation.

Figure 1: A compact laser cleaning machine. Copyright Fanuci & Falcon.

For more intricate applications pulsed lasers can be used which emit energy in short bursts, typically in nanosecond, picosecond or femtosecond pulses, providing high precision and doing minimal thermal damage which makes them better suited to delicate surfaces.

The physics behind laser cleaning

The cleaning mechanism depends on several interacting physical effects.

Ablation: Laser ablation occurs when the contaminant absorbs sufficient energy to exceed its vaporisation threshold. Effective cleaning requires the contaminant ablation threshold to be lower than the substrate damage threshold.

Thermal expansion and shockwave effect: Rapid heating causes microscopic expansion within the contaminant layer. This creates stress at the interface between the coating and the metal surface, leading to delamination. Pulsed lasers are especially effective because they generate high peak power over short durations, creating micro-shockwaves that dislodge debris.

Plasma formation: At high energy densities, a plasma plume forms above the surface. Plasma assists in removing particles but must be controlled to avoid energy shielding.

The key process parameters

Laser power: Higher power increases cleaning speed but may risk substrate damage. The use of a lower cleaning power allows more accuracy, allowing more intricate cleaning operations.

Pulse frequency: Pulse repetition influences overlap and cleaning uniformity. A higher frequency with lower peak energy will result in smother cleaning. When using a lower frequency you will achieve stronger ablation, resulting in more aggressive cleaning.

Scanning speed: The speed at which the laser beam moves across the area to be cleaned affects energy exposure. Slower speeds result in deeper cleaning with more heating. Fast scanning speeds can be used to reduce thermal load and provide faster component throughput.

Spot size: A smaller spot size provides higher energy density and better precision, whereas a large spot size will provide faster area coverage.

Metal surface applications

The process has gained widespread adoption in manufacturing, aerospace, automotive, shipbuilding, electronics, and restoration industries because of its precision, environmental benefits, and low operational waste. Applications in the metal working industries include:

Rust removal: Laser cleaning efficiently removes iron oxide without grinding away healthy steel and preserves dimensional tolerances with minimal secondary waste and no abrasive media contamination.

Paint and coating removal: Laser cleaning is highly effective for paint and coating removal because it uses targeted light energy to selectively vaporize the paint layer without harming the base material (Figure 2).

Oxide layer removal: Laser cleaning is ideal for removing oxide layers because it uses precise laser ablation to instantly vaporise the oxide without damaging the underlying metal (Figure 3). It eliminates the need for abrasive media or harsh chemicals, ensuring the base material remains completely intact while providing an ideal solution where improved weld quality or where optimum electrical conductivity is required.

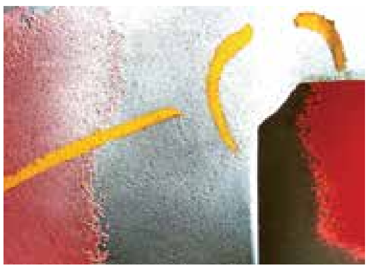

Figure 2: A weld, stripped of paint for inspection purposes.

Figure 3: Laser removal of cutting scale from a weld bevel. Copyright Fanuci & Falcon.

Mould and tool cleaning: Laser cleaning is highly effective for mould tools because it uses non-contact laser pulses to vaporise residues without damaging the precise geometries or surface finishes of the underlying metal. Unlike traditional abrasive blasting or chemical washing, it targets only the contaminants; such as polymer build-up, resins, and mould release agents, leaving the valuable substrate completely untouched.

Safety requirements

Laser cleaning safety should focus heavily on radiation containment, respiratory protection, and strict administrative controls. Safety requirements for industrial laser cleaning in Europe are strictly regulated because these machines typically operate as Class 4 lasers, which pose severe risks to eyes, skin, and respiratory systems. Compliance involves meeting explicit European Directives, equipment standards, and workplace control measures as defined below.

Core European directives & standards

Directive 2006/25/EC [1]: It governs worker exposure to artificial optical radiation, setting strict exposure limits.

EN 60825-1 [2]: This standard dictates the equipment classification, engineering requirements and mandatory warning labels for laser safety.

EN 207 [3] & EN 208 [4]: These standards mandate requirements for eye protection, specifying optical density (OD) ratings for filters.

CE Marking: Requires manufacturers to ensure systems comply with machinery, electrical, and electromagnetic safety standards.

Personal protective equipment (PPE)

Laser safety eyewear: This must be certified to EN 207 standards and precisely match the exact wavelength and power of the cleaning laser.

Skin protection: This requires flame-retardant, non-reflective clothing and heat-resistant gloves to prevent burns from stray reflections.

Respiratory masks: Respirators or specialised masks are required when vaporising paints, coatings, or toxic residues.

Workplace control measures

Controlled zones: These are required to demarcate either a Nominal Ocular Hazard Area (NOHA) or a Nominal Risk Zone (NRZ) using localised safety curtains or rigid barriers to block reflections.

Warning signage: Explicit laser warning labels are used at all entry points to the designated cleaning zone.

Fume extraction: High-efficiency particulate air (HEPA) and activated carbon filtration systems are used to capture dangerous vaporised particulates.

Interlock systems: Automated door switches or laser housing interlocks are used to shut down the beam immediately if the safety boundary is breached.

Training and administrative requirements

Laser Safety Officer (LSO): Workplaces running Class 4 lasers are required to appoint a trained LSO to manage risk assessments and compliance logs.

Operator logs: Documented proof of laser safety training and current competence logs are required for every operator.

Risk Assessments: Documented Operational Risk Assessments are required which have been updated within the last 12 months.

Advantages of laser cleaning

Laser cleaning offers a non-contact process, where no physical tool touches the surface, which means no abrasive wear, no tool replacement and reduced mechanical stress. It also offers enhanced precision and selectivity allowing a targeted approach to cleaning for specific coating thicknesses, micron-scale contaminants, and localised regions. This is especially valuable in aerospace and electronics.

Table 1 presents a comparison of laser cleaning with traditional methods.

Method	Contact	Waste Generation	Precision	Environmental Impact
Sandblasting	Yes	High	Medium	Poor
Chemical	No	High	Medium	Hazardous
Grinding	Yes	Medium	Low	Moderate
Laser	No	Very low	High	Excellent

Table 1: Comparison of cleaning methods.

Conclusion

Laser cleaning has become a transformative technology for metal surface treatment. Its ability to remove contaminants precisely, efficiently, and with minimal environmental impact makes it an attractive alternative to traditional cleaning methods.

As laser sources become more affordable and automation technologies mature, laser cleaning is expected to expand further into heavy industry, precision manufacturing, and maintenance operations. The combination of precision, sustainability, and reduced consumable use positions laser cleaning as a critical technology in modern industrial production.

References

1 Directive 2006/25/EC - artificial optical radiation. https://osha.europa.eu/en

2 EN 60825-1:2014+A11:2021. Safety of laser products - Equipment classification and requirements.

3 EN 207:2017. Personal eye-protection equipment. Filters and eye-protectors against laser radiation (laser eye-protectors).

4 EN 208:2009. Personal eye-protection. Eye-protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors).

About the author

Steve Purnell has been working within the welding & fabrication industry for 40 years, starting as an apprentice at HM Naval Base in Portsmouth, then spending 4 years as TIG welder before moving on to sales & marketing roles including working with two of the world's largest welding product manufacturers.

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Image courtesy of Langfields

BACK TO BASICS #15: WELDING OF AUSTENITIC STAINLESS STEEL

EUR ING Gene Mathers CEng MSc DipIIM FWeldI

Introduction

When someone mentions 'stainless steel' most of us think of those which we encounter in normal daily life, which are the austenitic stainless steels. There are, however, four additional families of the stainless steels: martensitic, ferritic, precipitation-hardening and duplex. See pages 29 and 47. All of these steels have the common characteristic of containing more than 12% of chromium, rendering the steel resistant to corrosion in many (but not all) environments and hence considered as 'stainless'. Since each family presents different welding challenges it is vital to know the steel type being used and hence the welding aspects to be considered. For clarity this article is limited in scope to the austenitic stainless steels, (which in some cases contain small quantities of delta ferrite).

All the stainless steels, including the austenitic grades owe their corrosion resistance to the presence of chromium that forms a very thin self-healing protective film on the surface of the steel. Austenitic stainless steels do not experience a ductile/brittle transition, unlike ferritic steels. They have very good toughness at extremely low temperatures so are used extensively in cryogenic (low temperature) applications. They can be hardened and their strength increased by cold working but not by heat treatment. They are the most easily weldable of the stainless steel families and can be welded by all of the welding processes, the main problems being avoidance of hot cracking and the preservation of corrosion resistance.

Common grades of austenitic stainless steels

This article refers to the grades of stainless steel using the ASTM designations as applied in ASTM A240 [1] (and many other standards). This notation consists of a three-digit number in the format '3XX', the '3' identifying the steel as an austenitic stainless. Type 304 grade may be regarded as the archetypal austenitic stainless steel (often referred to as an 18/8 stainless steel) from which the other grades have developed. A letter suffix indicates a modification to the composition of the base grade which is required to modify certain characteristics of the alloy to achieve specific performance requirements. Example designations are 304H or type 316L.

- L indicates that it is a low carbon austenitic stainless steel relative to the standard grade, used specifically to avoid 'weld decay' in aggressive corrosive environments (see below).
- H indicates that it is a high carbon steel with improved high temperature strength relative to the standard grade for use in creep applications.
- N indicates it is a nitrogen bearing steel which gives increased tensile strength relative to the standard grade.

The compositions of the main austenitic alloys are given in Table 1.

ASTM No.	Composition in percentage by weight							Structure (Note 2)
	C (max)	Si (max)	Mn (max)	Cr	Ni	Mo	Others (3)	
304	0.08	0.75	2.0	18/20	8/11	-	-	A+2-8% F
304L	0.035	0.75	2.0	18/20	8/11	-	-	A + 2-8% F
304H	0.04 - 0.10	0.75	2.0	18/20	8/11	-	-	A + 2-8% F
304N	0.08	0.75	2.0	18/20	8/11	-	0.1/0.16N	A + 2-8% F
316	0.08	0.75	2.0	16/18	11/14	2/3	-	A + 3-10% F
347	0.08	0.75	2.0	17/20	9/13	-	Nb: 10xC	A + 4-12% F
347H	0.10	1.0	2.0	17/20	9/13		Nb: 10xC	
321	0.08	0.75	2.0	17/19	9/12	-	Ti: 5xC	A + 4-12% F
310	0.15	0.75	2.0	24/26	19/22	-	-	100% A
309	0.08	1.0	2.0	22/24	12/15	-	-	A + 8-15%
308L (1)	0.03	1.0	2.0	19/21	10/12			A + 4-12% F

Notes
1. 308L is generally used as filler metal only.
2. This is the microstructure of this grade. A indicates austenite with the stated percentage of delta ferrite (F).
3. xC indicates that the minimum content is a multiplier of the carbon content.

Table 1: Typical compositions of some austenitic stainless steel alloys.

The metallurgy of the austenitic stainless steels

The Schaeffler diagram

Austenitic stainless steels are metallurgically simple alloys; they are either 100% face-centred cubic austenite or austenite with a small amount of ferrite, as shown in Table 1. This is not the ferrite to be found in carbon steel but a high temperature form known as delta (δ) ferrite. Unlike carbon and low alloy steels the austenitic stainless steels undergo no phase changes as they cool from high temperatures.

They therefore cannot be quench-hardened to form martensite and their mechanical properties are largely unaffected by welding. Cold cracking (or also termed hydrogen-induced cracking), which a common problem when welding carbon steels, is therefore not a problem and preheat is not necessary irrespective of component thickness. Fast cooling rates also do not result in an increase in hardness and heat input control is generally unnecessary.

Alloying elements in an austenitic stainless steel can be divided into two groups:

Those that promote the formation of austenite.

The main austenite formers are nickel, carbon, manganese and nitrogen.

Those that promote the formation of δ-ferrite.

The important ferrite formers are chromium, silicon, molybdenum and niobium.

By varying the amounts of these elements the steel can be made to be fully 100% austenitic or can be designed to contain a small amount of ferrite; the importance of this will be discussed later. In 1949 Anton Schaeffler published a constitutional or phase diagram, see Figure 1. This illustrates the effects of composition on the microstructure by assigning factors to the various elements classifying them as promoters either of ferrite or austenite and termed either as 'chromium equivalent' or 'nickel equivalent' and these form the x axis and y axis of the diagram. Knowing the composition of an austenitic stainless steel, the diagram enables the proportions of the phases to be determined.

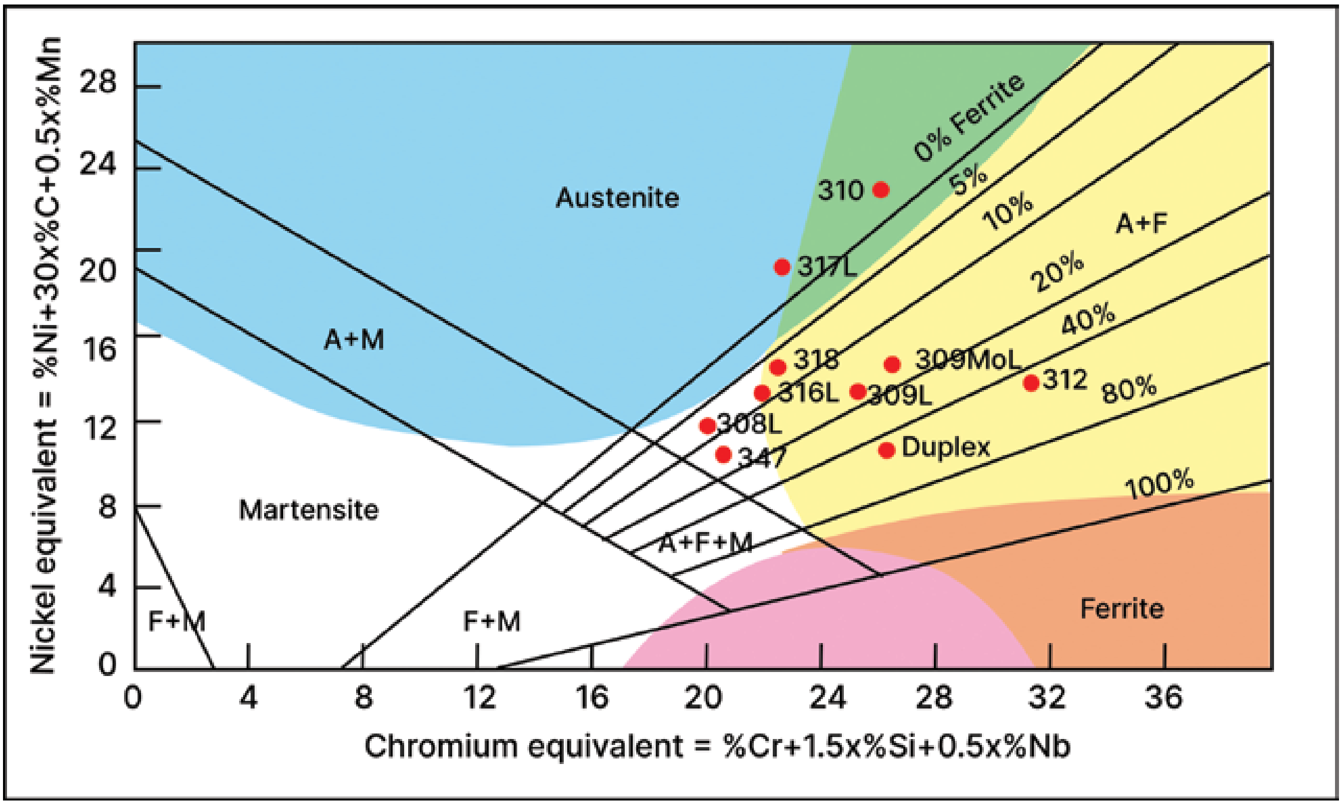

Figure 1: The Schaeffler diagram. (A = austenite, M = martensite, F= ferrite).

Typical positions of some of the commoner alloys are marked by dots in Figure 1 and the superimposed coloured areas relate to some of the fabrication problems that may be encountered with austenitic and ferritic stainless steels as identified in the following sections.

Key: Blue area: sensitive to hot cracking**, Yellow area:** sensitive to embrittlement, **Pink area:** sensitive to grain growth and embrittlement.

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Hot cracking

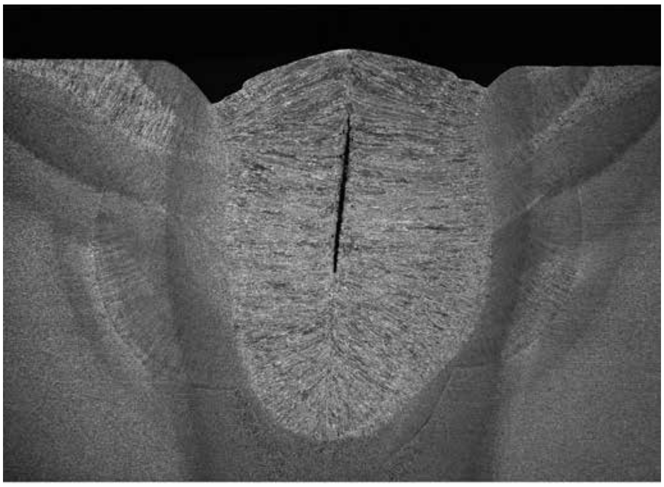


Figure 2: Hot cracking of a weld in austenitic stainless steel.

All of the austenitic stainless steels are sensitive to hot cracking along the grain boundaries but the fully austenitic steels falling within the blue area of the diagram, such as type 310, are particularly sensitive to this. The main culprits are sulphur and phosphorus which are classified as 'tramp elements'. To reduce the risk of hot cracking these tramp elements have been progressively reduced such that steels with less than 0.010% sulphur and less than 0.020% phosphorus are readily available (although ideally a type 310 or type 317 alloy should have sulphur and phosphorus levels below 0.003%).

Cleanliness is also most important and thorough degreasing must be carried out immediately prior to welding. The steels such as type 304, type 316, type 347 etc that fall within or close to the small white triangular region that can be seen in the centre of the diagram contain a small amount of delta-ferrite. Whilst not being immune to hot cracking these alloys have improved resistance to the formation of sulphur containing liquid films. The reasons for this are that a) ferrite can dissolve more sulphur and phosphorus than austenite so they are retained in solution in the ferrite rather than being available to form liquid films along the grain boundaries and b) the presence of quite a small amount of ferrite increases the grain boundary area such that any liquid films must spread over a greater area and cannot form a continuous film. The 100% austenitic steels obviously do not have these advantages.

Second phase embrittlement

The austenitic stainless steels falling into the yellow area may be embrittled as a result of the formation of hard brittle phases called "sigma" (σ) and "chi" (X). This embrittlement takes place in the temperature range of approximately 500 °C to 900 °C. It is a sluggish process and is not a problem during welding but may occur during elevated temperature service or if the welded component is post-weld heat-treated. Formation of these phases is promoted by high chromium and molybdenum contents which are the δ-ferrite forming elements, so that steels such as type 310 and type 316 are particularly sensitive and may show a substantial loss of ductility after heat treatment. Delta ferrite also transforms more rapidly than austenite so those alloys containing large amounts of this phase will degrade faster than an austenitic steel with only a small percentage of ferrite, hence the problem in the welding of duplex and super-duplex stainless steels. Detailed discussion of those steel types is outside of scope of this article but suffice it to say that when it is necessary to stress-relieve a stainless steel fabrication with any percentage of delta ferrite then the loss of ductility must be accounted for. In those austenitic stainless steels containing small percentages of delta ferrite then this phase should be held to a minimum, consistent with minimising the risk of hot cracking, by control of the ferrite forming elements. A typical acceptable range of delta ferrite is 2% to 5%.

The ferritic steels, which are those within the pink area of the diagram are not within the scope of this article, but will suffer from rapid grain growth and will embrittle at relatively low service temperatures.

Intercrystalline corrosion (weld decay)

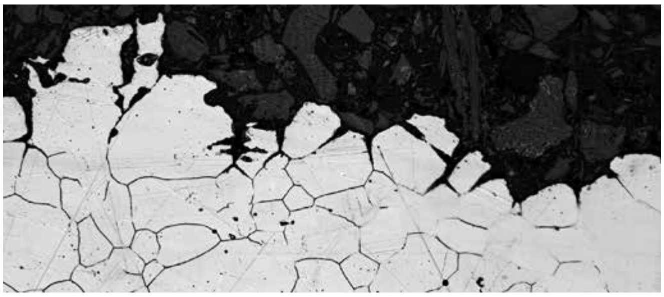


Figure 3: Intercrystalline corrosion. Image courtesy of ESAB.

Carbon has a major adverse effect on corrosion resistance, giving rise to a form of corrosion known as intergranular or intercrystalline corrosion (ICC) or 'weld decay', a localised effect confined to the heat affected zone (HAZ) as shown in Figure 3. Carbides present in the heat affected zone of an austenitic stainless steel dissolve on heating and reform on cooling during the welding heat cycle. Unfortunately, these form preferentially as chromium carbides on the grain boundaries, depleting chromium from the region immediately adjacent to the boundary, resulting in a local reduction in corrosion resistance. If sufficient chromium carbides are formed then this results in a network of steel, low in chromium and sensitive to corrosion, along the grain boundaries. The steel is said to have been 'sensitised'. This sensitisation occurs in the region in the HAZ that has seen temperatures between some 600 °C and 900 °C and times that may be as short as 50 seconds. If you want to see weld decay have a look at your stainless steel knives where the handle meets the blade and that have been in the dishwasher!

There are several methods that may be used to prevent this problem occurring:

A solution heat treatment. This is carried out at 1050 °C followed by a water quench which will redissolve the carbides and retain them in solution due to the rapid cooling. Whilst this will eliminate the chromium depleted regions it is rarely practical to solution-treat complex welded structures.

Reduce the carbon content of the parent steel. This is the obvious alternative technique which has two beneficial effects:-

a) the lower the carbon content then the longer is the time required to form the carbides. At 0.08% carbon this time is around 50 seconds, at 0.03% carbon the time required is some 8 hours, which is most unlikely to be achieved during welding!

b) the lower the carbon content then the fewer carbides there are to form a continuous chromium depleted network. Hence the "L" grades, for example 304L and 316L, are preferred where the best corrosion resistance is required.

