WELDING & JOINING MATTERS

A journal of The Welding Institute

The Welding Institute
ESTABLISHED 1923

Issue 9
August 2024

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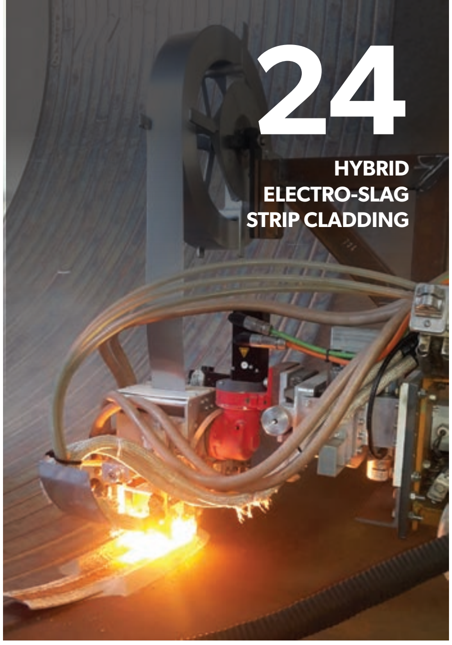

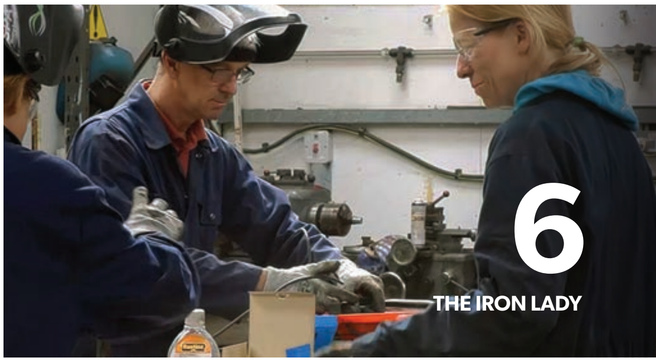

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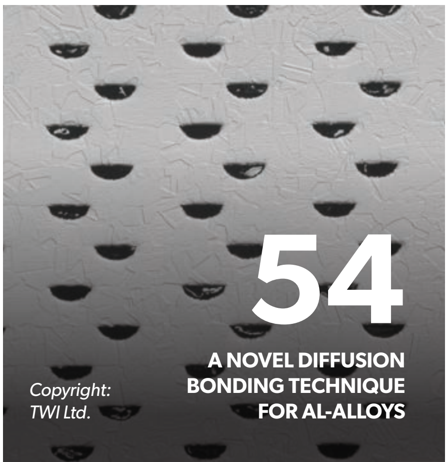

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On the Cover:
Trent 7000 aero engine. Courtesy of Gary Marshall/Rolls-Royce PLC.

On the cover (roundel picture):
Flame brazing, Image courtesy of CuP Alloys Metal Joining Ltd.

WELCOME TO WELDING AND JOINING MATTERS ISSUE 9 – FOCUS ON BRAZING, SOLDERING AND DIFFUSION BONDING

Phil Webb FIMMM. Technical and Commercial Director at VBC Group.

It's a great pleasure to contribute to the welcome page of this journal, especially as this issue is, in part, concerned with a subject close to my heart, brazing. I was a newly qualified graduate chemist in the late 1980s when I first came across brazing and soldering. My first job was working at a multi-national precious metals and chemicals group with a long-established metal joining products division. The closure of the main UK brazing alloy factory had recently been announced and the division was in the process of being downsized. I volunteered to do a graduate rotation there, secure in the knowledge that it would be a short-term diversion in my career path.

I can recall my colleagues telling me that brazing was 'yesterday's technology', and I should 'give it twelve months then move on'. Little did I know that, 35 years later, brazing would continue to be an invaluable technology for today's manufacturing applications and… that I'd still be working in the field.

Much has changed in manufacturing technology since that time and those changes reflect the world in which we live. Social trends, technological advances, economic factors, political decisions, market forces and environmental considerations have all influenced the industrial landscape and products being manufactured today. Joining techniques like brazing, soldering and diffusion bonding have tracked these changes, and their use continues to grow.