Use a 'stabilised' grade of stainless steel. These grades have the addition of the alloying elements titanium and niobium which form carbides in preference to chromium carbide, giving rise to the use of the label 'stabilised'. These are type 321

continues on page 18

(titanium stabilised) and type 347 (niobium stabilised). Titanium and niobium are very strong carbide formers that precipitate carbides at a higher temperatures than that at which chromium carbides form, so that there is no carbon available to react with the chromium. However, even these stabilised grades may corrode in a very narrow band close to the fusion line giving rise to so-called 'knife-line attack' in the presence of hot acids. This is due to the higher and more restricted temperature range at which the niobium or titanium carbides dissolve. If this is seen to be a problem for the service condition of the item then the solution is to limit the carbon to 0.03% maximum by the use of an L grade, as above.

Stress corrosion cracking

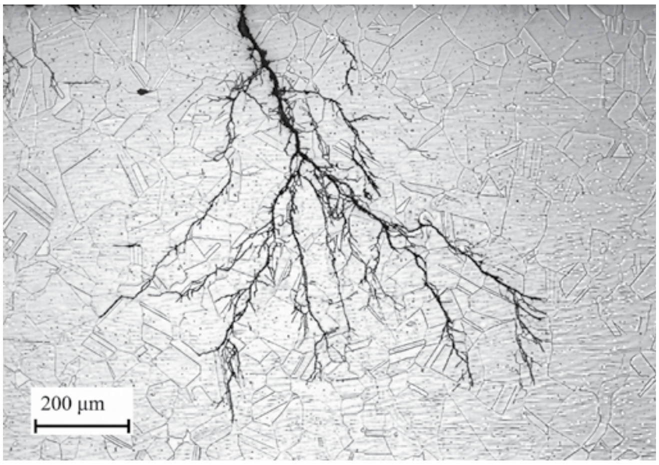


Figure 4: Stress corrosion cracking of an austenitic stainless steel.

A major service problem encountered with the austenitic stainless steels is that of stress corrosion cracking. This is primarily due to the presence in the working environment of chlorides, fluorides or bromides, (known as the halides), (such as in seawater or hydrochloric acid) but it can also occur in strong alkali solutions. Cracking takes place in areas of high stress, as the name suggests. Its occurrence is not confined solely to welds, but it is at and adjacent to welds where we find stresses approaching the yield point of the metal (due to welding residual stress) and hence these present a particular problem.

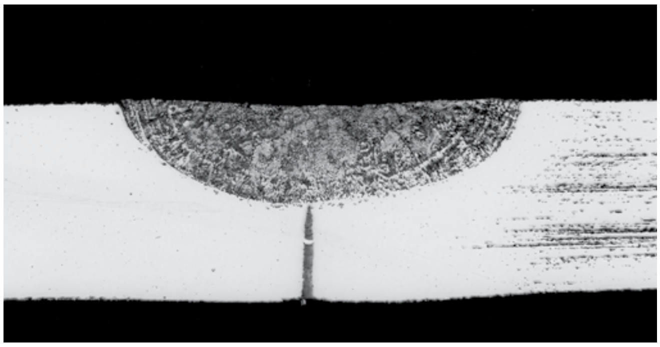
The cracking is transgranular and propagation rates can be extremely rapid given 'ideal' conditions. In hot concentrated chloride solutions, for example, penetration can occur in thin, sheet components within a few minutes. Failure at welds can occur in austenitic stainless steel equipment exposed in hot saline conditions in weeks or months if surface temperatures exceed approximately 60 °C, however the lower the temperature and/or the lower the halide concentration then the slower the rate of crack propagation. Austenitic stainless steels are therefore not generally used in hot service conditions where halides are present but stress corrosion cracking may occur due to unforeseen contamination, either of the product in the pipe or vessel or externally from sea water, particularly where the liquid is able to concentrate in crevices.

The only means of eliminating stress corrosion cracking is to stress relieve the weld at a temperature of around 700 °C to 900 °C. It should be remembered that a) this may sensitise the steel so only low carbon grades should be used and b) the steel may embrittle due to sigma phase formation at the lower heat treatment temperatures. Local stress relief should be approached with caution as the temperature gradients may result in stresses developing outside of the heated band. This may be mitigated by the use of wider heated bands and more stringent control of temperature gradients than strictly required by specifications or codes (where the focus may be on achieving stress relief rather than metallurgical control). Full body solution treatment (1050 °C soak followed by very rapid cooling, ideally a water quench) will eliminate all residual stresses whilst avoiding both sensitisation and embrittlement but is rarely practical on a welded assembly such as a pressure vessel or large storage tank.

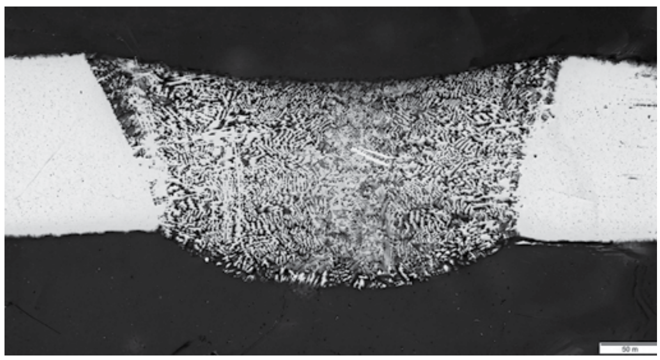
The alternative is to select a steel that is more resistant to stress corrosion cracking; for example the molybdenum bearing grade type 316 is better than type 304 or type 321. The ferritic stainless steels are not susceptible to chloride stress corrosion cracking. If in doubt consult an expert welding metallurgist, since the material selection can get quite complicated with the conflicting requirements which come into play, (including cost).

Cast to cast variation

A problem that arises with very low sulphur steels is a phenomenon known as 'cast to cast variation' which gives rise to variable weld penetration. This is caused by differences in surface tension of the weld pool caused by an effect known as Marangoni convection. With low sulphur steel, (typically less than 0.005%), weld pool surface tension is low causing the weld metal to flow from the centre to the edge of the weld pool, giving a wide, shallow penetration weld (Figure 5a). When welding a steel with a sulphur content over approximately 0.010% the weld pool surface tension is high and the weld metal flows from the edge to the centre of the weld pool giving a narrower, more deeply penetrating weld bead as shown in Figure 5b.



a) "low" sulphur 0.003%.



b) "high" sulphur 0.010%.

Figure 5: Effect of steel sulphur content with an autogenous TIG weld; identical welding parameters and surface conditions.

This is generally a problem only with the use of the fully automated TIG welding process or the power beam processes and particularly if the welds are autogenous. Adding filler metal reduces this effect and a manual welder is generally capable of coping with the variations in penetration. However, automated TIG or power beam welding procedures developed on a 'high' sulphur steel, if and when used to weld a low sulphur steel may result in lack of penetration type defects and the reverse situation may result in excessive penetration. This problem has been mitigated (but never eliminated) by making use of the following modifications to the procedure: a slow travel speed, using pulsed current and/or use of Ar/H_2 shield gas mixtures. Other methods include specifying a minimum sulphur of, say, 0.010% or segregating the steels into batches with known penetration characteristics and developing welding procedures to suit. The A-TIG activated flux process has also been found to be of benefit.

Welding the austenitic stainless steels

The austenitic stainless steels can be welded with all the commercially available welding processes, both fusion and solid phase. There are matching filler metals available for most of the austenitic range of alloys; the exceptions being that there is not a type 304 filler metal available (this alloy is generally welded with a type 308 filler metal) and no type 321 filler (due to the problems of transferring titanium across the arc). Type 321 steels are usually welded with a type 347 filler metal.

Room temperature mechanical properties are not significantly affected by variations in the welding procedure but increasing the oxygen and ferrite levels will reduce the toughness at cryogenic (~196 °C) temperatures. If optimum toughness is a requirement then manual metal arc welding requires the use of basic coated electrodes with a controlled short arc length and submerged arc welding requires the use of basic agglomerated fluxes. The steel and the filler metal should be selected with as low a ferrite content as possible; 1% to 3% for best Charpy-V test results. The 'H' grades are used for creep resistance and conversely, to achieve the creep resistance in the welds of these grades rutile or acid/rutile electrodes and acid submerged arc fluxes should be used. These improve the creep strength by increasing the titanium and niobium content of the weld metal, forming a greater concentration of grain strengthening carbides.

TIG (GTAW) welding of the root pass is a frequent requirement in pipework and vessel fabrication and this must always be carried out with an inert gas back purge to prevent loss of chromium and "coking" of the root bead which would lead to a major loss of corrosion resistance. Argon gas is generally used for this purpose. Nitrogen may be used but there is a risk of the weld deposit absorbing nitrogen, thereby becoming fully austenitic and sensitive to hot cracking.

Two characteristics of the austenitic stainless steels that differentiate them from the ferritic steels are the coefficients of thermal conductivity and expansion. Austenitic stainless steels have a low coefficient of thermal conductivity; approximately 1/3rd that of ferritic steel at room temperature and a coefficient of thermal expansion some 30% more than that of a ferritic steel. These physical characteristics mean that HAZs are very narrow, concentrating the heat in a smaller area and that the cooling rate is slower, allowing more time for carbide formation in the higher carbon content grades. In addition, higher expansion of a narrower HAZ results in higher residual stresses and more distortion. This is a particular problem with thin sheet fabrications where the achievement of the desired dimensional tolerances can be extremely difficult and costly to achieve. The use of accelerated cooling techniques such as copper chills or the low stress-no distortion (LSND) technique, which uses a trailing heat sink utilising a freezing gas such as liquid CO_2 , have been used to reduce distortion to acceptable levels.

Welding consumables must also be selected with low carbon content if best corrosion resistance is required. Most arc welding consumables contain less that 0.03% carbon but there are filler metals available with carbon contents of up to 0.10% and these should only be used to weld the "H" grades of steel where good creep resistance is required. Although MAG (GMAW) welding is often used it should be remembered that carbon pick-up is possible when argon/CO_2 mixtures are used, particularly if the welding is carried out in the dip transfer mode. Argon/2% oxygen mixtures are generally preferred where best corrosion resistance is required but argon/10% CO_2/2% O_2 is a good compromise that can be used for a broad range of applications.

References

1 ASTM A240/A240M-26. Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications.

FOR ALL YOU WELDERS AND WELDING EXPERTS OUT THERE…

Quiz time: welding of austenitic stainless steels

1. **How many different types of stainless steel are there?**
2. **What do all of these different types of stainless steel have in common?**
3. **Identify the common welding problems with austenitic stainless steels.**
4. **Can austenitic stainless steels be hardened by quenching?**
5. **Why is solidification cracking of concern when welding austenitic stainless steels? How may this problem be mitigated?**
6. **Does austenitic stainless steel exhibit a ductile/brittle transition?**
7. **What is sensitisation of an austenitic stainless steel and why is this of concern? How can this problem be avoided or reduced?**
8. **List the Cr and Ni elements of the Cr/Ni equivalents ratio. What effect do changes in this ratio have on the micro-structure of the steel?**
9. **Austenitic stainless steel is intrinsically ductile – are there any embrittling mechanisms?**
10. **What is Marangoni convection and when is this significant?**

Answers can be found on page 24.

TEESSIDE BRANCH NEWS

ANNUAL DINNER 2026

The Teesside Branch held its 71st annual Dinner in April. It was another highly successful event with 150 guests attending the Riverside Stadium in Middlesbrough where they were entertained by comedian Steffen Peddie, and our guest speaker, John Bikkerstaff, who started his working life as a welder at Laing's in Graythorpe before joining the police force and later becoming responsible for security on several major complexes in the North East. Guests also got an insightful update from TWI CEO Caroline Gumble.

Charity collection

The event has traditionally been an opportunity to raise funds for local charities and this year the branch was able to make donations of £350.00 each to My Sister's Place, Teesside Hospice and Billys Room at the James Cook University Hospital in Middlesbrough.

Teesside Branch Chairman, Lee Gordon, visited My Sister's Place to present the cheque.

Teesside Branch Secretary, Neil Fowler (left), and Branch President, Don Atkinson (right), visited Teesside Hospice to present the cheque.

Awards

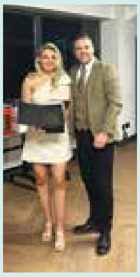
The event was also an opportunity to recognise those who have excelled in the industry during the past 12 months.

Best welding student 2026

This award was sponsored by WB Alloys and was presented by Dan Churchill, Special Projects Director for WB Alloys.

Winner: Sharne Tallon. Nominated by Hartlepool College and employed by Wilton Engineering.

Runner-up: Cole Sanderson. Nominated by Hartlepool College and employed by SeAH Wind.



Best practical welder 2026

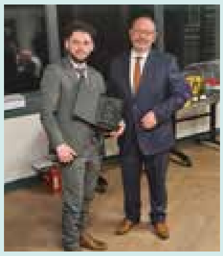
This award was sponsored by WB Alloys and was presented by Dan Churchill, Special Projects Director for WB Alloys.

Winner: Joe Taylor. Nominated by Newcastle College and employed by North East Pipeline Solutions.

Runner up: Natasha McLaren. Nominated by East Durham College and employed by Hydram Engineering.

Apprentice welder 2026

This award was sponsored by EAL and presented by Paddy Oakes, Industry Manager for EAL.



Winner: Jack Morley. Nominated by Neta Training and employed by Wood.

Runner-up: Ben Williams. Nominated by Middlesbrough College and employed by Allerton Steel.

Training Provider 2026

This award was sponsored by EAL and presented by Paddy Oakes, Industry Manager for EAL.

Winner: CATCH (Grimsby). The award was collected by Joel Broddle, Head of the Welding & Pipefitting Hub at CATCH in Grimsby.

SCOTTISH BRANCH – LONG SERVICE AWARD

Scottish Branch of The Welding Institute extend heartfelt congratulations to Eric Wallace as he reaches the distinguished milestone of over fifty years of membership of the Institute. This has been marked throughout by Eric's dedication to the industry and his commitment to supporting the growth of others.

It was a school visit to Anniesland College which sparked Eric's passion for welding and his lifelong journey started on May 13th 1966 at Govan Shipbuilders Ltd as an apprentice welder. Eric completed his apprenticeship and continued his education at Springburn College of Engineering which was the foundation for his later promotion to Welding Inspector. In 1974 Eric joined Lloyds Register of Shipping. He became a member of the TWI Scottish Branch and progressed from inspector to surveyor, then lead surveyor, and ultimately to a management role at Lloyds.

Eric's early involvement in the construction of offshore jackets and modules in Nigg Bay and Ardersier marked the beginning of a diverse, international career which included offshore and marine projects in Japan, Qatar, Abu Dhabi, Bahrain, Malaysia, as well as across Europe and the United Kingdom and, consistently, Eric used his accumulated knowledge to support, advise and mentor his colleagues.

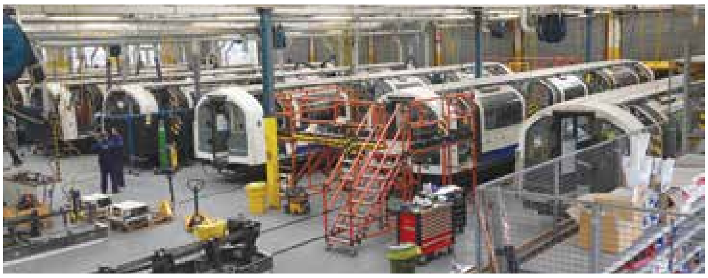
Eric has been an influential member of Scottish Branch of The Welding Institute during his 50 years of membership, where he has served as Chairman and President. His continuing membership stands as a testament to Eric's loyalty and his dedication to advancing our industry and nurturing the next generation.

The Scottish Branch express our deepest appreciation for Eric's enthusiasm, inspiration and steadfast support. Please join us in celebrating Eric Wallace's achievements and his influence on the welding and inspection community.

Eric Wallace (centre right) with TWI CEO Caroline Gumble (centre left), Tony Clough (left), and Hakan Gonenc, Branch president (right) at the Scottish Branch Dinner 2026.

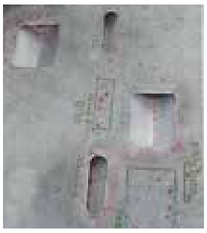
LONDON BRANCH VISIT TO LONDON UNDERGROUND ACTON WORKS, 10 JUNE 2026

A small group from London branch were fortunate enough to visit the impressive facilities at London Underground Acton works to see refurbishment work in progress on the 85 trains making up the rolling stock of the Central Line.



This involves a complete strip out of the cars to install CCTV, replace the train management system and change the motors from DC to AC traction but they are also carrying out structural repairs by welding, which involves dealing with train pillar cracks and localised corrosion to the aluminium alloy floor panels as shown in the images below.

Section through a floor extrusion plus an early prototype weld repair macro from procedure qualification.



Corroded areas cut and prepared ready for repair welding.

London Underground hold accreditations from TWI Certification Ltd under BS EN 15085-2 (for railway vehicles) and BS EN 3834-2 (welding quality management) and the attention to detail in setting working procedures and inspecting the work was evident.

Production inspection and test plan for repairs.

The welding team on the Central Line Project consists of a welding engineer (our Chairman Kristian Thomas), two inspectors, nine welders and three fitters (performing preparation work on the panels). We had a general tour of the Railway Engineering Workshop and saw work in progress on Bakerloo and Jubilee line trains including a significant fatigue crack found on an aluminium alloy subframe. We were reminded that these trains can run in the region of 180,000 km/year so such cracks are not a surprise. NDT inspection regimes are implemented to locate them long before the component can fail. It was a very full and interesting visit and we thank the management of Acton works for making this visit possible.

The visitors with Kristian Thomas and Tom Brookes of London Underground (right).

NEW VICE-CHAIR OF PROFESSIONAL BOARD

We're delighted to announce John Kell has been appointed Vice-Chair of Professional Board. John is a Fellow of the Royal Academy of Engineering who has made a remarkable contribution to attracting large-scale research and development investment to the UK during his role as an R&D Specialist within the Manufacturing Directorate (AMD) of the Department for Business and Trade where he has, until recently, worked for the past 18 years. Prior to this he was the automotive and motorsport sector business development manager for TWI Ltd.

John has a wealth of experience in research and technology development. His background in managing manufacturing, design and engineering research assignments has involved him with global projects across the defence, aerospace, oil and gas, and transport sectors. John also holds the rank of Major and Officer Commanding of No. 3 Company Cambridgeshire Army Cadet Force, where he is a passionate promoter of STEM.

Join us in congratulating John on his new role!

MEMBERSHIP UPDATE

NEW QUALIFICATIONS AWARDED **26 MARCH TO 26 JUNE 2026**

Name	Member Grade	EngC Registration
The following members have been awarded FWeldI		
Rahim Kurji	FWeldI	CEng
Roberto Morana	FWeldI	CEng
The following members have been awarded MWeldI and/or the Engineering Council registration as indicated		
Andrew Appleyard	MWeldI	IEng
Jonathan Benson	MWeldI	IEng
Angelos Dimakos	MWeldI	
Selmi Wissem	MWeldI	
The following members have been awarded TechWeldI and/or EngTech status		
Joseph Radcliffe	TechWeldI	EngTech
David Turnbull	TechWeldI	
The following members have been awarded Interim CEng/IEng status		
Selamawit Abate	AWeldI	Interim CEng
We send our congratulations to all the members listed above		

DECEASED MEMBERS

Name	Member Grade	EngC Registration
Steven P Brown	TechWeldI	2001
Carlton Boswell	SenMWeldI	1956
George Phipps	FWeldI	1958
Albert Henry Simmons	AWeldI	1994
Colin Ernest Boniface	SenMWeldI	1984
Jean-Pierre Pollien	AWeldI	1994
Tina Auger-Laverty	AWeldI	2026
Christopher Cobain	MWeldI CEng	2016

The Welding Institute wishes to reflect the lives and achievements of our members, and we would be pleased to receive tributes or obituaries written by family, friends and colleagues. These tributes will, where appropriate, and with the family's permission, be posted on our website.

TWI INDIA CONTINUES ITS DEVELOPMENT AND REACH

India continues to demonstrate strong economic resilience despite global uncertainties, with GDP projected to grow by around 6.6%* in the financial year 2026-27. Furthermore, there is a projected estimated growth of 7.2%* set for 2027. Supported by initiatives such as Make in India, the Skill India Mission, and significant investments in infrastructure and manufacturing the country is strengthening its position as a global engineering and manufacturing hub. As industries expand the demand for a highly skilled and internationally certified technical workforce has become increasingly important.

The rapid adoption of Industry 4.0 technologies, including: automation, robotics, digital manufacturing, artificial intelligence, and advanced inspection techniques, is transforming industrial operations. These advancements require professionals with specialised technical skills who can meet evolving quality, safety and productivity standards. Developing a future-ready workforce is therefore essential to sustaining industrial growth and enhancing India's global competitiveness.

TWI India is proud to contribute to this vision through internationally recognised training and certification programmes. As a subsidiary of TWI Ltd., we provide training, examinations and certification in welding, non-destructive testing (NDT), painting and coating inspection, and structural integrity. Our programmes are designed to develop technical competence, promote international best practice and equip professionals with globally recognised qualifications.

Today, TWI India trains and supports more than 5,000 professionals each year. Over the years, we have successfully contributed to the skill development of more than 30,000 individuals, many of whom have built successful careers across India and overseas. By supporting industries such as oil and gas, power generation, manufacturing, heavy fabrication, shipbuilding, construction and infrastructure, we help organisations strengthen quality, improve safety and develop a skilled workforce capable of meeting global industry standards.

At TWI India, we believe that skill development is fundamental to industrial progress. By combining internationally recognised qualifications with practical training and industry expertise, we continue to support India's growing manufacturing sector and help prepare professionals for the challenges and opportunities of an increasingly technology-driven future.

We invite you to visit TWI India at Stand E47 during the India Essen Welding & Cutting Exhibition (IEWC 2026), taking place from 30 November to 2 December 2026 at the Bombay Exhibition Centre, Goregaon, Mumbai, Maharashtra, India. Meet our experts, explore our internationally recognised training and certification programmes, and discover how TWI India is helping build the skilled workforce that will shape the future of industry.

We look forward to welcoming you.

***Source: World bank article -www.worldbank.org**

CONFERENCE WATCH 2026

NDT 2026 - THE 63RD ANNUAL BRITISH CONFERENCE ON NON-DESTRUCTIVE TESTING

This conference, organised by the British Institute of Non-Destructive Testing (BINDT) will take place from 8-10 September 2026 at The International Centre, Telford, UK. It will consist of three parallel technical sessions covering a broad range of non-destructive testing (NDT) technologies and applications to present the latest developments in NDT.

Throughout NDT 2026 The Research Committee for NDT (RCNDE) will stage 'RCNDE Showcase' which will present research from the eight university members, showcasing the benefits to industry.

For further information and to register visit: https://www.bindt.org/events-and-awards/ndt-2026/registration/

MATERIALS TESTING 2026 EXHIBITION (MT 2026)

The exhibition Materials Testing 2026 will take place alongside NDT 2026.

There are more than 70 exhibitors at this show which takes place once every two years and is recognised as one of the leading international exhibitions for NDT, condition monitoring (CM), structural health monitoring (SHM), diagnostic engineering and quality testing.

MT 2026 is free of charge for visitors, who will benefit not only from the exhibition with its displays of innovation in materials testing, but also from a programme of talks and seminars in the exhibition hall, covering practical aspects of non-destructive testing (NDT) and related technologies.

For further information and details about how to register, visit: https://www.bindt.org/events-and-awards/materials-testing-2026/registration/

To see the current list of exhibitors, visit: https://www.bindt.org/events-and-awards/materials-testing-2026/exhibitors/

SCHWEISSEN & SCHNEIDEN IS EXHIBITING AT EURO DEFENCE EXPO

SCHWEISSEN & SCHNEIDEN will exhibit at the first EURO DEFENCE EXPO (EUDEX) at Messe Essen 22-25 September 2026 hosting 14 companies demonstrating how welding, cutting and surfacing technologies support modern defence applications. The displays will cover innovative technologies, practical expertise, and solutions for production, maintenance and modernisation of security systems.

Growing European defence initiatives are increasing the demand for advanced industrial manufacturing, opening new market opportunities for the sector and welding and cutting technologies are critical in areas such as vehicle construction, shipbuilding, aerospace and infrastructure.

Further information is available at www.eurodefenceexpo.de and www.schweissen-schneiden.com

FABTECH 2026 – LAS VEGAS

FABTECH

Fabtech 2026 is taking place in the Las Vegas Convention Center on 21-23 October. FABTECH displays the latest in metal forming, fabricating, welding and finishing in more than 65,000 m^2 of exhibition space. Exhibits feature advanced manufacturing equipment and smart solutions designed to boost productivity and streamline operations. Admission to the show is complimentary if you register before October 16, 2026.

Printed copies of WJM will be available while stocks last at the Gullco stand No. S37020.

Location: Las Vegas Convention Center, 3150 Paradise Road, Las Vegas, Nevada 89109.

For further information:
https://www.fabtechexpo.com/about.

FORTHCOMING TECHNICAL GROUP MEETINGS AND WEBINARS

September 2026 (TBC)	**Materials, challenges and opportunities in joining in the automotive sector**	**TG7 Polymers and composites**
November 2026 (TBC)	**Fusion reactors**	**TG2 Welding and joining processes**
1 December 2026	**The role of the Welding Supervisor in realising weld quality**	**TG9 Training, qualification and quality**
16 December 2026	**Reducing inspection risks: protecting inspection personnel** Many inspection operations are required to take place when plant is running or in inhospitable locations. Operational plant may expose inspectors to factors such as high temperatures, noxious atmospheres, proximity to pressure-containing plant or rotating machinery and even in the presence of ionising radiation. Inhospitable locations may include working at height, confined spaces or subsea. *This webinar will explore strategies, procedures and technologies to mitigate the effects of such environments on inspection personnel.*	**TG5 Pressure and process plant** **TG8 NDT and condition monitoring**

The meetings above are online except where indicated otherwise. The programme is constantly developing.
For the latest information on the programme, speakers and their presentation titles please see:
www.theweldinginstitute.com/events

For members who hold TechWeldI, MWelding or FWeldI ATTENDANCE AT TECHNICAL GROUP WEBINARS IS FREE.
An administration charge is applicable for in-person events.

WELCOME TO DR KATE FRANKLIN – OUR NEW TECHNICAL GROUP CO-ORDINATOR

Over the last fifty years or more the Technical Groups have been at the centre of the Institute bringing together practitioners and specialists for presentations and discussion on technical topics of relevance to members and their work. We are now pleased to announce that Kate Franklin has taken up the role of Chair of the committee co-ordinating the programme. She succeeds Alan Denney who stepped down from this role after more than 30 years with the TGs, originally as Chair of TG4 and more recently as overall co-ordinator.

Dr Kate Franklin works at TWI Ltd, where she manages the Friction Welding and Processing team across Cambridge and Yorkshire. A Chartered Engineer and member of both The Welding Institute and IOM3, Kate combines specialist technical expertise with a strong commitment to professional engagement, knowledge sharing and member development. Her work spans friction welding, solid-state joining and advanced processing technologies. Alongside her technical leadership, Kate is active in event delivery including the organisation of the International Friction Welding Conference.

Her role as Technical Group Co-ordinator involves supporting Technical Group Chairs, volunteers and members in delivering high-quality, inclusive and accessible technical content. She is particularly interested in strengthening collaboration across the welding and joining community, expanding engagement among early-career professionals and ensuring Technical Groups continue to provide valuable technical insight, networking and professional development opportunities.

QUIZ ANSWERS: WELDING OF AUSTENITIC STAINLESS STEEL

The quiz is on page 19

1. There are five different types of stainless steel – austenitic, ferritic, martensitic, precipitation hardening and duplex (ferritic/austenitic).
2. They are all corrosion resistant due to the presence of over 12% chromium, giving the steel a tenacious, chromium oxide corrosion resistant surface, hence the term "stainless".
3. The common welding problems are hot cracking, inter-crystalline corrosion, elevated temperature embrittlement and, to a lesser extent, cast-to-cast variation.
4. No, austenitic stainless steel undergoes no phase changes, unlike a ferritic steel, and cannot therefore be hardened by quenching from a high temperature.
5. Austenite has very low solubility for sulphur which, during solidification, forms a low melting point film along the grain boundaries which part as residual stress increases. There are two solutions a) ensure there is some δ-ferrite present. δ-ferrite will dissolve most of the sulphur so that there is insufficient to form grain boundary films b) ensure a low sulphur content, typically less than 0.010%.
6. No, austenitic stainless steel does not exhibit a ductile/brittle transition due to having a face-centred cubic structure.
7. As austenitic stainless steel cools through the 900 °C to (around) 600 °C temperature range chromium carbides can form along the grain boundaries, reducing the chromium content of the adjacent area thereby "sensitising" that area to corrosion.
8. The chromium equivalent comprises chromium, silicon, molybdenum and niobium. The nickel equivalent comprises nickel, carbon, manganese and nitrogen. Increasing the chromium equivalent promotes the formation of δ-ferrite, increasing the nickel equivalent promotes the formation of austenite.
9. Yes, the embrittlement phases sigma (σ) and chi (χ) can be formed within a temperature range of 500 °C to 900 °C during service or PWHT.
10. Marangoni convention is a mechanism that affects weld penetration and is caused by differences in surface tension of the weld pool, essentially due to variations in the sulphur content. This can be of significance during welding using automated TIG/plasma and the power beam processes.

INVESTIGATION OF CAUSTIC STRESS CORROSION CRACKING IN A WELDED STAINLESS STEEL PRESSURE VESSEL

Sarah Bagnall CEng FIMMM FICORR.
Director Consultancy Services R-TECH Group

Background

A Grade 316L stainless steel pressure vessel operating in a process containing 22% caustic solution, hydrogen peroxide and zirconium carbonate developed cracking during service, operating at approximately 90 – 95 °C. 316L is a widely used austenitic stainless steel. The vessel was removed from service, and two plate sections were submitted to R-TECH Group to determine the cause of failure.

Figure 1: The stainless steel pressure vessel.

Although the cracking initiated adjacent to a circumferential weld, metallurgical examination confirmed that the weld itself remained unaffected. Instead, the weld acted as a source of residual stress, increasing the susceptibility of the adjacent parent material to stress corrosion cracking.

Visual examination and Scanning Electron Microscopy

Visual inspection revealed multiple longitudinal cracks about the internal surface. See Figure 2. The cracks corresponded precisely with the location of a circumferential weld on the external surface, although there was no evidence of cracking propagating into the weld metal itself.

Figure 2: Macro image showing longitudinal crack at internal surface of plate.

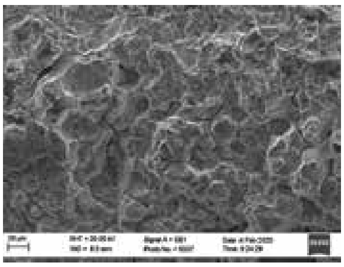


Figure 3: SEM image of the fracture surface of the crack. Note the intergranular morphology.

Scanning electron microscopy (SEM) of the fracture surface confirmed an intergranular fracture morphology. See Figure 3.

Metallurgical investigation

Cross-sectional metallography showed the cracks were extensively branched and propagated primarily along grain boundaries as shown in Figures 4 and 5. Scanning Electron Microscopy/Energy Dispersive X-Ray analysis detected deposits containing iron, oxygen, zirconium and significant amounts of sodium within the cracks.

Chemical analysis confirmed the material met the composition of 316L stainless steel. However, hardness testing revealed the parent material was significantly harder than expected for the fully annealed condition. One exhibited metallurgical evidence of cold work. The increased hardness indicated the possibility of the material retaining elevated residual stresses following the welding of the vessel.

Figure 4: Micro-section through the crack tip, showing the branched crack.

Figure 5 : Micro-section through crack tip at higher magnification, detailing intergranular cracking.

Findings and recommendations

The combination of crack morphology, intergranular fracture, chemical deposits and the service environment identified the failure mechanism as caustic Stress Corrosion Cracking (SCC). Although the cracking initiated adjacent to a circumferential weld, metallurgical examination confirmed that the weld itself remained unaffected. Instead, residual stresses associated with the welded joint, together with elevated residual stresses resulting from cold work, increased the susceptibility of the adjacent parent material to stress corrosion cracking.

SCC occurs when a susceptible material is exposed to a corrosive environment while under tensile stress, whether applied or residual. The reported operating conditions of 22% caustic at 90 – 95 °C lie close to the recognised susceptibility range for caustic SCC in austenitic stainless steels, meaning that relatively small increases in caustic concentration or operating temperature may have been sufficient to initiate cracking. The general recommendations, arising from this investigation, to avoid similar situations in practice are to maintain strict control of process temperature and caustic concentration, with a conservative operating limit of approximately 50°C where practicable for concentrated caustic environments. Fabrication practices should seek to minimise residual stresses through appropriate forming, solution annealing where applicable, and controlled welding procedures. Where exposure to hot concentrated caustic solutions cannot be avoided, consideration should be given to the use of nickel-based alloys, which offer significantly greater resistance to caustic SCC.

About R-TECH Group

This article has been contributed by R-TECH Group who provide independent materials consultancy, testing and analysis services for the engineering industries. R-TECH operates laboratories which are both UKAS and Nadcap accredited. The testing laboratories have specialist expertise in failure investigation, corrosion, welding, materials characterisation and plant integrity. All images are copyright R-TECH Group.

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STANDARDS UPDATE

The following standards have been updated during the period April to June 2026. The European (EN) standards and International (ISO) standards are listed as published in their British version with the full BS designation. Full details can be found at:

https//www.bsigroup.com/en-GB/products-and-services/standards/

EN standards are also published by CEN with just the EN designation and by other CEN member standards bodies with their national prefix (e.g. as DIN EN for Germany or NF EN for France). Note that ISO standards are not, invariably adopted as EN standards.

Gas welding equipment

BS EN 17931:2026

Gas welding equipment. Manual gas equipment for welding, heating, and cutting. Periodic inspection.

Non-destructive testing

BS EN ISO 15548-1:2026

Non-destructive testing. Equipment for eddy current examination. Instrument characteristics and verification. Supersedes: BS EN ISO 15548-1:2013.

BS EN ISO 18490:2026

Non-destructive testing. Evaluation of vision acuity of NDT personnel. Supersedes: BS EN ISO 18490:2015.

BS EN ISO 32543-3:2026

Non-destructive testing. Characteristics of focal spots in industrial X-ray systems. Measurement of the effective focal spot size of mini and micro focus X-ray tubes. Supersedes: BS EN 12543-5:1999.

STANDARDS APPLICABLE TO WELDING AND BRAZING OF STAINLESS STEEL

Welding Consumables	
BS EN ISO 3581:2023	Welding consumables. Covered electrodes for manual metal arc welding of stainless and heat-resisting steels.
BS EN ISO 14343:2025	Welding consumables. Wire electrodes, strip electrodes, wires and rods for arc welding of stainless and heat resisting steels. Classification.
BS EN ISO 14171:2016	Welding consumables. Solid wire electrodes, tubular cored electrodes and electrode/flux combinations for submerged arc welding of non alloy and fine grain steels. Classification. *Under review.*
BS EN ISO 14174:2019	Welding consumables. Fluxes for submerged arc welding and electroslag welding. Classification.
BS EN ISO 17633: 2025	Welding consumables. Tubular cored electrodes and rods for gas shielded and non-gas shielded metal arc welding of stainless and heat-resisting steels. Classification.

Welding practice and qualification	
BS EN ISO 9606-1:2017	Qualification testing of welders. Fusion welding – Steels.
BS EN ISO 15609-1:2019	Specification and qualification of welding procedures for metallic materials. Welding procedure specification - Arc welding.
BS EN ISO 15614-1: 2017+A1:2019	Specification and qualification of welding procedures for metallic materials. Welding procedure test - Arc and gas welding of steels and arc welding of nickel and nickel alloys. *Under review.*
BS EN 1011-3:2018	Welding. Recommendations for Welding of Metallic Materials: Arc Welding of Stainless Steels.
BS EN 1011-5:2003	Welding. Recommendations for welding of metallic materials - Welding of clad steel.
BS EN 1011-6:2018	Welding. Recommendation for welding of metallic materials - Laser beam welding.
ISO/TR 17671-3:2002	Welding. Recommendations for welding of metallic materials - Arc welding of stainless steels.

PD ISO/TR 22824: 2024	Welding - Best practices for specification and measurement of ferrite in stainless steel weld metal.
BS EN ISO 8249:2018	Welding. Determination of Ferrite Number (FN) in austenitic and duplex ferritic-austenitic Cr-Ni stainless steel weld metals. *Under review.*

Welded applications	
BS 4677: 1984	Specification for Arc Welding of Austenitic Stainless Steel Pipework for Carrying Fluids. *Under review.*
BS 4515-2: 1999	Specification for Welding of Steel Pipelines on Land and Offshore – Duplex Stainless Steel Pipelines.
BS EN 1993-1-4:2025	Eurocode 3. Design of steel structures - Stainless steel structures. *Under Review.*
BS EN 1090-2:2018+A1:2024	Execution of steel structures and aluminium structures - Technical requirements for steel structures.

Brazing	
BS ISO 11745:2022	Brazing for aerospace applications. Qualification test for brazers and brazing operators. Brazing of metallic components.
BS EN ISO 17779:2025	Brazing. Specification and qualification of brazing procedures for metallic materials.
BS EN ISO 13585:2024	Brazing. Qualification test of brazers and brazing operators.
BS EN 14324:2004	Brazing. Guidance on the application of brazed joints. *Under review.*
BS EN ISO 17672:2024	Brazing. Filler metals.

QUICK LINKS – WELDING AND FABRICATION OF STAINLESS STEELS

Compiled by Mark Cozens CEng FWeldI. Weld-Class Solutions Ltd

Application of stainless steels

https://www.meadmetals.com/blog/common-uses-for-stainless-steel

This article looks at some of the differences between stainless steels and normal type ferritic steels (mild steels). It also includes products and applications, a list of stainless steel uses and comments on corrosion resistance.

https://bssa.org.uk/bssa_articles/selection-of-stainless-steels-for-the-food-processing-industries/

This article looks at details such as the application of stainless steels specifically for food processing, including details for 'food' grades, examples of classification of stainless steels in EU regulations, corrosion hazards, brief explanations of corrosion mechanisms, disinfection of stainless steel equipment, maintenance of food process equipment and a table that lists grades, types and typical applications.

https://www.neonickel.com/technical-resources/top-applications-of-stainless-steel-across-industries

This article looks at some top uses of stainless steels, including in the following industry sectors: construction and architecture, automotive, medical and healthcare, food and drink, oil and gas, aerospace, the marine industry as well as other applications of the different alloy types.

Design of welded joints in stainless steels

https://bssa.org.uk/bssa_articles/design-strengths-of-welded-connections/

This article looks at a range of topics related to the design strength of stainless steel joints. Topics include, intermittent fillet welds and intermittent partial penetration butt welds and their use, the correct choice of welding consumables for the grade(s) of stainless steel to be joined, angles of intersection of members connected by fillet welds, effective length and throat size as well as a design calculation taken from BS 5950-1.

Joining & Fabrication of Stainless Steels

https://worldstainless.org/wp-content/uploads/2025/02/Module_09_Joining_and_Fabrication_of_stainless_steels_en.pdf

This PowerPoint presentation, available for download, shows a host of different joining methods including arc welding, mechanical fastening, adhesive bonding. It provides a very good overview of joining stainless steels with a variety of links, photographs and diagrams.

General welding of stainless steels

https://www.r-techwelding.co.uk/welding-stainless-steel

This article looks at some of the arc welding processes that can be used in the welding of stainless steels, using Metal Inert Gas (MIG), Tungsten Inert Gas (TIG) and Manual Metallic Arc (MMA) welding processes. The content is focused on each of the 3 welding process types and provides details on a number of topics including safety. There are also a number of other topics for other materials and applications too.

https://steelprogroup.com/stainless-steel/how-to-weld/

This article covers a range of topics including welding stainless steels versus ordinary steels, preparation before welding, different welding processes and their advantages /limitations including arc welding but also resistance welding. There are also tips on post weld cleaning, dissimilar joints between stainless steels and ordinary low carbon type steels as well as a range of details on welding parameters and defects.

https://www.twi-global.com/technical-knowledge/job-knowledge/weldability-of-materials-stainless-steel-020

This Job Knowledge article from TWI reviews the weldability characteristics of the austenitic, ferritic, martensitic and austenitic-ferritic (duplex) types and the welding procedure controls that are required.

https://salamanderfabs.com/latest-news/welding-stainless-steel/

This article reviews a range of welding process types and their suitability for welding stainless steels, including manual, semi-automatic and automated welding process types. There are other details which include challenges and best practices.

https://esab.com/ad/eur_en/esab-university/articles/types-of-stainless-steel-welding-ami/

This article includes a range of topics of stainless steels, welding including the different types of stainless steels, as well as other details on welding processes including Gas Metal Arc Welding (GTAW or TIG) and Gas Tungsten Arc Welding (GTAW or TIG) processes.

https://bssa.org.uk/bssa_articles/welding-joining/

This article from the British Stainless Steel Association (BSSA) covers a range of welding and joining methods including adhesive bonding, brazing, mechanical fastening and fixings, and soldering, as well as topics on selection of welding consumables, post weld cleaning and finishing, avoiding distortion, welding methods and procedures, welding stainless steels to other steels and avoiding corrosion at joints.

https://www.hobartbrothers.com/resources/technical-articles/how-to-weld-stainless-steel/

This article by Hobart in the USA looks at different materials, welding process types and well as welding procedure needs.

https://bssa.org.uk/bssa_articles/welding-stainless-steels-to-other-steels/

This is a short article which highlights various facts of welding dissimilar joints between stainless steels and low carbon and low alloy steels. The content includes an introduction, aspects of welding austenitic stainless steels to carbon and low alloy steels, dissimilar metal combinations, welding conditions, ambient service temperatures, elevated temperature services temperatures and the risk of bimetallic corrosion.

continues on page 28

Austenitic, ferritic and martensitic stainless steels

https://www.outokumpu.com/en/expertise/stainless-basics/welding

This article looks at some of the basics of different welding processes that can be used including fusion methods and pressure methods. It summarises weldment properties of ferritic, martensitic, duplex and austenitic stainless steels. There is also a link to a downloadable welding guide.

https://www.cwbgroup.org/resources/articles/weldability-of-differing-kinds-of-stainless-steel-part-2

This article looks at some weldability aspects of different kinds of stainless steel, with details related to the welding of martensitic, duplex and precipitation hardening stainless steels and links to other related topics.

https://www.twi-global.com/technical-knowledge/job-knowledge/welding-of-ferritic-martensitic-stainless-steels-101

This Job Knowledge article looks at the welding of ferritic and martensitic stainless steels and includes typical properties of ferritic and martensitic steels.

https://www.fushunspecialsteel.com/1-4021-x20cr13-martensitic-stainless-steel-comprehensive-technical-guide/

This article from China looks at a range of topics including an overview of 1.4021 X20Cr13 martensitic stainless steel; its industrial applications, chemical composition heat treatment processes and available product forms.

It also presents equivalent grades and general information on the martensitic family, gives information on material comparisons and includes a series of FAQs.

Welding duplex and super duplex stainless steels

https://www.engineersaustralia.org.au/sites/default/files/resource-files/2017-01/How_to_weld_Duplex_Stainless_Steel_Mechanical16April09.pdf

This link takes you to a PowerPoint presentation by Avesta Welding on the welding of duplex stainless steels. It features the steel grades (properties and microstructure), uses, fabrication and welding methods, corrosion resistance, welding methods and techniques and welding heat input control.

https://www.outokumpu.com/en/expertise/2021/welding-metallurgy-of-duplex-stainless-steel

This highly informative article explains why microstructure and properties are not always directly related, the issues of phase balance, explains use of the Ferrite Scope and Ferrite Number (FN), explains the reasons for differing ferrite requirements between standards, the role of inter-metallics, nitrides and presents conclusions.

https://esab.com/us/nam_en/esab-university/blogs/duplex-explained-a-guided-welding-procedure/

This article looks at the basic details for welding duplex grades including understanding different grades, storage and handling, purging and shielding gas controls, joint preparation and joint configuration, welding heat input and some aspects of welding techniques.

https://www.langleyalloys.com/knowledge-advice/how-straightforward-is-super-duplex-welding/

This article looks at some areas that contribute to good practices such as joint cleaning, heat input and interpass temperature controls, as well as any preheating and tack welding needs.

https://www.twi-global.com/technical-knowledge/job-knowledge/duplex-stainless-steel-part-1-105

This article is first part of welding duplex stainless steels and considers the required controls for success. There is also a link to part 2.

https://www.neonickel.com/wp-content/uploads/2016/12/12.-Welding-Super-Duplex-Stainless-Steel-Lincoln-NorweldSmitweld-NITO-conference.pdf

This article from the 1980s highlights the welding of duplex stainless steels and provides a fascinating insight to how the early years still influence today's requirements.