These days we talk about materials-joining rather than simply metal-joining. The use of ceramic materials, cermets, and composite materials has moved into mainstream manufacturing. With the introduction of new materials came the need to develop or adapt joining techniques and filler materials. In my role at VBC Group I am regularly confronted with applications involving combinations of new materials. This is the most exciting part of working in materials-joining and something which continues to engage me.

It is commonplace that today's applications also seem to place greater demands on joints. Components must be lighter, stronger, work for longer, and function in harsher environments at higher or lower temperatures. The development of lightweight, high-temperature components for future technologies such as hypersonic flight is a good example of this. Here joints are required to perform in the most demanding of applications.

Environmental considerations have also influenced the types of components being manufactured and this will continue as we meet the challenges of climate change. Recently I was talking to a manufacturing engineer working for a company who are leading an initiative to design and install air-source heat pump packages for new builds and retrofits. Brazing of copper pipework and fittings is part of the process and this work could help housing providers meet their de-carbonisation targets.

Unfortunately, the same conversation highlighted something which hasn't changed in our industry. The engineer explained that his company had to ask a former employee to come out of retirement because they couldn't find a skilled brazer to do the work. Clearly the need to attract and train tomorrow's welders and brazers into the industry remains a constant.

Looking to the future, I am optimistic that demand in the materials-joining market will continue to grow and evolve. Industry 4.0 and environmental imperatives will be major driving forces for change. Soldering technology is undergoing a transformation, fuelled by e-mobility, increasing demands for power electronics and battery modules which require precise and robust soldered joints.

As we undertake an energy transition and progress towards the goal of net zero the number of new materials-joining applications will grow. There will be developments in the hydrogen economy, e-mobility and nuclear energy generation.

With all these challenges ahead, it is hugely encouraging that cutting edge research from the UK is making a significant contribution to advancing our understanding of brazing, soldering and diffusion bonding technologies. A research group led by Professor Russell Goodall at the University of Sheffield and the team at TWI led by Dr Nick Ludford is producing top-class research papers and PhD researchers. This work was supported by modelling work done at the University of Leicester led by Professor Hongbiao Dong. Dr Amir A. Shirzadi of the School of Engineering and Innovation at The Open University is a renowned authority and researcher in the field of diffusion bonding.

It is a great source of pride that VBC Group has played a small part in this work funding two PhD students in the development of high entropy and eutectic high entropy alloys for brazing.

So to conclude this welcome note it is clear, I hope, that thermal joining technologies have an important part to play in the exciting manufacturing future ahead.

Phil Webb, FIMMM

Phil is a Director at VBC Group, the Loughborough based provider of welding, brazing and additive manufacturing consumables. Phil is Fellow of the Institute of Institute of Materials, Minerals and Mining, and a graduate chemist with 35 years of experience in the field of brazing technology, precious metals and associated chemicals.

He is involved in Standards for Brazing, chairing the BSI's WEE/19 committee - Brazing and Braze Welding and he sits on the ISO Brazing Standards Committee TC44 SC13. He is part of the International advisory panel to LOT the leading technical conference on brazing, high temperature brazing and diffusion bonding and was previously Hon. Sec. of The European Association of Brazing and Soldering (EABS), now part of the IoM3 technical community.

OUR GUEST EDITORS

Guest editors for this issue are Nick Ludford and Paul Brooker of TWI Ltd. **See page 30.**

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SHEFFIELD FORGEMASTERS GAIN ASME NUCLEAR ACCREDITATION

Sheffield Forgemasters have announced that they have recently been accredited to ASME Section III Division I NCA 3300 (NCA 3800), NCA 4000 and NQA-1 Code Material Organisation (MO), and welding (NPT). ASME MO and NPT status allows Sheffield Forgemasters to supply castings and forgings for civil nuclear applications and also be qualified to carry out weld construction activities on these materials.

Sheffield Forgemasters have developed electron beam welding (EBW) for the welding of large diameter nuclear grade vessels which gives the company a major lead in the development of small modular reactors which, together with the ASME accreditation, presents major opportunities for both the UK domestic and international markets.

Electron beam welding at Sheffield Forgemasters *Copyright: Sheffield Forgemasters*

The use of EBW for nuclear vessel manufacture is a major improvement in productivity – Sheffield Forgemasters have completed a nuclear demonstration assembly using local EBW, the welding of four thick nuclear grade welds taking some 24 hrs to complete. This is compared with approximately 12 months using conventional well established welding processes. Local EBW is a development eliminating the need for a large vacuum chamber, greatly reducing welding floor to floor time. The company has signed memorandums of understanding with a number of SMR developers in the UK, including Rolls-Royce SMR, NuScale, GE Hitachi Nuclear Energy, Holtec Britain and X-energy.