Welding precipitation hardened (PH) stainless steels

https://www.hobartbrothers.com/resources/technical-guides/stainless-steel-technical-guide/precipitation-hardening-ph-stainless-steels/

Stainless Steel Technical Guide: This article looks at a range of technical requirements related to welding the martensitic, semi-austenitic and austenitic precipitation hardening stainless steels.

https://www.twi-global.com/technical-knowledge/job-knowledge/precipitation-hardening-stainless-steels-102

This Job Knowledge article is a comprehensive guide to welding PH alloys and covers many topics that influence success.

Videos

Title: Tips for TIG welding stainless
www.youtube.com/watch?v=mpAle-YFn_A

Title: How To Tig Weld Stainless in 3 Hours- COMPLETE LESSON
www.youtube.com/watch?v=p2XORrC3PrY

Title: How To Get Gold TIG Welds On Stainless Steel:
www.youtube.com/watch?v=1pNj30wGV9M

Title: TIG Welding Stainless Steel: A Beginner's Guide:
www.youtube.com/watch?v=Ds6cLG3ThDY

Title: 6 Tips for MIG Welding Stainless Steel:
www.youtube.com/watch?v=XWfAxH49fhs

Title: How to Weld Duplex Stainless Steel | TIG welding
www.youtube.com/watch?v=GIF4V0DZBcg&t=3

Title: Weldability of Martensitic Stainless Steel- II
https://www.youtube.com/watch?v=j_zzyzvpjJE&t=931s

Title: Welding of super duplex steel | Part-2
www.youtube.com/watch?v=FvXV7yLZThM

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STAINLESS STEEL INFORMATION AVAILABLE FROM INFORMATION SERVICES AT TWI GRANTA PARK

The metallurgy, welding, in-service performance and recycling of stainless steel is an enduring topic of interest for both Industrial and Individual Members of the Institute. This is reflected in the library, which holds around 1800 articles, books and reports with stainless steel as their principal subject and an estimated further 5000 where it forms a large part of the publication.

Within this collection are a wide range of digital books that are accessible to members, including:

- Stainless steels for design engineers. ISBN 9781615030590.
- Stainless steel. Microstructure, mechanical properties and methods of application. ISBN 9781634820813.
- Duplex Stainless Steels. Microstructure, properties and applications. ISBN 9781845698775.
- Duplex stainless steel. ISBN 9781848211377.
- Steel heat treatment. Metallurgy and technologies. ISBN 9780849384523. (This includes a detailed chapter on heat treatment of stainless steel.)
- Corrosion of weldments. ISBN 9781615030514. (This includes chapters on corrosion of austenitic, martensitic, ferritic and duplex stainless steels.)

Members can action the digital library, including these books, as follows:

1. Go to 'theweldinginstitute.com' and login with your details and password.
2. Select 'Member Portal' on the menu ribbon.
3. Under 'MY PROFILE' select 'Access TWI Digital Library'.
4. If this is your first use of the digital library then this opens a 'Professional Member Login' and you will need to enter your login details to link with this service. This does not apply for subsequent visits from that device.
5. The digital library opens. Select the orange e-book tab and enter your search terms. If you use the ISBN then enter the number only.
6. If you'd like to download ebooks you will need to register an account with ProQuest, our ebook provider.

For any enquiries about this service please contact: paul.jones@twi.co.uk

THE STAINLESS STEELS – AN INTRODUCTION

Miles Goodwin. Wales Branch, The Welding Institute

This is an introductory guide to the main stainless steel families, their compositions, properties and typical grade naming systems, written, primarily, from a European perspective.

Introduction

By definition stainless steels are iron-based alloys containing at least 10.5% chromium. Chromium forms a very thin, protective oxide layer on the surface, which gives stainless steel its corrosion resistance. If damaged, this passive layer can self-repair in the atmosphere. Other alloying elements are added to improve strength, toughness, weldability, resistance to pitting, machinability and heat resistance.

Stainless steels are chosen mainly for their:

- corrosion resistance,
- heat resistance,
- useful mechanical properties.

Adding more chromium, nickel, molybdenum, nitrogen, and other elements can improve specific performance characteristics.

THE MAIN CATEGORIES OF STAINLESS STEEL

Stainless steels are grouped by their metallurgical structure:

Austenitic

These are the most widely used group of stainless steels with alloying elements chromium and nickel. They offer excellent corrosion resistance (in air and many working environments), toughness, formability and weldability.

- The essential alloying elements are chromium (16-26%) and nickel (6-12%). Higher grades contain molybdenum which enhances the corrosion resistance.
- They are non-magnetic, (but can become slightly magnetic after cold-working).
- They cannot be hardened by heat treatment.
- They are strengthened by work-hardening.
- They have good toughness even at cryogenic temperatures.
- They have lower conductivity than ferritic steels.
- Example grades to EN 10088 are: 1.4301 and 1.4833.

Ferritic

These alloys have chromium alloying and they are generally nickel-free. They are magnetic, have good corrosion and oxidation resistance, but with limited formability and toughness at low temperatures.

- The essential alloying element is chromium (typically 12.5% or 17%) with little or no nickel.
- They have good corrosion and oxidation resistance.
- They have similar thermal properties to carbon steels.
- They are not heat-treatable (generally).
- They have adequate formability.
- They have a ductile/brittle transition; i.e. they become brittle at low temperatures.
- Example grades to EN 10088 are: 1.4512 and 1.4016.

Martensitic

These alloys contain more carbon than the other families of stainless steel which results in their martensitic structure. Consequently their properties can be modified by heat-treatment and these alloys are used where strength/hardness is a requirement.

- The essential alloying elements are chromium (10.5-18%) and carbon (0.2-1.0%).
- They are heat treatable to achieve high strength and hardness.
- Corrosion resistance is generally lower than other stainless families.

continues on page 30

- The alloys are magnetic.
- They have poorer formability than austenitic steels.
- Example grades to EN 10088 are: 1.4006, 1.4028 and 1.4112.

Duplex

The microstructure of this family of steels comprises a mixture of austenite and ferrite, which gives a combination of high strength with strong corrosion resistance. They are categorised into three groups: lean duplex, standard duplex and super duplex based on their composition and chemical resistance.

- The alloying across the grades consists of chromium (18-26%), nickel (4-7%), molybdenum (0-4%), copper and nitrogen.
- These alloys have higher strength than the austenitic steels.
- They are magnetic, due to the ferrite.
- They are weldable, but the balance of the phases must be controlled.
- The thermal expansion lies between ferritic and austenitic steels
- Example grades to EN 10088:
  - Lean duplex: (2304) 1.4362
  - Standard duplex: (2205) 1.4462
  - Super duplex: (2507)1.4410, (Zeron 100) 1.4501.

THE ALLOYING ELEMENTS AND THEIR EFFECTS

Element	Key Effects
Chromium (Cr)	• The most important alloying element in stainless steel. • Forms the essential passive layer. • The minimum needed is 10.5%. • It creates the corrosion resistance. • It acts as a ferrite stabiliser.
Nickel (Ni)	• It improves general corrosion resistance. • It promotes austenite. • It improves workability and toughness. • It acts as an austenite stabiliser.

Molybdenum (Mo)	• Improves resistance to:
	  • pitting corrosion.
	  • crevice corrosion.
	  • general corrosion.
	• An important alloying element in high-performance grades.
	• It acts as a ferrite stabiliser.

Nitrogen (N)	• It increases strength. • It improves resistance to localised corrosion. • It acts as an austenite former.
Copper (Cu)	• It improves corrosion resistance in some acid solutions. • It reduces work-hardening rate. • It is used in some cold-headed products. • It acts as an austenite stabiliser.
Carbon (C)	• Increases strength, especially in martensitic steels. • It can reduce corrosion resistance by forming chromium carbides, including in the welding of some austenitic grades. • Acts as an austenite stabiliser.
Titanium (Ti) and Niobium (Nb	• These alloys are used to prevent intergranular corrosion caused by chromium carbides. • They tie-up carbon before chromium can form grain boundary carbides. • They act as ferrite stabilisers.
Silicon (Si)	• It improves oxidation resistance. • It is used in some special grades for service for aggressive acids. • It acts as a ferrite stabiliser.
Cerium (Ce)	• It improves oxide film adhesion at high temperature.
Manganese (Mn)	• It is an austenite former. • It increases nitrogen solubility. • It can replace nickel in part in some grades.
Sulphur (S)	• It improves machinability. • It reduces corrosion resistance.

STANDARDS AND DESIGNATIONS

In Europe, stainless steels grades for types are standardised under the designations given in:

EN 10088-1:2014. *Stainless steels – List of stainless steels.*

These designations follow the Werkstoff numbering system for steels originally developed in German (e.g. 1.4301). This standard is available in the UK as BS EN 10088-1:2014.

In the USA the AISI system of grade designation, which was introduced in 1974 has been in common use which includes designations such as 304, 304L, 316, 316L, 430, etc.

The compositions of the AISI grades has been made more specific by the introduction of the 'Unified Numbering System' established by the American Society of Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE). Designations under this system starts with letter S (to indicate stainless steel) followed by a five digit number. For example AISI type 304 becomes S30400 and 304L becomes UNS S30403.

There are numerous standards for product forms in stainless steels published by the standardisation bodies, such as The American Society of Mechanical Engineers (ASME), ASTM, BS, EN and ISO.

The following link provides access to large amounts of data on all stainless steel types and specification and property data including the requirements of the designations used under different classification systems: **https://bssa.org.uk/technical-help/types-grades/**

A considerable amount of information is available by following the link: **https://worldstainless.org/about-stainless/what-are-stainless-steels/categories-grades-and-product-forms/**

STAINLESS STEEL ASSOCIATION WEBSITES – WORLDWIDE

British Stainless Steel Association (BSSA)
https://bssa.org.uk/
World Stainless (formerly International Stainless Steel Forum (ISSF))
https://worldstainless.org/
https://worldstainless.org/about-stainless/properties/stainless-steel-standards/
https://worldstainless.org/wp-content/uploads/2025/02/stainless-steel-grades-listed-in-the-international-standard-iso-155102010.pdf
Specialty Steel Industry of North America (SSINA)
https://www.ssina.com/education/
https://www.ssina.com/education/library/
Southern African Stainless Steel Development Association (SASSDA)
https://sassda.co.za/
https://sassda.co.za/about-stainless/introduction-to-stainless-steel/
https://sassda.co.za/important-links/
Australian Stainless Steel Development Association (ASSDA)
https://www.assda.asn.au/stainless-steel/welding
https://www.assda.asn.au/stainless-steel/stainless-steel-industry-links
New Zealand Stainless Steel Development Association (NZSSDA)
https://www.nzssda.org.nz/
https://www.nzssda.org.nz/about-us/
https://www.nzssda.org.nz/downloads/blue-book/
Indian Stainless Steel Development Association (ISSDA)
https://www.stainlessindia.org/page32/Categories-of-Stainless-Steel
https://www.stainlessindia.org/publications

Other relevant organisations

Nickel Institute (NI)
https://www.nickelinstitute.org
https://nickelinstitute.org/en/nickel-applications/stainless-steel/
International Chromium Development Association (ICDA)
https://www.icdacr.com
International Manganese Institute (IMnI)
https://www.manganese.org
International Molybdenum Association (IMOA)
https://www.imoa.info
Steel Construction Institute (SCI)
https://portal.steel-sci.com/

TANICS™ - THE AUTOMATED WELDING SOLUTION FOR NUCLEAR FUEL AND WASTE CONTAINERS

Ben Cohen. Business Development Manager, Langfields
Martin Hooley FIMechE CEng MWeldI. Mechanical Engineer, Metamic Engineering Ltd
Wayne Griffiths IEng MWeldI. Operations Director, Langfields
Jonathan Poskitt CEng MIMechE, CIWE. Welding Manager, Langfields

Langfields, a UK-based fabricator of high-integrity products, has developed and qualified a robotic system to weld lids on stainless steel containers housing radiological waste or nuclear fuel. Named TANICS™ it provides a solution for a major technical problem facing the nuclear industry worldwide.

Background

The nuclear industry has a requirement to transport and store nuclear fuel and waste material in a safe way to avoid risks to site operations staff, the wider public and the environment. Transporting nuclear material in the public space is subject to additional risks due to the potential for collisions with other vehicles and containers must be capable of withstanding impacts without a loss of containment. Containment must also be maintained throughout the storage period, which can be up to 100 years, and hence containment vessels must be high quality in materials and fabrication standards. A fundamental requirement is that the seal between the container and lid must maintain leak tightness and this closure weld needs to be performed without human intervention to limit the exposure of the operations staff to radiation from the contents (and also to protect the wider environment).

Highly radioactive material is transported and stored in 316L austenitic stainless steel containers (UNS designation S31603, EN designation 1.4404). Generally, the lid to container is sealed by welding which ensures a robust, metallurgically stable joint. It provides a seal with predictable properties, maintaining structural integrity and containment during transport and throughout the storage period.

It is relatively straightforward to weld and inspect stainless steel containers to a high standard of quality during fabrication but once these are filled with nuclear material on the licensed site it is a different matter. Due to the radiation hazard, the final closure weld, which is between the lid and the container body, must be performed remotely using a fully-mechanised process.

Until recently the range of equipment available to the nuclear industry for remote or mechanised stainless steel welding was fixed diameter solutions such as orbital welding units or large bespoke static machines including lathe-style welding machines. Orbital systems are not designed to be deployed remotely and static equipment can only be installed in facilities designed to accommodate them, which places severe limitations on what is deployable on nuclear sites. In addition, both system types (orbital and lathe) will not be able to weld containers with different diameters or positions.

Langfields identified the need for a highly flexible, automated, site-deployable, robotic welding solution for the nuclear industry and developed TANICS™; The Automated Nuclear Irradiated Container Solution. TANICS is scalable; it can handle a variety of diameters and weld configurations, delivering a high integrity butt weld to a qualified procedure. Safety is paramount to protect the operators from exposure to potentially lethal radiation from radiological fuel or waste so the welding of the containers takes place inside specially created, shielded cells.

The potential market

Within the UK the decommissioning market is managed by the Nuclear Decommissioning Authority (NDA) and they have produced a strategy for the material in their inventory [1] which is summarised as:

Magnox: Transfer of all uranic material into interim storage by 2045.

Exotic fuel: Transfer all fuel material in interim storage by 2044.

Sellafield:
- All oxide fuel in storage by 2044.
- All plutonium in storage by 2060.
- All uranic material in storage by 2055.

The UK are not the only country with this requirement. Japan has a similar requirement for fuel material, including material damaged in the Fukushima nuclear accident. Decommissioning teams are currently removing all fuel from Fukushima's reactors for long-term storage in stainless steel containers. This involves hundreds of tons of material requiring an estimated 800 to 1000 sealed containers.

The list above for the UK is restricted to nuclear material and does not include UK radiological waste, the storage of which also requires stainless steel containers with a welded seal. The number of containers required for this is not currently known but a fair estimate is more than 1,000.

Description of TANICS™

TANICS™ consists of a robotic welding system moving around a static stainless steel container with the capability to weld different container diameters. It is capable of producing quality full penetration butt welds, partial penetration butt welds and fillet welds in both horizontal and vertical orientations. The development work was led by Langfield's welding engineers working in partnership with robotics engineers from Amentum with the aim to reproduce the skill of a human welder using a robotic arm.

TANICS™ can carry out welds in a variety of orientations using the Tungsten Inert Gas (TIG) welding process deposited in multiple passes and without the requirement for a pre-machined weld preparation. The lid is placed onto the container neck, centralised and welded in position. The system produces high quality welds and TANICS™ is qualified in accordance with the BS EN ISO 15614-1 [4] as well as ASME IX [5]. Qualified welding procedures have been reviewed and accepted by Sellafield's welding subject matter expert. Figure 1 shows TANICS™ during welding operation with the trailing shield in place to maintain an inert atmosphere during the cooling from peak welding temperatures.

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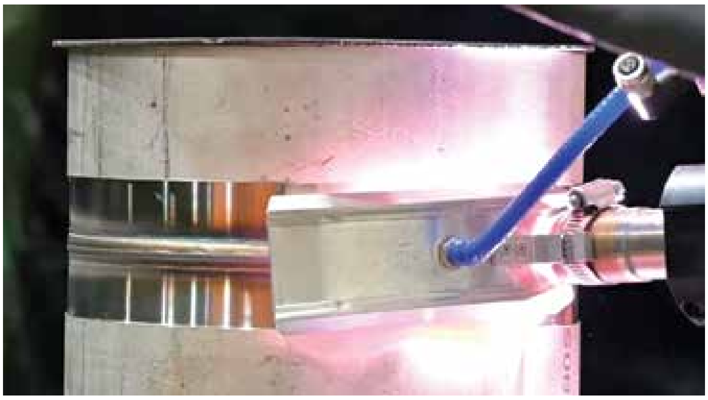

Figure 1: TANICS™ during welding showing trailing shield for inert gas supply.

TANICS™ flexibility provides an advantage over existing mechanised welding systems, which are fixed diameter machines capable of a single weld geometry. Currently there are no other systems capable of being deployed on client sites to work in highly radioactive environments. As the system does not rely on a standard weld preparation, this enables the remote fitting and alignment of the lid to be a straight-forward operation and enhances the remote deployment benefits of TANICS™.

Use of TIG welding on a robotic welding system allows consistent high-quality welds to be deposited to meet the Category 1 requirements of the UK Specification for Pressure Vessels PD 5500 [2] plus those of the Sellafield build level specification; ES_0_5391_2 - Build Level 1 [3]. Figure 2 shows a finished weld profile.

Figure 2: Completed weld profile.

Stainless steel welds require inert gas purging on the back face to mitigate the risk of weld root oxidation. TANICS™ can purge full penetration butt welds with a unique system with a single method of entry/exit. Standard purging techniques cannot reduce the oxygen level to the required level in a container fitted with a single valve, which necessitated the development of this bespoke automated system, thus reducing the risk of expensive re-work. Potential future developments in this area for waste container welding include the option for TANICS™ welding system to be used in an inert atmosphere thus removing the requirement for a purge.

Figure 3: Oxidation free root .

Macro examinations carried out as part of the weld procedure qualification process demonstrates the consistent weld quality achieved by the TANICS™ welding system (Figure 4).

Figure 4: Macrograph showing penetration and defect free geometry.

Welding on a licensed site

The shielded cells used for on-site work are designed and built to provide operations staff with essential shielding from radiation from the nuclear materials.

The TANICS™ welding control system and the other necessary equipment contain a substantial number of electronic components which are sensitive to radiation. These are protected from excessive radiation dose in the following ways:

- The majority of the equipment, such as sensitive electronic control panels, are located outside of the cells (along with the operations staff),
- The robot is located behind shielding until the time it is required to weld,
- The portion of the container within the cell is shielded as possible during welding operations, to further protect the robot, leaving the welded areas unshielded.

TANICS™ demonstrations

TANICS™ has been taken on a tour of nuclear licensed sites to demonstrate the high-quality welding which the system can achieve. The robot is mounted on a transport skid replicating the geometry of a fuel handling cell, which allows for rapid setup and the system can be ready to weld in under one hour after off-loading from the transporter.

Figure 5: TANICS™ welding robot on transportation skid.

'We took TANICS™ on tour to Sellafield and Dounreay and we were overwhelmed by the interest shown by site license operators and suppliers. It's a real game changer for a very technically demanding aspect of radioactive waste management' said Amentum Engineering Development Director Duncan Steel.

'The welds produced using TANICS™ were independently qualified in the UK and Germany and have now been endorsed by specialists from Sellafield Ltd. This shows that the system has the potential to set a new benchmark for automated welding in the nuclear industry,' said Langfields Operations Director Wayne Griffiths.

The system has been endorsed by the welding subject matter expert at Sellafield Ltd. David Campbell, Technical Manager for Sellafield Ltd, described TANICS™ as 'an exciting development where a high integrity welding process can be deployed remotely and adapted to suit a variety of container sealing activities and could almost be classed as off-the-shelf'.

Summary

The nuclear industry, increasingly, needs to move and store nuclear fuel material and radiological waste using bespoke containers. TANICS™ offers a number of benefits over existing solutions for on-site sealing of those, including its repeatability, flexibility and efficiency. The standard of welding produced by TANICS has been verified against the British pressure vessel code in addition to client specific standards (including Sellafield's).

Equally important, it is a safe, cost-effective and efficient means of achieving the required quality of weld which avoids putting the operators in harm's way. This innovative development meets the requirements of the UK's nuclear decommissioning organisations. Due to having dual welding qualification (to both UK and ASME requirements) it has potential for export to other nuclear markets which are experiencing similar technical challenges.

References

1 Nuclear Decommissioning Authority (NDA) Business Plan 2026 to 2029. Published 16th March 2026.

2 PD 5500:2024+A2:2025. Specification for Unfired Pressure Vessels. British Standards Institution.

3 ES_0_5391_2 Fabrication of Plant & Equipment (Stainless Steel). – Builds 1 & 2, Pipework; Build 1, Tanks; Builds 3 & 4, Pressure Vessels and Heat Exchangers. Sellafield specification.

4 BS EN ISO 15614-1. Part 1. Specification and qualification of welding procedures for metallic materials. Welding procedure test. Arc and gas welding of steels and arc welding of nickel and nickel alloys.