WESTINGHOUSE SMR FOR TEESSIDE GREEN ENERGY PROJECT

Community Nuclear Power Limited (CNP), a Cockermouth based consultancy, has signed an agreement with Westinghouse for the construction of four of their AP300 small modular reactors (SMRs) as part of the development of the Green Energy and Chemical Hub on the North Tees Group Estate. The project is to be the first privately financed SMR project to be installed in the UK.

A target date of 2027 has been set by CNP for the development of the nuclear licensed site with construction of the first unit scheduled for 2030 and commissioning by 2033. The Westinghouse AP300 SMR is based on their proven AP1000 design and comprises a single loop pressurised water reactor with a planned life of 80 years.

The four SMRs will provide clean, secure and stable energy that may be used for supplying power to the grid and also for producing "green" fuels and hydrogen, for district heating and for desalination. It is anticipated that this project will provide major employment opportunities in local supply chains, construction and operation. CNP also has similar plans at Moorside in Cumbria where the Rolls Royce 440MW pressurised water reactor SMR may be selected.

ROLLS ROYCE SMR FACTORY CANCELLATION

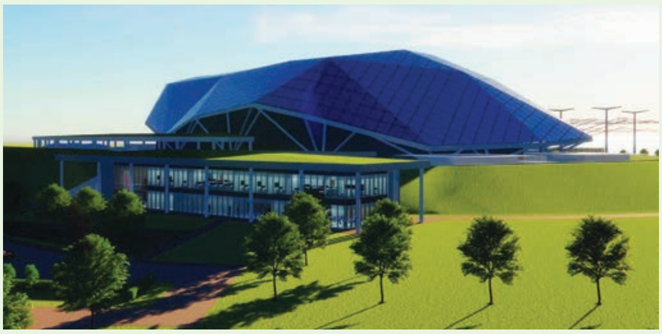


Image courtesy of Rolls-Royce

Regrettably Rolls Royce has delayed plans for the building of a £200M pressure vessel manufacturing facility as part of their SMR programme due to ongoing delays by Great British Nuclear (GBN), a government backed organisation, in making a decision on the preferred SMR design. Rolls Royce is one of six companies shortlisted by GBN in a competition aimed at providing SMR prototypes, the other firms being GE-Hitachi, Westinghouse, Holtec Britain, EDF Nuward and Nuscale. According to a spokesman from GBN "Our world leading SMR competition aims to be the fastest of its kind, helping secure billions in investment for the UK, meaning cleaner, cheaper and more secure energy in the long term". The decision on the preferred design(s), however, has been delayed until the 4th quarter of 2024, leaving insufficient time for RR to build the factory as part of their current SMR manufacturing programme. Although delayed, RR are continuing to plan for the erection of a heavy pressure vessel (HPV) manufacturing facility, the first of three factories, and are currently in the process of selecting a suitable site. The sites under consideration are IAMP Sunderland, Newton Aycliffe, Gateway Deeside in Wales, Ferrybridge North Yorkshire, Pioneer Park Stallingborough Lincolnshire and Kingmoor Park Carlisle.

The HPV factory is expected to be in the region of 23,000 sq.m and to provide employment for over 200 highly skilled staff. The other two factories will be designed for the manufacture of the civils infrastructure and the supply of mechanical/electrical equipment.

As part of the planning for SMR manufacture the University of Sheffield's Nuclear Advanced Manufacturing Research Centre Factory will host the first phase of RR's SMR Module Development Facility at a cost of £2.7 million. The purpose of the facility is to trial the manufacture of prototype SMR modules, ironing out fabrication issues, improving product flow and reducing the risk of late delivery. Nevertheless the BBC reports that the University has issued redundancy notices to 100 specialist staff at NAMRC whilst also saying that core manufacturing research and development activities would remain.

Late breaking news: power-technology.com reports a spokesman from EDF as saying that: "The Company will no longer consider building its Nuward SMR model in the UK due to 'incompatibility between the level of commitment and the time schedule required by Great British Nuclear (GBN) and the level of maturity of the Nuward SMR'."

LINCOLN ELECTRIC ACQUIRE INROTECH

Lincoln Electric® has announced from its headquarters in Cleveland Ohio that it has acquired Inrotech A/S. Headquartered in Odense, Denmark, Inrotech is a privately-owned automation system integration and technology firm specializing in automated welding systems that are differentiated by proprietary adaptive intelligence software and computer vision which guides and optimizes the welding process without the need for programming or the use of CAD files.

The state-of-the-art vision-based technology has proven to be valuable in the shipbuilding, energy, and heavy industry sectors, where welding accessibility can be challenging for traditional automated systems, but precision and quality are critical.

"We are pleased to welcome the Inrotech team to Lincoln Electric and are excited to expand the reach of their automated welding systems and incorporate their proprietary vision-based adaptive intelligence technology across a broader range of Lincoln systems, enabling the next generation of welding solutions," stated Mike Whitehead, Lincoln Electric's Senior Vice-president, President of Global Automation, Cutting and Additive Solutions. **For further information contact: elizabeth_barry@lincolnelectric.com**

THE CARBON BORDERS ADJUSTMENT MECHANISM (CBAM)

This may be the most important piece of impending legislation that you have never heard of.

Few people will not be aware of the urgent global need to reduce the amount of carbon being released into the atmosphere. We currently have the UK Emissions Trading Scheme (UK ETS), however, the ETS is not deemed sufficiently rigorous to prevent 'carbon leakage' between trading nations. The UK Government's web site www.gov.uk describes carbon leakage as 'the movement of production and associated emissions from one country to another due to different levels of decarbonisation effort through carbon pricing and climate regulation'.

A fairer and more appropriate system has been devised, the Carbon Borders Adjustment Mechanism (CBAM). This will see that the price paid for a given product is made according to the embodied carbon it contains. The UK CBAM will place a carbon price on some of the most emissions intensive industrial goods imported to the UK including aluminium, hydrogen and the iron and steel sectors (ref. www.gov.uk).

CBAM is already underway in the EU with mandatory reporting by importers and companies on the amount of embodied carbon in their products. See https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en. The consultation period in the UK has just ended and it is expected that the UK will commence mandatory reporting next year with the UK ETS being discontinued at the end of 2025.

TVC UPDATE THEIR GAS PURGE MONITORING EQUIPMENT RANGE

Above: Image reference GPM-4.0

TVC has specialised in designing and building purge monitoring equipment and systems for the welding industry for over 12 years and has now revised and updated the original Gas Purge Monitor (GPM) to be Industry 4.0 compliant. This latest-generation gas purge monitor features a 7 inch full colour TFT Touchscreen and options for wireless and wired ethernet connections for faster, easier data transfer and storage.

The GPM 4.0 provides the option for full optical sensor technology with the sensors claimed to deliver exceptional accuracy and repeatability, and to work seamlessly with all types of gases, including Formier gas which contains 5% hydrogen. There are additional options for comprehensive gas analysis, including measuring and data-logging of gas dew point to -100 °C, moisture to 1 ppm, and gas flow. For optimal efficiency, the GPM 4.0 offers a 3-stage Flow Control unit that automatically adjusts purge gas flow based on preset oxygen levels, saving costs. Additionally, a clear 3-colour traffic light warning beacon keeps operators informed about the purge status with a simple and intuitive visual indicator.

In addition to the GPM 4.0 TVC also offers handheld purge monitors. These include the Basic Purge Monitor (BPM), a cost-effective option with lower accuracy (±100 ppm), and the Hand-Held Purge Monitor (HPM-02), which utilises Hybrid Sensor Technology for high-precision measurements down to 1 ppm at an affordable price.

Contact sales@tvcalx.co.uk for more information.

WALL COLMONOY ACQUIRES INDURATE ALLOYS LTD

Wall Colmonoy Corp. has announced the acquisition of Indurate Alloys Ltd., a Canadian supplier of hardfacing products. Indurate Alloys, located in Edmonton, Alberta, Canada, supplies metallic and carbide powders in HVOF, Plasma Spray, Thermal Spray, Laser and Plasma Transferred Arc (PTA) forms as well as wires and electrodes. Indurate also provides Additive Manufacturing powders. **For more information on Indurate Alloys, see induratealloys.com**

WALLCOLMONOY

INDURATE ALLOYS LTD

PRF COMPOSITE MATERIALS TO BE PREPREG SUPPLIER TO THRUSTWSH

PRF Composite Materials has been announced as the prepreg supplier to ThrustWSH. Led by Richard Noble OBE and Lorne Campbell, ThrustWSH aims to set a new water speed record, using pioneering research and innovative design to create a safe and fast hydroplane with the target of setting an officially ratified two way average speed of 400+mph over a measured course.