5 ASME BPVC.IX – 2025. Boiler and Pressure Vessel Code. Section IX. Welding, Brazing and Fusing Qualifications.

POOLEY BRIDGE - THE UK'S FIRST STAINLESS STEEL ROAD BRIDGE

Image courtesy of WEC group

Background: loss and opportunity

In December 2015 storm Desmond brought devastating flooding to Cumbria, washing away the historic stone bridge at Pooley Bridge; a structure that had stood since 1764. This three arched masonry crossing was not only a key transport link but also central to the village's identity. However, its design contributed to its own downfall. The stone piers restricted river flow during high water, causing debris build up and increased hydraulic pressure. This ultimately led to scouring of the riverbed and the collapse of the structure. Its loss created both a challenge and an opportunity: the need to replace a beloved landmark while addressing flood resilience, environmental impact and modern expectations.

Designers, engineers and contractors

Cumbria County Council led the project and appointed Knight Architects to deliver a new bridge concept. The design team worked closely with local residents to ensure the bridge met both technical requirements and community expectations. It was led by Hector Beade Pereda, Head of Design at Knight Architects and the key engineering collaborators included: Mott MacDonald (conceptual structural design and project management), GHD (detailed engineering design) and Eric Wright Civil Engineering (main contractor). Fabrication of the bridge was by WEC Group.

The design concept

From the outset, the design was shaped by community consultation. Residents highlighted several priorities: the reduction of flood risk, the need to maintain views of the surrounding landscape, the wish to include elements of traditional stonework and the need to minimise environmental disruption during construction. The preferred concept focused on a low impact, visually transparent structure using durable materials. The final 40 m single span design adopted a slender composite arch form, combining stainless steel with a reinforced concrete deck. Key advantages of this concept included improved water flow beneath the bridge, which reduced the flood risk due to absence of mid river piers, a lightweight structure enabling minimal site disruption and an elegant, transparent visual appearance.

The sandstone abutments hide the 7.5 m long hidden back-spans which transfer the horizontal component of the arch compression to the deck providing a traditional deck-arch appearance, but without transferring horizontal reactions to the low-capacity ground.

Material and fabrication

The defining feature of the project is its use of Outokumpu Forta LDX 2101 lean duplex stainless steel, making it the UK's first stainless steel road bridge.

This steel complies with 1.4162 to EN 10088-2 and UNS S32101 to ASTM A240/A240M, It has a typical chemical composition of 21.5% chromium, 1.5% nickel, 0.3% molybdenum, 0.22% nitrogen plus 5.0 % manganese and 0.30 % copper. The carbon content is typically 0.03%. It has good resistance to pitting and crevice corrosion due to the alloying elements chromium, molybdenum and nitrogen.

The tensile properties are dependent on the product form and thickness but for hot rolled plate of 15mm thickness the typical 0.2% proof strength (Rp0.2) is 500 MPa and the ultimate tensile strength (Rm) is 700 MPa. This material was selected for several reasons:

Strength and structural efficiency. Duplex stainless steel is at least 25% stronger than conventional S355 carbon steel, allowing for a slender structural form. This reduced the volume of both steel and concrete required, improving sustainability and lowering embodied carbon.

Durability and maintenance. The bridge's stainless steel structure offers excellent corrosion resistance, eliminating the need for repainting over its lifespan. This is especially important in a sensitive environment such as the Lake District National Park, where maintenance activities like blast cleaning (for preparation for painting) could impact the river ecosystem.

Economic benefits. The lean duplex grade has a low nickel content, helping to provide more predictable and cost effective material pricing compared to other stainless steels.

Aesthetic qualities. A matt surface finish was selected to reflect the rural setting, resembling galvanised steel commonly used in agricultural contexts but without the corrosion which occurs within a generation with that material.

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Fabrication challenges

Duplex stainless steel can be fabricated by all the main arc welding processes including MMA/SMAW, TIG/GTAW, MIG/GMAW and FCAW. This grade has good weldability. However duplex stainless steels require specialised fabrication techniques with care taken in the selection of appropriate grades of filler metal. Arc energy input requires good control to maintain phase balance and interpass cooling is necessary.

In addition there are the commonsense requirements: fabrication areas for stainless steel must be segregated from carbon steel to avoid contamination and surface finishing must be handled carefully to preserve appearance. Due to these constraints, only three UK fabrication shops submitted tenders for the project and WEC Group in Darwen secured the contract and successfully delivered the fabricated structure.

Fabrication welding. Image courtesy of WEC Group.

It was fabricated in four section at WEC Group's Darwen facilities requiring approximately 22,000 man-hours, with component profiling in Rotherham. A custom jig was designed to allow simultaneous work on multiple sections, increasing efficiency and precision.

Installation

Site assembly. Image courtesy of WEC Group.

After delivery to site in sections ready for assembly there was a delay due to Covid-19 restrictions, but once assembled it was lifted into place in a single operation using a 1,200-tonne crane, one of the largest in the UK. The bridge's lightweight design enabled it to be lifted into place in a single operation, avoiding the need for temporary supports within the river. this significantly reduced environmental impact, protecting the riverbed and surrounding habitat during construction - an important consideration in a UNESCO World Heritage Site.

Community connection

The process of replacing the bridge featured extensive community participation and this is reflected in the final project. It incorporates stone cladding on the abutments, referencing the original bridge's materials and visual character.

The bridge – installed. Image courtesy of WEC Group.

The bridge maintains a single lane traffic system controlled by lights, similar to the original crossing which reduces vehicle speeds and creates a more pedestrian friendly village environment. The design has minimal barriers and widened sections at midspan. People can cross from side to side, (possibly playing 'Pooh sticks') and the bridge remains a place to pause and appreciate the landscape.

Sustainability and long-term vision

Sustainability was central to the project's philosophy and the bridge has a design life exceeding 120 years, with expectations that it may last far longer. The composite design and use of high strength stainless steel represents an economical use of materials. The stainless steel itself has a high content of recycled steel and has an exceptionally low maintenance requirement. The expectation is that it will be valued by future generations, encouraging long term stewardship.

Conclusions

The new Pooley Bridge is a landmark project in UK infrastructure; not only for its technical innovation but also for its collaborative and community focused approach.

By combining advanced materials, thoughtful design, and local engagement, the project delivers a structure that reduces the risk of local flooding and is architecturally refined, environmentally sensitive and belongs in its setting. As the UK's first stainless steel road bridge, it sets a precedent for future sustainable infrastructure while restoring a vital link and identity to the village of Pooley Bridge.

Further information

Cumbria County Council Fabrication video:
https://www.youtube.com/watch?v=SHNIumYtS8k

The story of the bridge. Cumbria County Council video:
https://www.youtube.com/watch?v=xKdDFt7YKsQ

The collapse of the old bridge: Atlantic Geomatics (UK) Ltd video:
https://www.youtube.com/watch?v=C4v7Kn0vuOU

Time lapse Installation video Cumbria County Council and Eric Wright Civil Engineering:
https://www.youtube.com/watch?v=HMOUK9TgEn0

WEC case study: **https://www.welding-eng.com/pooley-bridge/**

WEC Photo gallery:
https://www.flickr.com/photos/wecgroup/albums/72157712802613928/with/51300002653

WEC press release from 2020:
https://www.wec-group.com/news/pooley-bridge-fabrication-update.html

EXPLORATION OF NOVEL INSIDE-OUT ELECTRON BEAM WELDING USING 'EBOBEND'

Dr Tim Mitchell CEng MWeldI. Principal Engineer, TWI Ltd

Introduction

TWI's Power Beam Processing Team has completed a programme of work exploring the capabilities of a recently acquired 15 kW, 150 kV electron beam (EB) machine manufactured by Steigerwald Strahltechnik GmbH (SST) who are an original equipment manufacturer of EB welding machines and are part of the Global Beam Technologies Group. Since its founding in 1963, SST has continuously developed EB technology for industrial applications. These developments include machines for welding, drilling, surface treatment and additive manufacturing.

Electron beam machines are used across a wide range of applications, from welding thin sheet material (~0.1 mm) to substantially thicker sections (up to ~200 mm). A key characteristic of EB welding is its ability to achieve deep penetration welds, often in a single pass and without the need for filler material. The process is fundamentally a line-of-sight technique, requiring access for the beam to reach the joint. However, the beam can be deflected and focused using electromagnetic lenses, enabling controlled manipulation of beam position and intensity for welding complex geometries. The EB machine at TWI incorporates several innovations, including Steigerwald's EBOBend device. This apparatus enables the electron beam to access the internal surfaces of tubes or cavities by deflecting the beam through a 90° arc using a specially designed electromagnetic control system. The EBOBend system allows internal welding and processing at full beam power, facilitating welds in materials such as titanium with thicknesses exceeding 20 mm.

Equipment Design

The electromagnet is encased within a tubular assembly mounted to the chamber wall. The tube length can be adjusted in sections up to approximately 1300 mm and has an outer diameter of 76 mm (Figure 1).

Figure 1: EBOBend equipment inside the EB vacuum chamber.

In addition to bending the beam through 90°, the system incorporates backscattered electron detection plates, enabling imaging of internal surfaces and improving beam alignment to the joint.

A further feature of the EB machine is the EBOSet beam quality device. This system adjusts beam quality through control of alignment and astigmatism, using integrated sensors and proprietary software to compensate for beam distortion automatically (Figure 2).

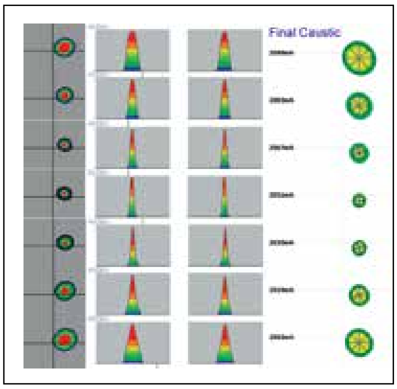

Figure 2: Final caustic measurements after optimisation using the EBOSet device, showing improved beam quality.

Welding programme

The programme of work was divided into a series of tasks to investigate and demonstrate the capabilities of the system:

- Welding the interior of a small pipe
- Repair of defects in niobium cavities
- Welding of niobium cavities from the inside
- Demonstration on a larger component
- Thick-section welding

Welding the interior of a small pipe

The first task was to demonstrate a circumferential melt run on the internal diameter of a 4 inch NPS Schedule 10 duplex stainless steel pipe (Figure 3).

Figure 3: Internal welding set-up showing beam path within the EBOBend device.

Following a short development programme, a weld produced at 2.7 kW and 1 m/min was found to be of high quality. The internal weld cap profile was superior to that typically achieved at the root which would conventionally be on the inside of the tube (Figure 4).

Figure 4: Full penetration internal weld in duplex pipe and corresponding transverse macrosection.

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Repairing defects in niobium cavities

The second activity explored internal repair of defects in niobium superconducting radio-frequency (SRF) cavities (Figure 5).

Figure 5: Electron beam welded twin-cell demonstration SRF cavity.

The internal surface condition of such cavities is critical to performance. Significant effort is made to ensure high material quality and defect-free welds. However, defects or processing damage may still occur, directly affecting performance and requiring repair. Following fabrication, cavities are chemically etched to remove approximately 150 µm of material. Defects exceeding ~200 µm in depth cannot be removed by this process alone.

Conventional repair methods involve complex internal grinding and polishing, while low-power pulsed laser systems can address shallow defects (~60 µm). The EBOBend system offers an alternative by enabling internal EB repair via access through the beam tube or iris (Figure 6).

Figure 6: Repair simulation set-up for a single SRF cavity.

In this study, simulated defects were introduced using a vibro-etching tool. These were intentionally larger than typical service defects to demonstrate capability (Figures 7 and 8). The introduced flaw was approximately 9 mm long and up to ~450 µm deep.

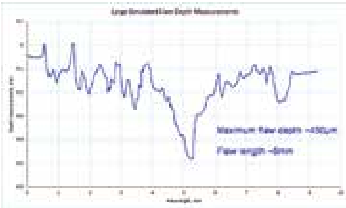


Figure 7: Simulated flaw on weld root prior to repair (left). *Figure 8: Profile measurements of simulated flaw (right).*

Repair welds were performed at 2.4 kW and 300 mm/min using a defocused beam with beam deflection. The results showed effective removal of the defect, producing a smooth surface with a lower profile than the original weld cap (Figure 9).

Figure 9: Internal repair of niobium cavity: before and after processing.

These results demonstrate the potential for recovering components that might otherwise be scrapped.

Welding niobium cavities from the inside

A further phase investigated welding the final equator joint in cavity assemblies from the inside. Traditionally, this joint is welded under tightly controlled conditions with high vacuum and cleanliness to prevent contamination and preserve superconducting properties (Figure 10).

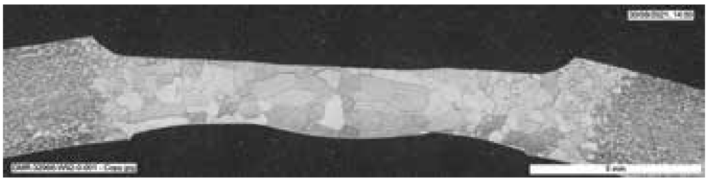


Figure 10: Equator weld in SRF cavity.

The internal weld profile must be smooth, with limited protrusion (typically <250 µm), as this directly affects performance. Conventional weld thicknesses are typically 1.7 mm to 2.1 mm, with thicker welds leading to increased root profiles and reduced performance.

Inside-out welding offers new possibilities. Thicker material sections can be welded while controlling internal weld profile, and cosmetic (wash) passes can be applied to improve surface smoothness.

Results demonstrated high-quality welds in approximately 3 mm thick material (Figure 11). The internal weld surface was smooth, with only a modest increase in heat input compared with conventional processing (372 J/mm vs 322 J/mm).

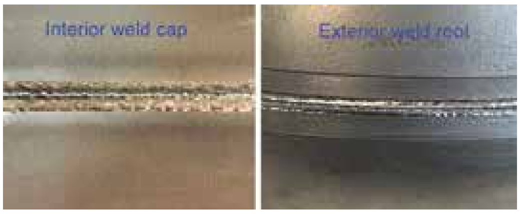
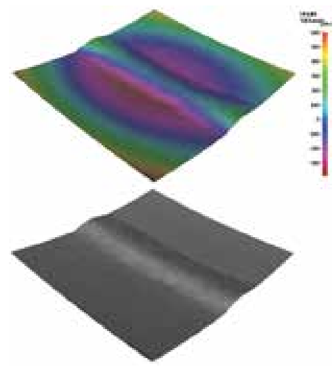


Figure 11: Internal weld in ~3 mm niobium showing smooth cap and root profile.

Laser scanning of welds (Figure 12) indicated a weld cap height of approximately 300 µm, which was further reduced to <100 µm following a cosmetic pass (Figure 13).



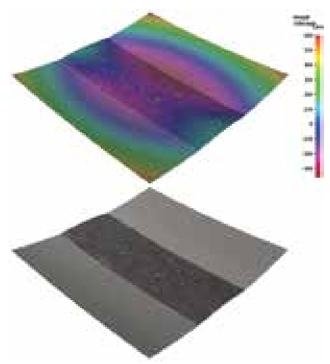


Figure 12: Laser scan of internal weld cap profile. *Figure 13: Internal cosmetic pass producing a very low-profile weld.*

Larger aerospace components with restricted access

Recent work has also explored EB welding of aerospace components, including satellite fuel tanks and landing gear structures, where internal access is limited. In such components, weld roots are often inaccessible for post-processing, and the as-welded condition directly influences fatigue performance. The EBOBend system offers the potential to improve internal weld profiles and enable novel fabrication routes.

A 400 mm diameter stainless steel vacuum vessel was used for demonstration trials (Figure 14), with access provided via a 100 mm port.

Figure 14: Stainless steel vacuum vessel used for internal welding trials.

The resulting welds exhibited smooth internal profiles along the full length (Figure 15). In addition to circumferential welds, the system has potential for welding internal features such as penetrations, subject to access constraints.

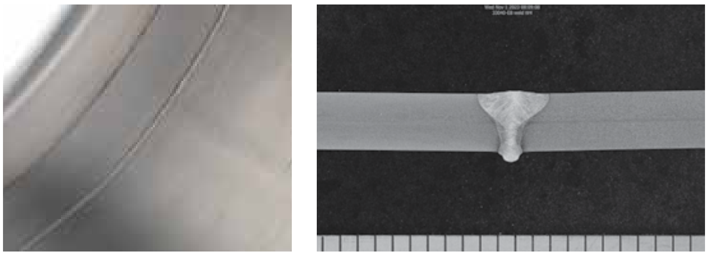


Figure 15: Internal EB weld next to the TIG weld root with a metallographic section of the EB weld.

Thick section welds

The final experiments investigated thick-section welding capability. Trials on titanium alloys demonstrated penetration of at least 20 mm at 6 kW and 200 mm/min (approximately 40% of available power) (Figure 16). Further trials achieved penetrations of approximately 26 mm at 60% power. The results indicate that thicker sections may be welded using double-sided approaches, extending the capability of the process.

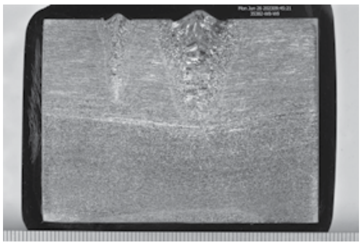


Figure 16: EBOBend welds in thick-section titanium alloy.

Conclusions

The programme has demonstrated the capabilities of the EBOBend system for internal electron beam processing:

- Internal welding of tubes with diameters $\geq$80 mm is achievable, with access depths of up to ~1000 mm.
- Internal repair and reprocessing of welds is feasible, enabling component recovery and potential performance improvements.
- Inside-out welding provides new options for component design and assembly.
- Thick-section welding can be achieved, with potential for increased section thickness using double-sided approaches.
- Future developments may include internal wire feed systems for enhanced repair capability.

These results highlight the potential of inside-out EB welding as a novel manufacturing approach for high-value and complex components.

About the author

Dr Tim Mitchell is a Principal Engineer at TWI having joined in 2001. Tim leads a diverse range of research and production projects in electron beam welding as well as interdisciplinary programmes incorporating other joining technologies. Tim has contributed to quality standards, developed specialist training, and advises on all aspects of electron beam welding including welding procedures and design for welding and fabrication as well as responding to technical challenges in the manufacture of complex components made from difficult to weld alloys.

THE RADIATION HAZARD FROM MANUAL HANDHELD LASER WELDING AND CUTTING EQUIPMENT

George Assimacopoulos BSc MSc MBA CEng and Ioannis Kordatos PhD

Figure 1: Typical handheld laser torch equipped with wire feeding system.

Handheld laser welding and cutting equipment can result in excellent quality work and it is to be expected that there will be considerable growth in industrial application for these processes. It is also the case that whilst new technologies provide technological and scientific advantages they can also provide new and sometimes unexpected hazards. The radiation from the laser beam is one of these hazards and this article analyses the nature of this radiation and the measures that have to be taken to mitigate the associated risks.

The hazard

The danger in handheld welding and cutting technology originates in the actual laser beam. The laser beam radiation used is in the infrared part of the spectrum with a wavelength of λ=750 nm - 1 mm and is invisible to the human eye.

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Practically this means that if an infrared beam impinges on our eye, our defence system; the blink reflex, is not activated and the beam impinges our cornea resulting in a cataract or even blindness. Additionally it must not be forgotten that the optical nerves are in close proximity to the human brain with possible acute biological consequences.

The laser beam can be either direct or indirect. A direct beam is one that is emitted directly from the handheld device during welding or cutting (as well as other handheld laser applications such as cleaning or marking processes). Indirect radiation results from reflection, such as from the weld pool, which can reflect something like 50 % of the direct radiation, as well as reflection from polished/reflective surfaces such as aluminium or stainless steel plates.

This is one of the main reasons why it is usually required to use separate working rooms where laser work is done or, alternatively, specialised partitions or curtains are used to provide essential shielding.

It has been noticed, quite often, that operators of handheld laser welding equipment operators do not use goggles designated as suitable for laser welding, or they use traditional welders'/cutters' goggles just because they cannot see the laser beam and believe (wrongly) that there is no hazard.

It has to be emphasised that traditional welders'/cutters' goggles or visor provide minimal protection towards the infrared laser beam. This type of beam penetrates the lens almost as if there is no barrier at all.

Figure 2: Handheld 2 kW laser welding equipment - safety signs.

Classification of the hazard

The standard EN 60825-1 [1] classifies the hazard and associated safety requirements for laser equipment in 7 categories as described in Table 1 below. This Table shows that handheld laser welding or cutting equipment is classified as category 4. This is considered the most dangerous category and requires definite protection measures. Additionally, the laser equipment manufacturers are obliged by law to declare to the end users the class of their equipment, enabling them to provide the appropriate Personal Protective Equipment (PPE).

Class	Details
Class 1	The radiation in this class is not considered dangerous and therefore there is no need for eye protection.
Class 1M	The radiation in this class is not considered dangerous for the eyes unless optical systems are used.
Class 2	The radiation in this class is not considered dangerous and therefore there is no need for eye protection.
Class 2M	The radiation in this class is not considered dangerous unless optical systems are used.
Class 3R	The radiation in this class exceeds the Maximum Permissible Exposure (MPE). Therefore it is considered dangerous for the human eye and the use of appropriate protective eyewear is required.
Class 3B	The eye exposure to the radiation of this class is considered dangerous therefore the use of protective eyewear is required.
Class 4	All the current handheld devices relating to welding, cutting, cleaning and marking belong in this class and therefore the use of appropriate protective eyewear is imperative.

Table 1: Classification of radiation from laser equipment according to EN 60825-1.

The protective goggles and eyewear required for Laser beams must comply with and EN ISO 19818-1:2021 [2]. The filters are totally different in nature compared to the ones used in the traditional welding and cutting work and must comply with EN 207:2017 [5].

The following information is required in order to facilitate the selection of the right lenses for laser work:

1. The Laser beam wavelength (λ) in nm. This value can be obtained from the laser system manufacturer.
2. The required Optical Density (OD). This value is usually provided by the manufacturer of the equipment or, alternatively, it can be calculated with information provided by the manufacturer.

OD of filters is defined within the following categories:

OD = 1: It allows 10% of the Laser beam (in relation to the wavelength) to pass through the protective barrier.

OD = 2: It allows 1% of the Laser beam (in relation to the wavelength) to pass through the protective barrier.

OD = 3: It allows 0.1% of the Laser beam (in relation to the wavelength) to pass through the protective barrier.