PRF will be supplying innovative prepreg materials for the fully instrumented data collection model test programme part of the project; supporting the construction of a concept model, and then the ¼ scale 240mph operational model, constructed by 3DCM. The model programme is essential preparatory research and testing to ensure the safety and performance of the full-scale hydroplane. The build of the ¼ scale model is currently underway and the team are preparing to launch the test programme once the model is completed. **Website: www.prfcomposites.com**

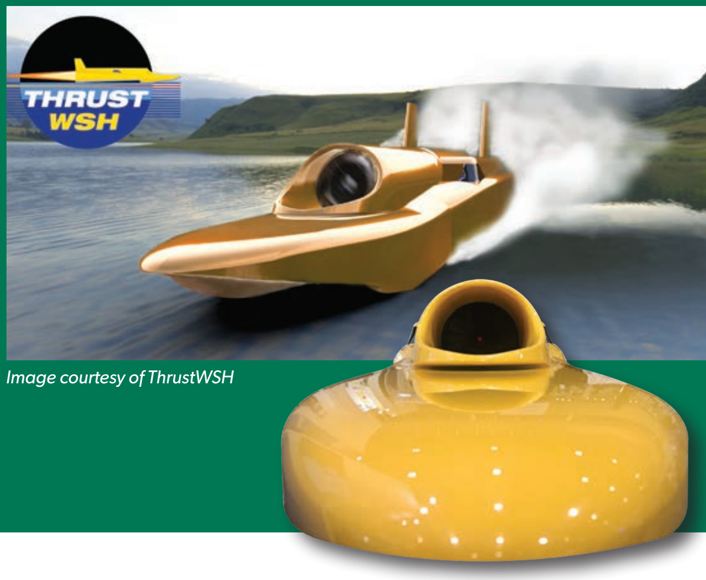
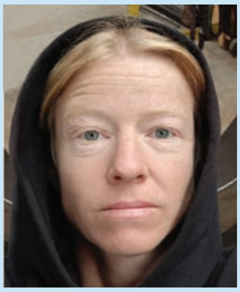


Image courtesy of ThrustWSH

THE ‘IRON LADY’ INTERVIEW



Fabrication & welding has many facets and here we are talking to a lady blacksmith who has a background in welding, Natalie Bradwell who goes under the name of the ‘Iron Lady’. With her partner Georgie Sworder, they run courses on different facets of the metalworking industry, with Georgie specialising in costume jewellery. They are based in Sussex National Park [1].

WJM: Natalie, how did you come into the industry, did you have relatives or friends who were in the industry that influenced you and what attracted you?

For myself there was no relative or friend that influenced me. It was purely a desire to work with my hands, making art or taking things apart! Materials have always been fascinating to me. So feeling something in my hands, its weight, temperature, flexibility and texture. I remember my brother had one of those “un-shatterable” plastic rulers. I quickly found out that it was indeed shatterable. So experimentation and pushing materials is something I like to do, especially with a TIG welder.


Spiral staircase in Cor-Ten steel

WJM: What training and qualifications did you receive?

After taking the Art route from school, Art Foundation into a BA, I still did not feel I had enough expert tuition, by real craftspeople. In fact the technicians at University would “gatekeep” the good and interesting stuff. After messing around in office jobs, living for the weekend I decided to go back to college and enrolled in a BTEC Certificate in Artist Blacksmithing. There was a small amount of welding, fabrication and draughtsmanship. However when I moved back down south I still struggled to find work. I was on job seekers allowance for long enough to be offered a free college course, and at that time, a Level 1 in welding was available at Crawley College. I chose to focus on TIG Welding. Since then, as a professional welder I have achieved a variety of codings, some still valid and some now out of date!

WJM: Could you give the readers a flavour of the range of work that you do.

The range of work is very varied! Anything from structural to fine limit TIG. I am open to working outside of the workshop which creates whole new challenges and problem solving to work with what is available. I am well known with the breweries in the area so I have a few repeat clients who require stainless TIG, hygienic welds and other items. I have a pump manufacturer sending regular work and it is them who mostly requires the codings. I try to focus on artistic objects but the bills have to be paid, so it really is anything and everything. Cars are the only item I will stay away from. That side of welding is the worst!! But again if someone has a vintage item I can be tempted. The variety of work has allowed me to experience a wide range of metals and techniques.

WJM: Natalie, what areas of blacksmithing do you specialise in?

I was trained as an artist blacksmith but honestly I don’t practice enough. I have my forge and teach basic techniques on the courses. I use the forge to soften metals and bend thick stuff! I have recently moved my fly press next to the forge to use as a power hammer/press but I have yet to focus myself more on my skills as a blacksmith. Blacksmithing is something that must be practiced everyday and I admit I am lazy!

WJM: I believe that you also run welding courses. Could you elaborate on that?

Yes, the courses have been instrumental in me having the current workshop and my ability to comfortably afford the rent. I love teaching and am, apparently, quite good at it. I run a one-day course which introduces people to MIG, TIG and MMA. And a two-day project weekend called 'Taster Weekend.' Which is exactly that; it gives beginners a taste of metalworking. On day one they try MIG and TIG, plasma cutting, grinders and forge work as a group. I encourage them to think about a project to achieve in one day and if they require the use of other machines I will provide individual demos to get them on their way, including for example the rollers, pillar drill, saw, box and pan and finishing techniques.

WJM: Who has had the most artistic influence in your career directions?

In fact I try not to be influenced by others because I am hoping to discover or produce something original! The artists that work on a large scale are those that impress me the most. Recently, an artist I am in awe of is called Junkmori, a Japanese artist working with precious metals and TIG.

WJM: Fabrication & welding has often been seen by many women as a male dominated industry, what advice would you give to young women about coming into the industry?

In theory there is no need to be strong. Health and safety laws restrict what risks we can take with our bodies and so I'd say the image of a big burly strong man is dated. My experience as a welder-fabricator was overwhelmingly male dominated. A welder-fabricator has no requirement for academic subjects and so is often not very well paid. Its suits the tearaways and the troublemakers! So my advice to women is to expect bullying, teasing and casual sexism, unfortunately. They must however try to nip it in the bud straight away by reporting it to the boss. Equality laws are there to be used so don't put up with it! If nothing changes then try to find employment somewhere else. These backwards companies are becoming less and less common. In my case I was too scared and naïve to go to the boss so I developed a thick skin and

'A hand's turn' - public sculpture in Farnham, Surrey. [2]

learnt how to "give it back." I am not portraying an inviting scenario, so in my case it really was doing it because I loved it, and men had the knowledge I wanted to absorb. The whole time I endured the teasing and casual sexism I held on to the ambition of having my own business and workshop where I could make the rules. The first rule would be, no bullies!! Only positivity and encouragement. 15 years later and I think culture has changed a little but there is still huge work to be done. I think the best thing is to not rely on others to change their attitudes but to look for role models who have proved that it can be done.

WJM: Did you come across obstacles in trying to further your career, and how did you overcome these?

The first obstacle was apparent early on, when someone told me that I wasn't getting the job because I am female. This only served to make me angry enough to register as a sole trader. Which was the best thing that ever happened to me! Nowadays when approaching new suppliers I often sense a reluctance to be listened to, in which case I will just move on to the next supplier. And sometimes with clients I feel I have to prove myself first as being skilled, but I get great satisfaction from seeing them return to their place.

References:

[1] https://www.bradwellblacksmiths.com/

[2] https://www.liviaspinolo.com/gallery/private-commissions-tyafg-863x5

REVISION TO WELDING APPRENTICE LEVEL 2 STANDARD IN ENGLAND

Martyn Fletcher FWeldI FIMMM FInLM. Chair, Welding Apprenticeships Standards Committee, IfATE

Introduction - Changes to level 2

The Level 2 General Welder (arc processes) standard has undergone a fundamental revision, which will go live for new registrations from 1st June 2024 under the title 'Welder', but carrying the existing designation ST0349.

Previous welding apprenticeship standards focussed only on manual welding. However, whilst the revised Level 2 Welder Apprentice Standard still continues to require two different welding processes to be adopted, the standard now provides an optional route allowing one of those processes to be a mechanised welding process.