OD = 4: It allows 0.01% of the Laser beam (in relation to the wavelength) to pass through the protective barrier.

OD = 5: It allows 0.001% of the Laser beam (in relation to the wavelength) to pass through the protective barrier.

OD = 6: It allows 0.0001% of the Laser beam (in relation to the wavelength) to pass through the protective barrier.

Another very important factor which defines the quality of these filters, is the Visual Light Transmission (VLT). This factor indicates the light that passes through the filter enabling the operator to see the working item clearly. The lighter the lens is, the greater the ability for the operator to clearly see the working item as the blocking effect of the visual rays is decreased. A good practice is that VLT must not be less than 20% for good visual capability.

Hence the following are the essential requirements for protective eyewear for any specific laser process:

1. Selection of the appropriate goggles/eyewear complying with ISO 19818 selected in accordance with the required wavelength, OD and VLT.
2. Use of ergonomic/comfortable frames/visors with side protection ("fenders"). According to the specification, these frames/visors must have the applicable wavelength as well as the OD values marked on them.

For those that like formulas and calculations, OD can be estimated as follows:

$$OD = \log \frac{E}{MPE}$$

where:

E: Laser beam Irradiance in $\frac{mW}{cm^2}$.

MPE: Maximum Permissible Exposure in $\frac{mW}{cm^2}$.

The value of E will be provided by the manufacturer.

MPE is the maximum Laser beam energy density which will not adversely affect (in the biological sense), the human eye. It depends on the laser beam wavelength (as provided by the manufacturer). The MPE values can be derived from tables existing in the specifications ISO 19818 or ANSI Z136.1 [3].

A simple example will follow indicating the calculation of OD as well as the proper selection of the laser protection eyewear.

Example

The application

In a certain handheld laser welding operation, the manufacturer of the equipment provides the following technical information:

Irradiance = 650 $\frac{mW}{cm^2}$.

Wavelength = 500 nm

EN 60825-1 classification = 4

The task is to select the appropriate/safe eyewear for the laser operator.

The resulting requirement

First of all, since the equipment hazard classification is 4, it is imperative to provide eye protection for the Laser operators.

According to the appropriate tables of ISO 19818 and for a beam with a wavelength of λ=500 nm, the maximum permissible exposure is derived to be: MPE = 2.55 $\frac{mW}{cm^2}$.

Therefore $OD = \log\frac{E}{MPE} = \log\frac{650}{2.55} = \log 254.9 = 2.2$

We round up this value, therefore OD = 3.

The resulting selection

Based on the above, we select eyewear complying with ISO 19818 with OD equal or higher than 3 and VLT at least equal to 20%. If we have any doubt we contact the specialised eyewear manufacturer directly.

Closing remarks

Recently, the PPE manufacturers that specialise in handheld welding protection equipment, have produced special Passive Laser Masks. These masks look very similar to the traditional welders' masks, however, they are made using materials that block the laser beam and hence protect the welder's head from exposure to it.

It should be remembered that laser beams have an extremely high energy density. Therefore it is necessary to minimise the fire risk by having appropriate fire extinguishers in workplaces using lasers. Another good safety measure is to avoid the existence of any flammable material within (at least) 5 meters of the point of operation. Exposure of skin to laser beams should also be avoided, as the burns produced can be very severe. For completeness we mention that the referenced standards provide separate MPEs (Maximum Permissible Exposures) for the exposure of human skin to laser beams.

Finally, it is common practice to perform, if possible, laser operations in a special, well-marked room equipped with a welding fumes extraction system. If this is not practicable special partitions or curtains complying to EN 60825-4 [4] can be used, which are specifically designed for laser beam protection. Partitions and curtains that are used for traditional welding are not applicable in laser handheld operations.

Finally we emphasise the need for training of the handheld laser operators in the correct use and maintenance of the laser-specific PPE, which can be relatively simple to do.

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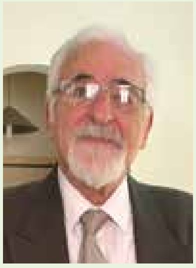
About the authors



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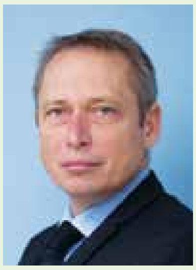

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FUME HAZARDS FROM ARC WELDING OF STAINLESS STEELS AND OTHER ALLOYS

Geoff Melton FWeldI

Introduction

The health hazards from welding fume are generally well known, as particulate fume is clearly visible when welding. However, it is not just the fume that you can see, but some gases generated by the process which are also harmful. Historically, fume from welding stainless steels was considered more of a concern than that from other materials, because of hexavalent chromium and nickel oxides in the fume, which are known carcinogens. However, in 2018 The International Agency for Research on Cancer (IARC), published Monograph 118, in which welding fumes (including those from welding carbon steels) were evaluated and reclassified as Group 1 (carcinogenic to humans) when previously they were classified as Group 2B (possibly carcinogenic). IARC also classified UV radiation from arc welding as Group 1. The individual limits for exposure (workplace exposure limits in the UK, abbreviated to WELs) vary between countries, with a trend of being reduced at each revision, particularly for hexavalent chromium and manganese.

Fume formation mechanism

Particulate welding fume originates primarily from the welding consumable, as vapour from the hot molten droplet. However, the welding consumable composition cannot be taken as a guide to fume composition. Substances with a high vapour pressure and low vaporisation temperature transfer into the fume more readily than other constituents, so, for example, manganese transfer is high but chromium and nickel transfer is low. Furthermore, hexavalent chromium is produced in the arc by conversion of chromium in the consumable. The percentage of hexavalent chromium in the fume is influenced by the type of welding consumable. With solid wires the conversion is low, but it is much higher with manual metal arc (MMA) electrodes and flux-cored arc welding (FCAW) consumables.

Figure 1: Fume arising from MMA welding. Courtesy: TWI Ltd.

Welding parameters affect the quantity of fume produced and in general, the higher the welding current the greater the quantity of fume produced. However, an unstable welding condition at low current will also increase the fume. Pulse and other waveform control technologies may reduce fume emission and shielding gases play a role. Welding consumable manufacturers are also developing products that emit lower levels of fume and are formulated to reduce specific constituents such as hexavalent chromium.

Tungsten inert gas welding is widely used for welding stainless steels. The fume is produced by vaporisation from the weld pool and the quantity is significantly lower. However, there are concerns because particle size is smaller and limits for hexavalent chromium may still be exceeded.

Particulates

The main particulate welding fume constituents with health concerns are given below.

Chromium (III and VII) compounds

Welding consumables do not contain hexavalent chromium. It is produced when the chromium in the stainless steel is vaporised in the arc and then oxidised which produces very small particles of hexavalent chromium. Hexavalent chromium is a highly toxic human carcinogen and exposure limits are extremely low. Inhaling hexavalent chromium can cause lung cancer, occupational asthma and chronic obstructive pulmonary disease (COPD), and damage to kidneys and liver. Other welding consumable with chromium alloys may also produce hexavalent chromium.

Nickel compounds

Welding stainless steels and nickel alloys will produce welding fume containing nickel oxides. Other welding consumables may also contain small additions of nickel which will be present in the fume. Nickel compounds are also a human carcinogen and exposure can cause lung and nasal cancer. Nickel is also an asthmagen and allergen, causing industrial asthma and allergic contact dermatitis.

Manganese compounds

Stainless and other steel consumables often contain manganese. Inhalation of manganese oxide fumes can lead to a build-up in the body and central nervous system. Chronic exposure can result in a neurological disorder known as Manganism, which has similar symptoms to Parkinson's disease.

Other particulates

There are also exposure limits for iron oxide fume, zinc oxide fume, copper fume, cadmium oxide fume, beryllium and beryllium compounds, and fluorides from MMA and FCAW, but these are not consistent around the world.

Gases

Welding fume also contains gases, which are harmful to health. These gases are listed below.

Nitric oxide (NO) and nitrogen dioxide (NO_2) are known collectively as nitrous gases (NO_x). They are generated by oxidation of nitrogen in the air by heat from an arc or flame. Nitrogen dioxide is highly irritating but may not cause immediate distress at low levels. Acute exposure causes immediate irritation of the eyes, nose and throat. Chronic low-level exposure permanently degrades lung tissue, accelerating the development of chronic obstructive pulmonary disease (COPD) and emphysema.

Carbon monoxide (CO) is generated in fluxed welding processes by the action of heat on flux materials such as carbonates and cellulose. In MAG welding carbon dioxide (CO_2) in the shielding gas breaks down in the arc to form CO. When inhaled it binds to red blood cells, depriving the body of oxygen. Mild exposure may cause headaches, dizziness and nausea. Severe exposure can lead to unconsciousness and irreversible heart and brain damage.

Ozone is generated by a reaction between UV light from the arc and oxygen in the air. Ozone is only generated during arcing and decays quickly on arc extinction. Ozone is a highly reactive gas generated during gas-shielded welding processes, such as Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding. Ozone generation is particularly high when welding stainless steel because the reflective surface of the metal bounces UV radiation back into the surrounding air, increasing the reaction rate. Ozone is a severe respiratory irritant that attacks the epithelial lining of the respiratory tract. Inhaling ozone causes headaches, chest pain, and a dry throat. High exposures cause rapid airway constriction, reducing lung function and aggravating pre-existing conditions like asthma. Heavy exposure can cause long-term pulmonary haemorrhages and fluid accumulation in the lung.

Harmful gases may also be produced by the breakdown of organic materials such as shop primers, organic coatings, adhesives, sealants, degreasers, oils, etc.

Welding fume gases and shielding gases can build up in confined spaces, so additional care and specific measures to reduce exposure should be taken.

UV Light

Welding arcs emit intense ultraviolet (UV) radiation that can cause severe skin burns (Erythema) and "arc eye" (Photokeratitis; a painful inflammation of the cornea). Welders are well aware of the hazard of the UV light and suitable eye protection is generally well used, but occasionally they see a flash by mistake. Sometime later, they may experience severe pain and a gritty feeling in the eyes. Also, UV radiation from welding has been classified by IARC as carcinogenic to humans. Long term exposure to UV radiation poses a serious long-term risk of Ocular Melanoma.

Recommendations

Local exhaust ventilation (LEV) and respiratory protective equipment (RPE) should be used as appropriate to reduce welders' exposure to welding fume. The relevant exposure limits and guidance documents should be followed, for the region/country in which the welding activities are taking place.

Figure 2: MAG welding with adjustable local exhaust ventilation. Courtesy TWI Ltd.

About the author

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WELDER COMPETENCE REQUIREMENTS IN INDUSTRY: PART 1. THE BASICS

EUR ING Mike Baverstock MSc CEng FWeldI. Director, Welding Engineering Consultancy Ltd

This is the first part of a two-part article presenting an overview of welder competence requirements and is taken from a presentation given at **The Welding Institute Members' Day 2025 by Mike Baverstock**, who works as a welding co-ordinator supporting clients across a range of industries.

The Welding coordinator's role

The welding coordinator's role is defined in BS EN ISO 14731:2019 Welding coordination - Tasks and responsibilities [1], with the roles and responsibilities as laid out in Section 4 and Annex B of the standard.

Annex B4 deals with welding personnel and states that welders must be qualified for the relevant contract requirements but it does not state any requirements regarding their training or skills development and nor does it state any requirements how those skills are to be maintained. However although the necessities of training and job knowledge are undefined they remain within the responsibilities of the welding coordinator.

BS EN ISO 9606 is the international standard for the qualification testing of welders; but there is no compulsory requirement to test job knowledge in any part of that standard (although it is recommended). Some might say that welders do not need any job knowledge as they are qualified by the practical test but if the welder has better understanding of the welding process, the possible welding defects and their causes, etc then they would be more knowledgeable and skilled in their work.

Specification requirements for qualification of welders and operators

BS EN ISO 9606 is in multiple parts specifying the requirements for the qualification testing of welders for manual and partly-mechanised fusion welding for (in sequence) steels, aluminium, copper, nickel and titanium/

continues on page 42

zirconium alloys [Refs 2 – 6] and BS EN ISO 24394 [7] is the welder qualification specification for aerospace applications.

Once a welder has passed their qualification test the manufacturer, and hence the welding coordinator has to maintain records to ensure that qualification remains valid otherwise it expires after six months. In addition even with the 'six month' rule in place the original qualification runs out after a period of some years and it requires revalidation. Table 1 below summarises how the qualification of the welder is maintained current and the various revalidation requirements within these standards.

Note that the table states simplified requirements and in any work situation the user should work from the requirements as stated in the current version of the applicable standard.

Standard	Materials (alloy types)	Base requirement which always apply (simplified)	Revalidation requirements and options for a further period of years			
			Option/ clause	Validity period of qualification (years)	Notes (simplified specification requirements)	Job Knowledge Mandatory Yes/No
BS EN ISO 9606-1	Steel	Clause 9.2 Welders qualification reconfirmed every six months by the responsible person. Extends validity by six months.	Option 9.3a	3	New test required after the 3 years.	No
			Option 9.3b	2	New test is not required if during last 6 months 2 welds are performed, NDT is done and passed. Gives revalidation for further two years.	
			Option 9.3c	No end point	New test NOT required if: Clause 9.2 complied with. Same employer. Quality programme in place to BS EN ISO 3834-2 [8] or BS EN ISO 3834-3 [9]. Welders' work is to be the same configurations etc.	
BS EN ISO 9606-2	Aluminium	As 9606-1 above	Clause 9	2	New test is not required if during last 6 months 2 welds are performed, NDT or mechanical testing is done and passed. Gives revalidation for further two years.	No
BS EN ISO 9606-3	Copper	As 9606-1 above	Clauses 9 and 10	2	New test is not required if during last 6 months a weld is performed, NDT or mechanical testing is done and passed. Gives revalidation for further two years.	No
BS EN ISO 9606-4	Nickel					
BS EN ISO 9606-5	Titanium/ zirconium					
BS EN ISO 24394	Aerospace	Welders qualification reconfirmed every six months by the responsible person. Extends validity by six months.	Clause 12	2	Complete retesting required - the same requirements as for the initial qualification tests apply.	Yes

Table 1: Summary of requirements for maintaining and revalidating welder qualifications.

Job knowledge requirement for welders

The job knowledge test is recommended, but not mandatory in parts 1 to 5 of BS EN ISO 9606 but is rarely required within the UK, however it is mandatory in BS EN ISO 24394 which applies in work for the aerospace sector. Where it is done it may be by written paper or verbal test and the key areas to be covered are:

i. Welding equipment
ii. Welding processes
iii. Parent materials
iv. Filler materials
v. Welding sequence and procedures
vi. Joint preparations and weld representation
vii. Weld imperfections
viii. Safety precautions

More subjects or detail can be added or removed at the discretion of the manufacturer.

Training and development of welding personnel

This section addresses how you can establish a method of qualification and development of welding personnel given that there are not many standards providing guidance on this essential activity.

BS 1295: Code of practice for training in arc welding skills [10]

This standard contains training programmes which remain relevant and could provide the basis for development of a company's welder training programme even though it was withdrawn in 2000. This standard:

- gives recommendations for the content of a series of practical courses for training in arc welding skills and related job knowledge.
- sets requirements for the achievement of proficiency at each stage (it does not define time limits for the training tasks).
- covers TIG, MMA, MIG & MAG welding processes.
- states requirements divided into plate, pipe and sheet welding tasks.

Note that job knowledge is compulsory in this (withdrawn) standard for the factors under the control of the welder which influence weld quality, the welder's safety and the safety of other workers. Assessment either can be oral, written or multiple-choice.

National Welder Training Standards

A set of welder training Codes of Practice were established in 2009 to deliver greater uniformity in welder training in the UK and were published by TWI Certification Ltd. The National Welder Training Standard (NWTS) aims to "provide a visible, recognised benchmark for welder training and competence upon which industry can rely". See **https://www.twicertification.com/certifications/national-welder-training-standard-nwts.**

It was a prototype for adoption as the national standard for the training of welders, covering practical training for skills, essential job knowledge, welder approval and requirements for training organisation, It remains available but, since the standard was published 17 years ago, it will be out-of-date in some areas. It is published as four Codes of Practice:

CP1 Training of welding operatives
CP2 Training of craftsman welders
CP3 Training of master welders
CP4 Training of supervisory staff

For the purpose of this Code, a craftsman welder is defined as a person who has undergone a programme of theoretical and practical training in arc welding; and has demonstrated theoretical knowledge practical skills accordance with recognised standards the range of welding positions.

CP2 is in three parts:

Part 1 theoretical knowledge
part 2 fillet welding practical
part 3 plate welding practical

IIW International Welder

The International Institute of Welding (IIW) have published a number of guidelines covering welder training and qualification which provide detailed training programmes. These can be found on the IIW website iiwelding.org by doing a search in the 'Knowledge Centre' and searching for:

IAB-089r5-14	IIW Guideline for the education and training of Welders - Part 1
IAB-089r5-14	IIW guideline for the education and training of Experienced Welders - Part III

If you register with IIW these are available as free downloads. The intent is that this scheme is used under the IIW Qualification System by organisations authorised by IIW. The scheme is comprehensive and you are advised to read the source documents in detail, but for the International welder it defines the following:

Requirements for theoretical education:

- Module A: covering welding equipment, safety, welding consumables, welding practice and qualification.
- module B: covering joint preparation, weldability, imperfections, process overview, inspection testing and quality.
- module C covering joints in pipes, materials other than steel, failures, IIW standards.
- Further modules covering supplementary theoretical education related to specific welding processes.
- Further modules covering supplementary theoretical education with specific requirements for stainless steel and aluminium.

The practical welding modules are organised by process and material:

- MMA welding for ferritic and stainless steels. Process 111.
- MAG welding for ferritic and stainless steels. Processes 135, 136 and 138.
- MIG welding for aluminium alloys. Process 131.
- TIG welding for ferritic and stainless steels. Process 141.
- TIG welding for aluminium alloys. Process 141.
- Gas welding for ferritic steel. Process 311.

There are then specific requirements related to training, teachers and instructors, examiners, examinations, testing of test pieces and theoretical examinations.

Look ahead to Part 2 of this article

Part 2 of this article will be published in a future issue of WJM and covers:

- Maintaining welder skills.
- Using BS EN ISO 9606-1 to the manufacturer's advantage.
- Approaches to mentoring.
- Weld surveillance.
- The use of virtual welding systems in training.
- Implementing job knowledge tests for a manufacturer.
- Learning by reviewing weld repairs.

References

1 BS EN ISO 14731:2019 Welding coordination - Tasks and responsibilities.
2 BS EN ISO 9606-1:2017 Qualification testing of welders. Fusion welding – Steel.
3 BS EN ISO 9606-2:2004 Qualification test of welders. Fusion welding - Aluminium and aluminium alloys.
4 BS EN ISO 9606-3:1999 Approval testing of welders. Fusion welding - Copper and copper alloys.
5 BS EN ISO 9606-4:1999 Approval testing of welders. Fusion welding - Nickel and nickel alloys.
6 BS EN ISO 9606-5:2000. Approval testing of welders. Fusion welding - Titanium and titanium alloys, zirconium and zirconium alloys.
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About the author

Mike Baverstock has worked in the welding industry for over 40 years having started as a welder. He is now running his own welding consultancy business helping companies across different industries improve their welding quality and dealing with their other welding engineering issues. Mike has completed the International and European Welding Engineer Diploma and is certified by both the European Welding Federation (EWF) and the International Institute of Welding (IIW). He holds an MSc in Welding Engineering and is a Chartered Engineer (CEng), a European Engineer (EUR ING), and a Fellow of The Welding Institute (FWeldI). In addition, Mike serves as Secretary of the Southern Counties Branch of The Welding Institute (TWI).

THE ROLE OF THE WELDING COORDINATOR - AND THE REQUIREMENTS OF EN ISO 14731

Parthapratim Brahma MWeldI

Welding coordination forms an integral part of the quality system of a fabricator and the Responsible Welding Coordinator needs to have overall competence matching the complexity and criticality of the fabricator's welded products. This article presents an overview of welding coordination as defined in EN ISO 14731, explains its relationship with ISO 3834 and product standards, and discusses how welding coordinator competence is defined, achieved and assessed.

Quality system requirements for equipment fabricated by welding

Welding plays an important role in the fabrication of pressure vessels, boilers, structural steelwork, pipelines, railway vehicles and many other safety-critical products and the readers will be fully aware that failures associated with welded joints may have severe consequences; potentially leading to loss of life, environmental damage, and significant economic impact.

Welding is stated to be a 'special process' in ISO 9001: 2015 [1] because the quality of a welded product cannot be fully verified by final inspection and testing alone. Nor does qualification of welding procedures and use of qualified welders ensure the welded component will have the desired properties for its intended service unless consistency of execution is ensured by all welding related activities being performed under appropriate and effective supervision and control. Consequently international product standards and regulations now require systematic control of welding activities through technical specification, design, materials selection, fabrication and testing until final delivery of the product. This is formalised as a quality system focussed on welding process control and EN ISO 3834, 'Quality requirements for fusion welding of metallic materials' is a standard which states specific quality system requirements for different classes of welded fabrication.

Quality levels and EN ISO 3834

ISO 3834 defines three levels of welding quality requirements:

- Comprehensive quality requirements (EN ISO 3834 - Part 2) [3]
- Standard quality requirements (EN ISO 3834 - Part 3) [4]
- Elementary quality requirements (EN ISO 3834 - Part 4) [5]

The extent of welding coordination, the degree of process control, and the level of documentation increase with higher quality requirements. Complex products and safety-critical applications typically demand 'Comprehensive Quality' requirements, which in turn require welding coordinators with higher levels of competence and experience. Products requiring 'Standard Quality" would require a reduced degree of welding coordination. EN ISO 3834 - Part 4, for products with elementary quality requirements, requires that appropriate fabrication and inspection skills are in place but do not state specific welding coordination tasks.

The purpose of welding coordination

Figure 1: The cover of BS issue of EN ISO 14731. Image courtesy of BSI .

It is inherent, within a quality system meeting the requirements of EN ISO 3834, that the fabricator has the appropriate level of welding coordination within their organisation.

The primary purpose of welding coordination is to ensure that welding activities are planned, executed, monitored, and documented in a controlled manner, such that the welded products meet the specified technical, quality, and regulatory requirements.

Welding coordination relates to all welding and welding-related manufacturing activities which have an influence on the final quality of welded joints and therefore these need to be monitored.

EN ISO 17431 [2] covers the duties of welding coordination personnel, their competency and their assessment. Its principal sections are:

Section 4: Tasks and responsibilities

Section 5: Job description

Section 6: Technical knowledge and competence

There are also two (informative) annexes:

Annex A: Assessment of welding co-ordination personnel

Annex B: Essential welding and related tasks to be considered when appropriate

The role may be performed by a single individual or by a team of people sharing specific coordination tasks as allocated to them to meet the overall objectives. Personnel performing these tasks are commonly referred to as Welding Coordinators or Responsible Welding Coordinators (RWC).

Welding coordination is not an isolated technical role. It is a key function within the welding quality system, meeting the relevant quality requirements of EN ISO 3834 and is driven by the fabrication contract, the contractually defined product standards and specifications and the applicable regulatory obligations (which may arise from national legislation).

The relationship between the welding quality system and welding coordination

Many product standards and regulations mandate welding coordination, either directly or indirectly, by requiring compliance with a defined part EN ISO 3834 which in turn requires manufacturers to appoint competent welding coordination personnel in compliance with EN ISO 14731. For example, the Construction Products Regulation (CPR) in Europe [6], implemented through harmonised standards such as EN 1090-2 [7], requires welding to be carried out in accordance with the relevant part of the EN ISO 3834 series.

EN 1090-2; the construction standard for structural steel, defines four Execution Classes with EXC2 being that applicable to standard commercial and residential buildings with complexity increasing through EXC3 and EXC4. The standard specifies that for Execution Classes EXC2 (basic), EXC3 (specific), and EXC4 (comprehensive), welding coordination must be performed by suitably qualified and experienced welding coordinators in accordance with EN ISO 14731; the required competency level being related to the Execution Class, product complexity, and criticality of design.

Similarly, standards for unfired pressure vessels (EN 13445), water tube boilers (EN ISO 12952), piping systems (EN ISO 13480), and rail vehicles (EN ISO 15085) impose minimum welding quality requirements aligned with ISO 3834. The key point is that if a fabricator is to comply with the fabrication code then competent welding coordination is a necessity.

It follows that a competent Responsible Welding Coordinator (RWC) is at the centre of the welding quality system and their performance is key to making it effective. EN ISO 14731 provides the structure for aligning welding coordinator competency with desired quality levels.

Competency levels in EN ISO 14731

EN ISO 14731 defines three levels of competency for welding coordinators, based on the nature and complexity of production:

Comprehensive level: Requires advanced proficiency in welding technology, specialised problem-solving skills, and the ability to manage highly complex welding situations.

Specific level: Requires in-depth knowledge related to specific products or applications, with advanced problem-solving capability for complex but defined situations.

Basic level: Requires general knowledge of welding technologies, fundamental problem-solving skills, and the ability to manage predictable welding situations with limited variability.

These levels align with similar classifications in other standards, such as EN 1090-2, which designates welding coordination personnel as C, S, or B for comprehensive, specific, and basic levels respectively.

Welding coordination and welding-related tasks

The tasks and responsibilities of a welding coordinator are not restricted to the role of a welding engineer, welding supervisor or welding inspector and the role demands competence and understanding across all aspects of welding fabrication.

Annex B of EN ISO 14731 provides a detailed, (but not exhaustive) list of welding and welding-related tasks that may be assigned to welding coordination personnel. These tasks span the entire fabrication lifecycle, from contract review to final documentation. The key categories include review of requirements, technical review, subcontracting strategy and control, qualification of personnel and procedures, production planning, inspection and testing, non-conformance management, and quality records.

The technical review involves evaluation of parent materials, joint design, acceptance criteria, weld accessibility, inspection requirements, and any special welding conditions.

Production planning covers sequencing of welds, allocation of qualified personnel, environmental controls, and heat treatment arrangements.

Inspection and testing activities are divided into before, during, and after welding, ensuring control of essential welding parameters, consumables, joint preparation, and final weld quality.

Traceability and quality records are critical elements for demonstrating conformity with applicable standards and contractual requirements.

It is the responsibility of the welding coordinator to determine appropriate monitoring and control measures at the stages described above. The level of controls would depend not only on the basis of complexities in manufacturing but also on available resources including qualification and skill of people performing welding related activities.

Site work. Welding coordination becomes particularly challenging at field or site locations, where environmental conditions, limited access, and variable skill levels can affect welding quality. Additional considerations include suitability of weld design for site conditions, compatibility of welding processes with available equipment, optimisation of weld joints, and prevention of material or consumable mix-ups.

Safety is one of the key aspects which has impact on productivity and quality. It is particularly significant at field sites. Welding coordinators must address hazards related to fumes and gases, heat exposure, burns, radiation from arcs, noise, and working at heights. Effective site welding coordination therefore requires not only technical competence but also strong organisational and safety management skills.

Competence, skill, knowledge, and qualification

The earlier version of EN ISO 14731 had requirements for appointing a welding coordinator based on educational attainment and qualification. However, the current version (2019 edition) has more emphasis on demonstrable competence rather than formal education or qualifications. EN ISO 14731 distinguishes between knowledge, qualification, skills and competence.

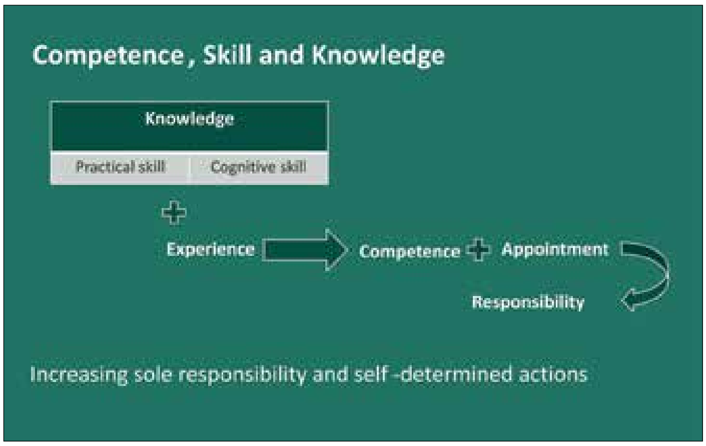

Figure 2: The path from knowledge to competence and responsibility.

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Knowledge is defined as the assimilation of information, principles, theories, and practices related to a specific field of work.

Qualification is the formal outcome of an assessment and validation process confirming that specified learning outcomes have been achieved.

Skills represent the ability to apply knowledge in practical and cognitive contexts to solve problems. To explain further: skill is a combination of cognitive (use of logical, intuitive and creative thinking) and practical (manual dexterity, and use of methods, tools, materials) aspects of a job.

Competence, as defined in ISO 14731, is the proven ability to utilise knowledge, skills, and personal, social, and methodological abilities effectively and autonomously in a variety of work situations, in an independent capacity.

Competence can further be split into four areas:

- Self-competence: the ability to act with sole responsibility.
- Professional competence: the ability to understand and to apply practical and cognitive skills.
- Methodical competence: the ability to use avenues of approach, learning strategies and work techniques.
- Social competence: ability to manage people by using cooperative, communicative and integrative skills.

The balance between formal education and experience

While the value of formal education or training in welding can't be ignored for determining competence, the actual ability to apply acquired knowledge and skill would certainly depend on exposure to various situations and experience of working with people, materials and equipment. Practical and cognitive skills coupled with technical knowledge in welding technology would contribute towards desired competence of a welding coordinator. They may develop a competency in a particular area of work based on their experience in that sector. EN ISO 14731 emphasises competence over formal qualification, recognising that effective welding coordination depends on the integrated application of knowledge, experience, and judgment.

Technical knowledge and demonstration of competence

EN ISO 14731 requires welding coordinators to demonstrate technical knowledge in welding and related topics relevant to the tasks assigned to them which has been acquired through a combination of education, training, and experience. The required depth of knowledge for a particular quality level would depend on the criticality of the product and the consequences of failure. ISO 14731 does not mandate any specific certification, (but formal qualifications such as International Welding Engineer, International Welding Technologist or International Welding Specialist are commonly used to demonstrate technical knowledge corresponding to comprehensive, specific, and basic levels). Equivalent education or experience-based pathways are also acceptable, provided competence can be demonstrated for the intended application.

Assessment of welding coordinator competence

Annex A of ISO 14731 is entitled 'Assessment of welding coordination personnel' and provides guidance on their assessment. This process should be conducted by a competent person, typically at peer level or above, and it may take place as part of an audit of the fabricator carried by a third-party accredited body for conformity with (a specific part of) EN ISO 3834. The coordinator's assessment is of the individual and includes review of educational qualifications, training records, and their relevant work experience, particularly in respect of products, materials, and welding standards similar to those of their intended area of work. The process includes an interview or on-the-job assessment to verify the co-ordinators understanding of welding technology and the applicable standards. Key practical elements are that the coordinator demonstrates experience in the qualification of welding procedures and welding personnel and has experience of relevant problem-solving and troubleshooting.

Appointment of the welding coordinator

Organisations are responsible for appointing welding coordination personnel and for defining their roles, responsibilities, and authority. The job description should clearly define their authorised level of authority in regard to the approval of technical documents and their authority over contractual obligations for welding-related activities. EN ISO 14731 has no requirement for certification of welding coordinators to a specific standard. It is the duty of the employing organisation to define the necessary education, experience, and knowledge based on assigned tasks. The level of competence and on-the- job experience is to be determined based on the criticality, complexities in manufacturing of welded products and taking consideration of the consequences of failure of the fabrication. The organisation is also responsible to ensure that competence is assessed adequately and is documented.

Final thoughts

EN ISO 14731 provides a comprehensive and flexible framework for managing welding activities through competent welding coordination within an overall welding quality system complying with the relevant part of EN ISO 3834. By focusing on personal competence rather than prescriptive qualification of the welding coordinator(s), the standard allows organisations to tailor welding coordination arrangements to suit the specific needs of the products being manufactured, the risks to be mitigated and regulatory requirements within the industry and country of operation. Effective implementation of EN ISO 14731, in conjunction with ISO 3834 and in compliance with the product standards required under the manufacturing contract enhances welding quality, ensures regulatory compliance, and reduces the risk of welding-related failures. As industries continue to demand higher levels of safety and reliability, the role of the welding coordinator, supported by structured competence assessment, will be firmly established as a critical element of modern fabrication practice.

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Note that EN standards are published in the UK by the British Standards Institution with a prefix of BS and these versions may contain a national annex containing informative and complementary information.

About the author

Parthapratim Brahma is a welding professional with more than 40 years of experience in shipbuilding, boiler pressure vessel and general fabrication. He holds an MTech in Mechanical Engineering and has in-depth experience in manufacturing, quality control and quality assurance, testing, inspection and certification. He started as a shipyard welding engineer and later joined Lloyd's Register where he progressed ultimately to be Area Technical and Quality Manager, South Asia Middle East and Africa for Lloyd's Register inspection services. He holds numerous inspection qualifications, sits on a number of influential technical committees and has life membership of the Indian Institute of Welding. He is currently associated with TWI India as a Mentor.

ASK THE EXPERT: SUPER DUPLEX STAINLESS STEEL

Dr Glenn Byrne BMet FIMMM MWeldI CEng. GB Metallurgical Services Ltd

ZERON 100 Super Duplex Stainless Steel seawater cooled, sulphuric acid heat exchanger. (Courtesy Steve Clarke, SJC Materials)

The super duplex stainless steels are versatile and attractive alloys and they find application in many industries. The attractive features are high strength, reasonable toughness, excellent resistance to stress corrosion cracking (SCC) in chloride and hydrogen sulphide containing environments and resistance to pitting and crevice corrosion in chloride environments including seawater. They have erosion resistance in aggressive slurries and resistance to corrosion in oxidising mineral acids and organic acids and caustic environments [6]. **Dr Glenn Byrne,** a specialist in these materials answers some key questions regarding this group of alloys including welding topics.

Can you summarise the difference between a super duplex stainless steel and a conventional duplex stainless steel?

Conventional 22% chromium duplex stainless steel (DSS) (UNS S31803 type) and 25% chromium super duplex stainless steel (SDSS) (for example UNS S32750) are differentiated by strength, and cost (Table 1) and chemical composition and correspondingly, corrosion resistance (Table 2).

Grade	Min. 0.2% PS (MPa)	Min UTS (MPa)	Relative cost (Note 1)
22% Cr standard duplex	450	620	1.1-1.4
25% Cr super- duplex	550	750	1.5-2.2
Note 1: Cost is given relative to grade 316L austenitic stainless steel (316L = 1). The relative cost will vary with the alloy surcharge at time of purchase and it also differs for different forms of product.			

Table 1: Comparison of tensile properties and relative cost of grades of duplex and super duplex stainless steel.

The differences between 22% Cr DSS and 25% Cr SDSS in PREN and corrosion performance are summarised in Table 2. Corrosion resistance is correlated, via regression analysis, with chemical composition to give the Pitting Resistance Equivalent Number (abbreviated to PREN). This takes account of the empirical weighted contribution of the elements to resistance to corrosion in a chloride environment. The higher test figures for the 25% Cr super duplex stainless steel demonstrate its superior ability to withstand extreme pitting and crevice corrosion, chloride stress cracking and resistance to hydrogen sulphide, which are beneficial for service in aggressive marine and chemical environments.

Grade	Min PREN (Note 1)	Resistance to chlorides Test temperature requirement in an ISO 17782 G48A test. (Note 2)	Sour service resistance Limiting partial pressure of H_2S at 80 to 90 °C when stressed to the 0.2 % proof strength. (Note 3)
22% Cr standard duplex	35	25 °C	<0.1 bar at pH 3.5 with 46,000 ppm chloride
25% Cr super-duplex	40	50 °C	0.2 bar at pH 3.5 with 120,000 ppm chloride
Note 1: PREN = %Cr + 3.3 (%Mo +%W/2) + 16 (%N) Note 2: The test temperature where the material survives for 24 hours in ferric chloride solution without pitting and the weight loss does not exceed 4 g/m^2 Note 3: The partial pressure of H_2S can increase if chloride contents are lower and or the pH is higher			

Table 2: Comparison of corrosion performance of standard duplex and super duplex stainless steels under chloride and sour service test conditions.

Is it correct that super duplex stainless steels are difficult to manufacture?

Both standard duplex and super duplex are considered difficult to make, requiring attention to detail in hot working, heat treatment, fabrication and other forms of thermal processing like stress relief heat treatment of shafts. But this is particularly true in the case of SDSS, because deleterious phases precipitate more readily. When these phases are formed the toughness and corrosion resistance of these alloys is usually seriously degraded. This was emphasised first by the Norwegian oil industry [1] in 1998, and repeatedly ever since [2 - 4]. Discerning buyers require manufacturers to qualify production routes, with the qualification range limited by product form, thickness qualified and all manufacturing facilities, processes and procedures used in qualification. They also augment the applicable ASTM product specifications with the supplementary microstructure checks, impact and corrosion tests detailed in ISO 17781 [5].

Where does SDSS fit into the market for special alloys?

The duplex market is about 10% of the total stainless-steel market and the super duplex market is about 1% of the duplex market. SDDS occupies a space in a technological and commercial gap between other stainless steels and the nickel alloys. For example, alloy 625 has about the same strength as SDSS but it costs about 5 times as much as super duplex grades.

The key to the success of the duplex grades is their minimum maintenance capability and low through life costs, with SDSS grades providing this benefit in more aggressive environments than standard DSS.

What are their features which make them attractive for service applications?

Their strength, corrosion resistance in natural and chlorinated seawater, erosion resistance, resistance to chloride SCC and moderate resistance to sulphide SCC makes SDSS grades very attractive to the oil and gas industry, notably in the offshore sector.

They find application in pipework systems and associated, pumps, valves, manifolds, vessels, heat exchangers, risers, subsea flow lines, umbilicals and pipelines, both subsea and on land.

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Seawater applications

Similarly, their corrosion resistance in seawater makes SDSS an excellent and highly utilised grade for Seawater Reverse Osmosis (SWRO) applications. For the high-pressure feed, the chemically treated seawater is pressurised to about 70 bars, before entering a membrane system that removed the chlorides and makes drinking water (Figure 1).

Figure 1: The Torrevieja 200,000 m^3/day SWRO plant using ZERON 100 SDSS. Courtesy, Rolled Alloys.

This industry took time to realise that lower grade stainless steels did not perform well in seawater. It was not until the 6% Mo grades of stainless steel were introduced that acceptable corrosion resistance was achieved. However, in the mid-1980s SDSS were introduced to the industry, offering the same corrosion resistance as 6% Mo grades but at a 30% lower cost. The industry response is shown in Figure 2 which shows the great increase in the use of the SDSS grades UNS 32750 and UNS 32760 for these plants since 2000. The steep increase in installed capacity of drinking water between 2002 and 2004 coincides with the industry building many larger capacity SWRO plants. Today individual plants with drinking water production capacity approaching 1 million m^3/day have been built using SDSS and they are the preferred material of construction for these plants worldwide [10].

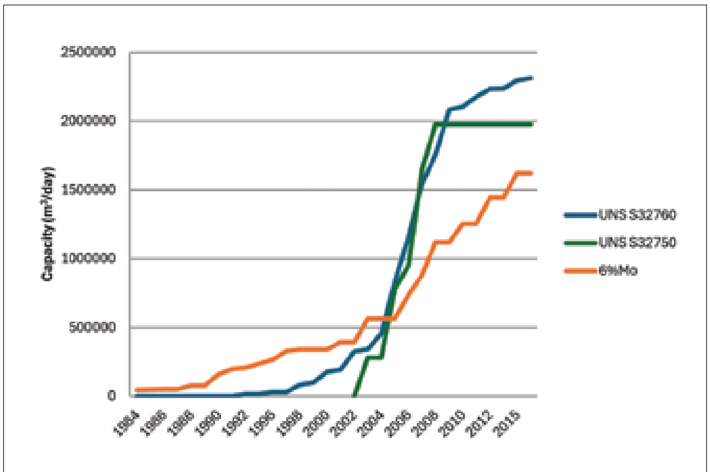

Figure 2: The growth in installed capacity of SWRO plants showing the grade of steel used to build the high-pressure feed and brine reject pipework.

Other industrial sectors

Other significant industrial users include mineral processing [11], chemical processing [12], flue gas desulphurisation [13], marine [14] and more recently civil and structural engineering [15]. These industries tend to utilise SDSS in niche sections of their production processes where singularly aggressive conditions prevail. Figure 3 illustrates something of the breadth of applications.

Figure 3: Left: Vortex breaker. Middle: Phosphoric acid agitator/mixer. Right : FGD pump impeller. Courtesy, Rolled Alloys.

Much is made about weight saving advantages in the use of super duplex grades. Can you explain the benefits?

The high strength of SDSS grades makes them important in higher pressure/higher temperature applications. Allowable stresses are higher so thinner, lower weight components can be utilised. This weight saving is an important factor in offshore applications, including subsea. In some cases, weight saving alone has been the principal factor in the selection of SDSS for offshore oil and gas processing applications [7]. Even in low pressure applications like seawater cooling and fire protection pipework, weight saving has been a significant determinant in the selection of SDSS grades. Comparisons with 90/10 copper-nickel options [8] for a seawater deluge and ring main showed a weight saving of about 10 tonnes for the deluge system and 41 tonnes for the ring main. These savings were brought about by the higher erosion resistance of SDSS compared to 90/10 copper-nickel. This allowed a reduction in the pipe sizes and reduced the cost by 46%. SDSS grades also displaced 6% molybdenum (6% Mo) grades from these applications because of their lower cost. However, in recent years Grade 2 titanium and/or GRP has been used for these applications where the operating temperature exceeds 20 °C because of its tolerance to variations in operating temperature and chlorination control. A recent FPSO project in Norway [9] used both 22% Cr and 25% Cr duplex grades and a comparison was made of designing to Chapter IX of ASME B31.3 and designing to Chapter II. Chapter IX allows the use of a higher utilisation factor on material properties by applying more stringent rules on inspection and qualification testing. Table 3 below presents the comparison of pipe wall thickness and weight per meter of 355.6 mm (14" NPS) seamless pipe operating at 656 bar and 100 °C and shows the weight saving achieved by the use of chapter IX requirements relative to each grade.

Design Code	UNS S31803		UNS S32750	
	Minimum Wall thickness (mm)	Weight (kg/m)	Minimum Wall thickness (mm)	Weight (kg/m)
ASME B31.3 Chapter II	53	393	42	323
ASME B31.3 Chapter IX	39	303	32	251
Weight saving (kg/m of pipe used)	90		72	

Table 3: Comparison of the use of standard duplex and super duplex stainless steel pipework – thickness, weight and weight saving.

What are the main welding processes used industrially for SDSS?

SDSS have been welded by all the conventional welding processes. Initially GTAW (with filler metal) was the main process because it facilitated good control when welding root passes and provided the high toughness that was required for oil and gas applications. Indeed, GTAW was often employed when welding very thick-walled joints when higher deposition rate processes would have been preferred, but the requirement for weld metal toughness determined the process choice (Figure 4).

Figure 4: A WPQR microsection through a GTAW welded joint from a 609.6 mm (24" NB) x 62 mm thick Hot Isostatically Pressed ZERON 100 SDSS injection manifold [7]. Courtesy, Rolled Alloys.

The Norwegian FPSO project referred to above [9] utilised SDSS pipes in a range of thicknesses from 3.4 mm to 76.2 mm (Figure 5). The largest size qualified was 660.4 mm (26") x 76.2 mm wall thickness. This size was qualified using all GTAW using 175 passes and GTAW+FCAW in 95 passes.

Figure 5: Welding procedure qualification test piece in a thick wall SDSS pipe. Courtesy, Equinor [9].

What determines toughness in SD weld metal?

Figure 6 [16] shows the toughness levels at minus 50 °C associated with various welding processes. The oxygen content reflects the level of non-metallic inclusions in the deposit that lower upper shelf toughness and increase impact transition temperature.