The Level 2 standard is set to serve the widest range of employers, so it does not mandate welding in all positions, nor to a high level of volumetric inspection. This is the standard that should be considered where the employer and apprentice are working in a production environment where ultrasonic or radiographic testing is not a routine requirement.

The structure of Welder apprentice standards in England

IfATE
Shaping skills training

In England there are currently 3 Apprenticeship Standards available. Level 2 Welder (ST0349), Level 3 Pipe Welder (ST0851) and Level 3 Plate Welder (ST0852). The level 3 standards were published in 2019 to address the specific requirements for welders working in industries manufacturing & constructing high safety critical products where volumetric inspection (e.g. ultrasonic and radiographic testing) is routinely required. The cost of delivering these standards resulted in the funding values being set at £27,000 each compared to the previous underfunded Level 3 Multi-Positional Arc Welder which was £12,000.

continues on page 8

Assessment of the previous level 2 standard and the resulting change of requirements

The Welding Apprenticeship Standards committee comprises employers, training providers, end-point assessment organisations, the professional body TWI, IfATE and awarding body organisations. Since its launch in early 2016 feedback on the relative merits of the Level 2 standard have been received from a range of users.

One of the primary requests has been to try to simplify and speed up the end point assessment process. To achieve this we have followed the logic applied in the Level 3 standards. Welders are expected to hold certification to demonstrate their welding capabilities.

For the type of work applicable to Pipe Welders and Plate Welders, achieving a welder qualification certificate to a recognised international standard (c.f. ASME IX, BS EN ISO 9606) would be a necessary requirement before entering a production environment and physically welding on a product. At Level 2, the breadth of scope is so large we needed to be more inclusive. Therefore we have set the requirement to include certification to BS 4872, which does not require the employer or training provider to have Weld Procedure Specifications or Welding Procedure Qualification Records.

The welder qualification certificates have been defined within the revision as embedded qualifications. This means that they are a permissible cost in the delivery of the apprenticeship. This will simplify the final end-point assessment process.

The revision to the Level 2 standard has necessitated a full detailed re-costing exercise. It is IfATE policy that funding will always be set, based on the lowest cost route through the apprenticeship standard. On that basis the revision will increase the allocated funding from £9,000 to £13,000.

Detailed information can be found at

https://www.instituteforapprenticeships.org/apprenticeship-standards/welder-v1-2

Next Steps in developing the welder apprentice standards

With the Level 2 Welder standard going live from 1st June, the Welding Apprenticeships Standards Committee are turning their attention to four key areas.

1. Exploring the potential to align the three existing standards to the international qualification standards philosophy to focus more on Filler Metal than parent material. The hope is that this change will help reduce the cost of training and testing on some of the higher alloy materials. For training purposes it is common practice to be able to use a carbon steel parent material and weld with low alloy, high alloy, stainless steel and nickel based consumables.
2. The Level 3 Pipe Welder Standard currently requires welding of four different materials groups with two different welding processes. With some changes to the power generation and oil & gas sectors it is becoming clear that the number of employers able to cover those four materials has diminished. The Committee are considering reducing the number of material groups covered. However, this needs to align with item 1 above. In addition some organisations have asked about consideration for the second process being broadened to allow mechanised welding (e.g. orbital TIG, Mechanised MAG/FCAW).
3. The Committee are set to explore the appetite and interest for developing a Welding Supervisor apprenticeship standard. Some time ago ECITB published a Level 4 NVQ (Managing Welding Operations) focussed on the role of the front line welding supervisor. The old NVQ4 was withdrawn around 2014/15 due to the lack of uptake when Nuclear New Build projects were delayed. With the industry entering a significant growth phase, demand for correct training and recognising the key competencies related to welding supervision is coming to the fore again.
4. There is some discussion emerging around a higher level apprenticeship leading to professional Welding Engineer. Any employers interested in utilising an apprenticeship pathway to Welding Engineer in the future should contact **david.bage@twi.co.uk**

Information on existing registrants on the superseded level 2 standard

IFATE have advised that any apprentice who registered prior to 1st June 2024 on the old Level 2 standard will be eligible to re-register on the revised standard. However there will be no associated increase in their funding, and will remain on the existing £9,000 band. It is therefore strongly recommended that the Apprentice, their Employer, Training Provider and End Point Assessment Organisation discuss the relative merits of any change over to the new revision. The potential advantages of changing to the new revision would be the reduced multi-choice question paper, and more defined practical assessments. However the disadvantage for some may be the additional cost of obtaining the necessary welder qualification certificates prior to the gateway to end-point assessment.