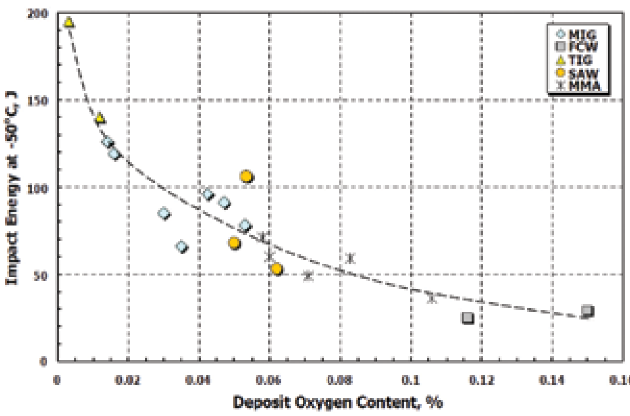

Figure 6: The effect of weld metal oxygen content on the toughness of welds deposited using different welding processes.

What welding processes are used other than GTAW?

SMAW and SAW have been commonly used in applications where toughness is not a concern. Plasma and electron beam welding have been used when welding long seams in large diameter pipes [17]. Although not a main welding process for either DSS or SDSS electron beam welding using localized vacuum chambers brings some attractive benefits for niche welding applications of thick section DSS and SDS joints [18]. 60 mm thick DSS plates have been welded in a single pass with low distortion and high completion rates. Phase balance issues have been addressed by placing nickel consumable inserts into the joint and then welding. Laser welding has been used for welding SDSS structural "I" beam sections [15] and tubes [19]. Figure 7 shows the microstructure of a laser welded SDSS tube 22.2 mm (7/8") OD x1.65 mm thick.

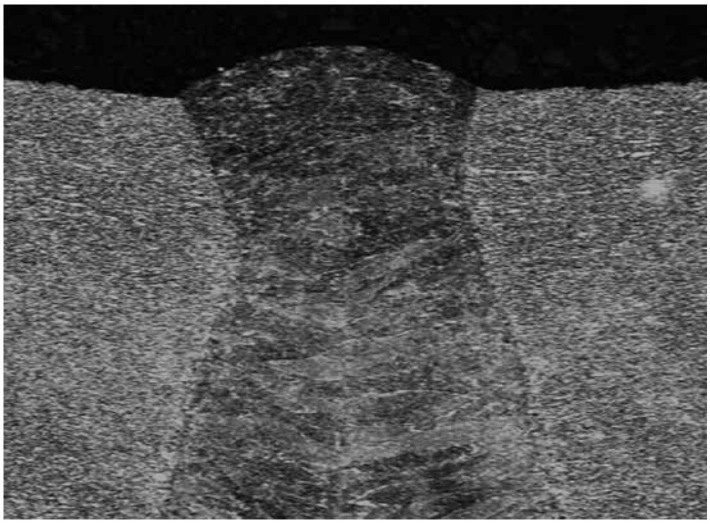

Figure 7: The microstructure of a laser welded ZERON 100 SDSS tube. Courtesy, Rolled Alloys.

What are the key factors to be addressed in their welding and how critical are they in terms of properties and service?

Phase balance is one thing and the other is controlling the intermetallic phases such as sigma phase (which otherwise causes a marked reduction in toughness).

The phase balance of welds is closely controlled by the composition of the consumable and the parent material via the nickel and chromium equivalents. These are set by the steelmaker. It is quite hard to fail to meet phase balance requirements because they are so wide (30% to 70% ferrite) and fabricators also have the option to promote austenite formation by alloying the deposit with nitrogen by using argon/nitrogen shielding gas mixes. The correlations between corrosion resistance, toughness and phase balance are tenuous [20] and this is reflected in the wide range of phase balance accepted in specifications. Interestingly, austenite that is formed during reheating of the weld bead by subsequent passes is not as corrosion resistant as primary austenite, yet specifications do not require this phase to be differentiated in measurements of phase balance. This is probably because the heat input of the second pass can be reduced to make sure that the reheating and secondary austenite reformation and sigma precipitation in the root run does not reach the surface of the root that is in contact with the process fluid. This technique is known as the "cold pass" technique [21].

The main issue in welding SDSS is minimising the precipitation of intermetallic phases like sigma in both the weld metal and in the HAZ at the location of the 850 °C to 900 °C isotherm created by the weld thermal cycle, as this temperature range corresponds with the temperature at which sigma phase forms most readily. It also must be remembered

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that the time increments spent by the steel in the temperature range for precipitation of sigma is cumulative as weld passes and thermal cycles are applied. Fortunately, the sigma formed during the weld thermal cycle is not as detrimental as sigma formed isothermally by soaking in a furnace. Its composition and morphology are very different, such that welds can tolerate some low level of sigma phase and still provide acceptable properties [22]. However, every effort to avoid sigma phase and retain corrosion resistance and toughness in welding should be made [21]. The methods used include:

a) Heat input control. If the heat input is too high the cooling rates are lower and the time spent in the temperature range for precipitation is longer.

b) Interpass temperature control. Low interpass temperature increases the cooling rate of the weld and minimises the risk of sigma formation.

c) The use of the cold pass technique. As described above.

d) Controlled run out lengths. This is done by welding in equal length of segments around the pipe alternating between diametrically opposite segments. This lowers the build-up in temperature ahead of the weld pool.

e) Minimising the total number of welds passes and hence total heat input into the joint. To do this high deposition rate, low heat input welding processes (of which there are many) should be considered for the fill passes.

Until recently the requirements of ASME IX for procedure qualification were not sufficient to ensure duplex and super duplex weld quality. This caused users to write their own specification that contained supplementary requirements to ASME IX to ensure quality joints. However, in 2025 ASME added a "non-mandatory" Appendix M for duplex stainless steels entitled "Procedure and Performance Qualification of Duplex Stainless Steels". I understand that it was added as an appendix because all duplex grades had previously been grouped under P-No. 10H, even though lean duplex, standard duplex, super duplex, and hyper duplex have significantly different metallurgical sensitivities and corrosion-performance requirements. It is "non-mandatory" because ASME avoids making mandatory supplementary requirements for all users but it is worthy of review as it gives code users a specific qualification framework that they can use where appropriate.

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About the author

Dr Glenn Byrne has a BMet and PhD from Sheffield University. He is a Fellow of IoM3, is MWeldI and a Chartered Engineer. Glenn started his career at CAPCIS in 1984 and moved to Weir Materials in 1989 where he worked on industry and worldwide application development and sales of duplex and super duplex stainless steel in all product forms. In 1994 he became Director and General Manager. In 2008 Weir sold the business to the American company, Rolled Alloys and Glenn became Managing Director. Glenn retired from Rolled Alloys in 2023 and established GB Metallurgical Services Limited; an independent metallurgical consultancy. He has authored or co-authored 55 technical papers.

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AI-ASSISTED DIGITAL MACROGRAPHY FOR WELD INSPECTION: WORKFLOW, REPEATABILITY AND TRACEABILITY

Renan Floriani. Chief Operating Officer, DIGIMET Solutions
Dr Tiago Vieira da Cunha. Federal University of Santa Catarina (UFSC), Joinville, Brazil

Introduction

Macrostructural inspection (macrography/macroetch test) is a well-established method for assessing the dimensional characteristics of welded joints in production control, procedure qualification and routine quality inspection. After cutting, preparation and etching, the weld cross-section is examined to verify features such as penetration, bead morphology, throat dimensions, root gap and material thickness. These measurements are then used to confirm whether the joint meets the requirements defined for a component by the process or customer specification; throat dimensions, root gap and material thickness.

Although the method is robust and well established, conventional macrographic workflows are prone to human error and operator-dependent variation during measurement and result classification. Variability may arise from instrument handling, datum selection, edge interpretation and human factors such as operator fatigue and person to person variations.

In many laboratories, this measurement variability is combined with a fragmented inspection workflow. Image capture, measurement, reporting, calibration control, acceptance verification and statistical analysis are often managed in separate tools or files. As a result, the same inspection data may be handled several times before it becomes a complete and traceable quality record.

A typical workflow may include the following:

- capturing the image on a stereomicroscope,
- drawing the lines to measure each dimension specified in the standard,
- copying the image into a report template,
- entering measured values into spreadsheets,
- checking the results against customer-defined limits,
- storing calibration records separately,
- retyping the same measurements into another system for statistical analysis.

This fragmented workflow can delay process release, make historical data difficult to retrieve and increase dependence on manual transcription. It also means that information obtained from macrographic inspection is often used primarily in the report, rather than being immediately available for process monitoring.

Digital macrography systems have been developed to address these practical difficulties by combining image capture, calibrated measurement, reporting and data storage in the same reporting environment. Advances in computer vision and machine learning also enable assisted or automated feature segmentation and dimensional measurement from weld bead/joint macrographs. This allows laboratories and quality teams to improve measurement repeatability, shorten inspection cycle time and generate traceable reports aligned with customer requirements, internal procedures and audit needs.

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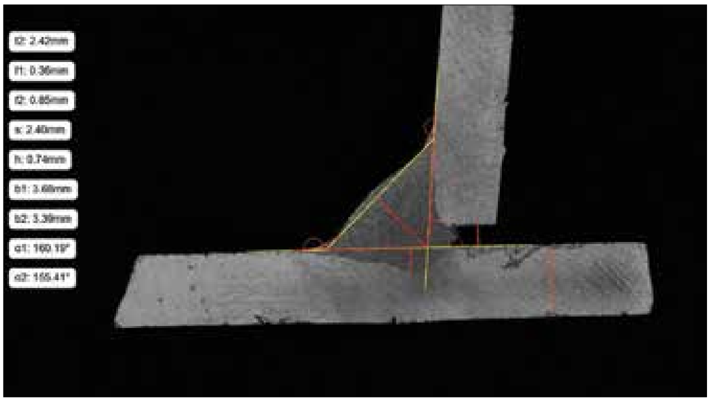

Figure 1: DIGIMET's DIS macrographic image of a single fillet T-joint with AI-made measurements.

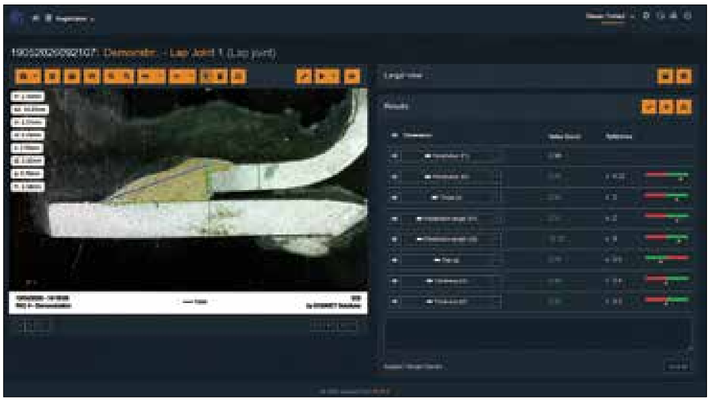

Figure 2: AI-assisted measurement interface in DIS, showing automatic feature detection and dimensional results for a macrograph of a lap joint.

In this context, DIGIMET's DIS platform was developed to integrate image capture, measurement, reporting and statistical monitoring within a single macrographic inspection workflow. The platform also has an AI-powered measurement engine, which is used to automatically identify weld bead features and perform measurements from macrographic images (Figure 1).

AI-powered automatic measurements with over 99% repeatability

In manual macrostructural inspection, the measurement of weld bead features begins with the operator selecting reference points on the etched cross-section. For characteristics such as penetration, bead width, root gap and throat dimensions, small differences in datum selection or edge interpretation can affect the final value, especially when similar samples are inspected repeatedly over long shifts or by different operators.

In DIGIMET's DIS, the AI model is first configured using a single manual reference measurement, which serves as the basis for the subsequent automatic measurements. After this configuration, the system follows the inspection criteria already used by the company or customer. DIS currently includes more than 50 computational models adapted to different standards, helping ensure that measurements remain aligned with the previously established analysis method.

Once the model has been configured for the inspection routine, the calibrated macrographic image can be processed automatically. The system identifies the main regions of the weld joint cross-section, including base material, fusion zone and weld geometry, and measures the features defined for that examination. This approach differs from a conventional digital measurement tool.

In a conventional workflow, the image may be displayed and measured on screen, but the operator still performs the point selection manually. In an AI-powered workflow, the same computational logic is applied whenever the macrograph image is processed, reducing variation associated with operator fatigue, shift-to-shift differences and differences in interpretations between operators.

Internal validation performed by DIGIMET Solutions has shown that, when the exact same weld bead macrograph image is measured repeatedly, the results are reproduced with over 99% repeatability. This improves confidence in the measured data and helps reduce variation in the analysis process.

After measurement, the values are compared with the limits configured for the part, customer or internal procedure. The system automatically generates a macrographic examination report, indicating whether each dimension is within the defined range, after which the inspector reviews the image and confirms the result before completing the analysis (Figure 2).

Reporting, calibration history and traceability

In weld inspection laboratories the report is the formal evidence that the macrography activity has been completed. It records the image, measured dimensions, acceptance status and analysis information required for customer or internal quality records. However, when reports are built manually or through spreadsheet templates, the reporting stage can become one of the main bottlenecks of the analysis process.

This is particularly relevant when the macrographic image, measured values, acceptance limits, calibration records and statistical indicators are not stored in the same reporting environment. In such cases, the operator may complete the measurement but still needs to assemble the report, check whether the file has been saved correctly, maintain calibration evidence separately and, when required, re-enter the same values into another system for statistical analysis.

In the DIS workflow, the analysis record is generated from the data already captured during the examination. The macrographic image, measured dimensions, configured limits, approval status and analysis information are stored together (Figure 3). Once the examination is completed, the system generates the report automatically, reducing the time spent copying images, typing values into spreadsheets and rebuilding the same report structure for each sample.

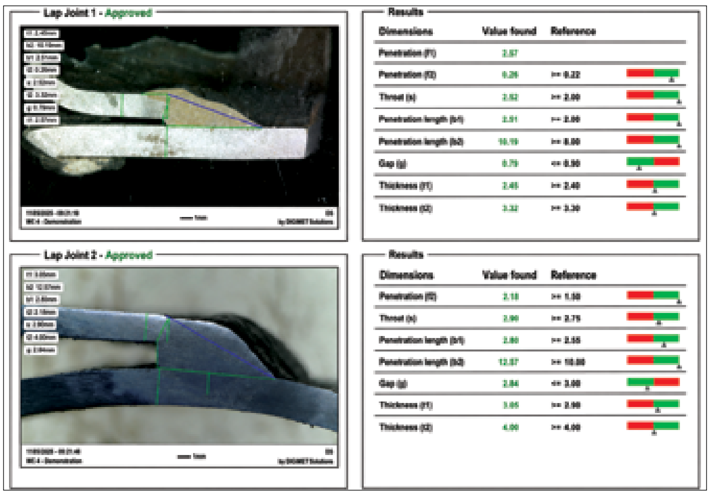

Figure 3: Macrographic report generated by DIS, showing automatic measurement overlay and comparison of measured values with configured acceptance limits.

Calibration history is also linked to the analysis workflow. This is important for audit evidence, since the calibration condition associated with the analysis can be reviewed without searching for a separate file or external record. In applications where previous calibration control was performed outside the analysis system, integrating this information into the same platform improves the completeness of the quality record.

PDF reports reduce the risk associated with editable spreadsheet files after the inspection has been completed. Traceability also affects how quickly information can be used. When inspection records are stored in a searchable digital environment, all previous macrograph images, reports and measured values can be retrieved by part, weld joint, customer or inspection period. These features support process release, rework validation and investigation of trends without depending on manual searches through folders or spreadsheet archives.

Case studies of industrial applications

The practical effect of digital macrography image interpretation is most evident when inspection volume is high and reporting is still dependent on manual work. The following examples present two applications of DIGIMET's DIS in large-scale manufacturing environments.

One of the largest automotive manufacturers in Brazil carried out a high volume of weld macrographic inspections as part of production control and procedure validation. The previous workflow relied on a stereomicroscope software for image capture, while dimensional measurements, acceptance checks and reports were completed manually using spreadsheets and editable templates. This fragmented process increased inspection time and introduced variation between operators, particularly in repetitive measurements such as penetration depth, throat dimensions and root gap. It also made traceability more difficult, since calibration records and historical reports were stored separately. After implementing DIGIMET's DIS platform, the workflow was centralized in a single reporting environment. Macrographic images were captured, measured automatically using AI-assisted feature recognition, compared with customer-defined limits and converted into PDF reports within the same analysis routine. Calibration history and previous analyses also became searchable inside the platform. The result was a measurable reduction of more than 65% in inspection cycle time, improved measurement consistency between operators and faster access to historical records for production release and audit requirements. Statistical dashboards also enabled the welding team to monitor dimensional variation and identify process trends directly from macrographic inspection data.

In another application a leading steel wheel supplier in Mexico performed macrographic weld inspections as part of routine quality control for high-volume automotive wheel production. The inspection process focused on validating weld bead geometry and dimensional compliance in welded rim and disc assemblies, following customer-specific requirements and internal manufacturing standards. Before implementing DIGIMET's DIS platform, the company already used a digital macrography system capable of capturing images, performing manual dimensional measurements and generating inspection reports automatically. While this workflow eliminated paper-based reporting and improved document standardisation, the measurement stage still depended entirely on operator input. Inspectors manually selected reference points on each macrograph image, which introduced variation between operators and limited productivity during high inspection volumes. In addition, the previous system did not provide integrated statistical dashboards or process indicators, making trend analysis and performance monitoring dependent on separate manual consolidation. To improve consistency and expand process visibility, the company adopted DIGIMET's DIS platform. Once the inspection criteria were configured, DIS automatically identified weld features through AI-assisted image processing and applied the same measurement logic across all analysed samples. Measured values were immediately compared against acceptance limits, stored in a searchable digital database and made available for statistical monitoring. After implementation, the plant reported a reduction of more than 50% in inspection cycle time, mainly driven by AI-assisted automatic measurements and the elimination of repetitive operator interaction during dimensional analysis. The transition also introduced real-time process indicators directly from the inspection data, giving welding and quality teams immediate visibility into process performance.

These examples show that productivity gains are not limited to faster measurement. The larger improvement comes from reducing duplicated data entry, manual report assembly, separate calibration control and delayed access to statistical information.

Statistical monitoring and process control

Macrographic analysis generates dimensional values that can be useful beyond the individual report. When these values are stored in a structured system, they can be grouped and analysed by part, weld type, production line, period or customer requirement. DIS includes dashboards for statistical monitoring, including CP (Process capability), CPK (Process capability index), SPC (Statistical Process Control) (Figure 4), Health chart (Figure 5) and other process indicators. These tools allow welding and quality teams to follow variation over time and identify conditions that may require investigation. This is especially useful in high-volume analysis environments because the statistical view is generated from the same data used in the analysis record. The laboratory does not need to build a separate database after the report has been issued. Once the analysis is completed, the information is already available for review and comparison. For production teams, this can shorten the interval between analysis and action. If a weld bead characteristic begins to move towards a limit, the information can be seen without waiting for manual consolidation of several reports.

Figure 4: DIS dashboard showing CP, CPK and SPC.

Figure 5: DIS dashboard showing Health Chart.

Requirements for reliable AI-assisted macrography

AI-assisted measurement does not remove the need for a controlled macrographic analysis procedure. The quality of the result still depends on sample preparation, etching, image clarity, calibration and the correct definition of the analysis criteria. For this reason, the organisation should define how samples are prepared, how the image is captured, how calibration is performed, which dimensions are required for each weld joint type and which limits apply to each customer or internal requirement. Training is also important.

Operators need to understand how each measured feature is defined and when the image or sample condition requires review. When these conditions are controlled AI-assisted macrography provides a more consistent analysis workflow without removing the technical responsibility of the welding specialist.

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Conclusion

Macrographic weld analysis is a well-established and reliable method for evaluating the dimensional characteristics of welded joints. In many laboratories, however, the main difficulty is no longer only the examination of the sample, but the manual work required to document, report, store and analyse the results. AI-assisted digital macrography addresses this by combining calibrated measurement, automatic feature recognition, customer-defined limits, report generation, calibration history and statistical monitoring in the same workflow.

The industrial applications presented in this article indicate reported reductions of 50% to 65% in macrography inspection time, depending on the analysis volume and the previous workflow. Beyond time reduction, the main gains were related to automatic report generation, elimination of duplicated data entry, registered calibration history, easier access to previous analysis and immediate availability of welding process indicators.

DIS brings the main stages of macrographic inspection into a single platform: AI-powered automatic measurements, comparison with approval and rejection limits, automatic report generation, calibration history, searchable records and real-time statistical monitoring. This moves macrographic data beyond isolated reports, making it part of a traceable workflow for process release, rework validation, trend analysis and quality control.

About the authors

Renan Floriani is COO of DIGIMET Solutions. He has a background in Information Technology and over 30 years of experience in industrial digital solutions. His work includes platforms for laboratory and quality control processes, including weld macrography, metallographic analysis and hardness testing.

Dr Tiago Vieira is an Associate Professor at the Federal University of Santa Catarina (UFSC), Joinville Campus, and supervisor of the Welding Technology Laboratory (LTS). He was Editor-in-Chief of Soldagem & Inspeção from 2021 to 2024 and currently serves as Associate Editor of Soldagem & Inspeção and Welding in the World.

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UPCOMING EVENTS

September 2026

Date: 9 September
London Branch with Kent Branch
Event: Joint meeting with IOM3. Subject TBC.
Venue: Lancaster Hall Hotel, London W2 3EL / hybrid.

Date: 12 September
Eastern Counties Branch
Event: Annual Dinner
Venue: The Jockey Club, Newmarket CB8 8JL

Date: 17 September
Southern Counties Branch
Event: Orbital Welding for Hygienic Pipework
Venue: Rapid Welding, 26 Solent Industrial Estate, Southampton SO30 2FY

October 2026

Date: 8 October
Eastern Counties Branch plus London Branch with Kent Branch
Event: Visit and demonstration of Sonatest new XEO phased array system.
Venue: 4:30 p.m. Sonatest Ltd., Dickens Rd, Wolverton, Milton Keynes MK12 5QQ

November 2026

Date: 11 November
London Branch with Kent Branch
Event: Meeting title TBC.
Venue: Lancaster Hall Hotel, London W2 3EL / hybrid.

Date: 18 November
Eastern Counties Branch
Event: Energy Storage Solutions
Venue: Online

Date: 26 November
Southern Counties Branch
Event: Friction Stir Welding
Venue: The King Rufus Pub, 135 Winchester Rd, Chandlers Ford, SO53 2DU