How to involve yourself in developing realistic apprenticeship standards

These four tranches of work represent a significant level of effort that is largely borne by only a small number of individuals acting in a voluntary/out-of-hours capacity. We have already been warned by IFATE that items 1 and 2 above will result in a full re-costing exercise. From experience, this will be more time consuming and problematic than the drafting of the actual apprenticeship documentation. We are therefore very much looking for other people with a passion and drive for welding skills who may be interesting in joining the Welding Apprenticeship Standards Committee or any of the working groups. If you wish to get involved please drop an email to **kate.day@twi.co.uk**, with the subject line Welding Apprenticeship Standards Committee, and we will be in touch.

Acknowledgement and thanks

Finally I would like to thank the existing members of the committee and working groups who have put in immense effort, thought, time and experience over many years. You have set the standards and built the infrastructure for others to train the future of our industry.

TWI USING AUGMENTED REALITY WELDER TRAINING

TWI has been using augmented reality training systems to teach a new generation of welders in Malaysia. This has been achieved in conjunction with Seabery, who are global leaders in augmented reality welding systems, by uploading TWI training curriculum content to their Soldamatic machines.

Augmented Reality or Virtual Reality?

Augmented reality and virtual reality are often used as synonyms, but there are a number of key differences between these two technologies.

While many people are familiar with virtual reality (VR), augmented reality (AR) differs in a number of important ways. With virtual reality, users are immersed in a completely digital, simulated environment. This immersive VR environment is constrained by the control system and uses pre-built scenarios.

Rather than replacing the physical environment, AR uses digital elements to enhance the real-world physical environment, combining the digital and the physical world. This creates a more life-like, 'hands-on' training experience.

VR is a 75% virtual experience that always requires the use of a headset, while AR is just 25% virtual and does not always require a headset to use, although it requires a higher bandwidth than VR.

Virtual Reality

Virtual reality involves an immersive computer generated simulation where the user interacts with a fully digital world. This means that the VR headset needs to be able to translate real world movements into a modelled reality. To achieve this, two lenses between the user and the screen interpret the movement of the eyes so that any movement can be adapted to the VR.

While this allows for immersive learning, a genuine interaction is not possible in the virtual environment so it cannot completely replace a real training experience. Nevertheless, it has found uses for military training with flight simulators or battlefield simulations and to train surgeons, for example.

Augmented Reality

Where VR isolates the user from the real world, AR accents the real world with digital elements. This is achieved through the implementation of computer vision, mapping and depth tracking so that data can be collected via cameras and processed in real time. This allows for an enhanced learning experience that can help you improve accuracy and efficiency.

AR opens up a plethora of possibilities for training and, in the case of welding, allows users to learn without wasting materials while also getting real-time feedback.

Augmented Reality Training with TWI

Courses from the TWI training curriculum have been uploaded to Seabery Soldamatic systems and made available to trainees in Malaysia. These systems reduce the time and cost associated with welder training while also reducing the environmental impact of training by minimising the amount of materials and energy used.

Far from being a video game, the training systems have been developed by welding teams to ensure they match real welding with real components. But, being digital, they also offer some additional benefits, such as being able to monitor and record all training data in real time, allowing any errors to be identified and corrected right away. In addition, video replays and 3D views allow you to examine the final simulated weld bead results.

In January 2024, TWI Malaysia embarked on a pioneering initiative, integrating augmented reality (AR) into our standard welding training for what was called the 'Zero to Hero' programme. This initiative, fully funded by Majlis Agama Islam and Adat Melayu Perlis (MAIPs) and comprising 20 students, aimed to revolutionise the learning experience. By infusing AR technology into regular training sessions, the objective was to elevate engagement, effectiveness and safety, providing novice welders with a secure environment to refine real-world skills within a virtual setting.

Training instruction on a vertical up weld in plate

Upon reviewing the outcomes of the inaugural cohort of TWI Augmented Reality Training, it became evident that AR simulations had significantly bolstered students' proficiency in honing their psychomotor skills. The incorporation of two weeks of AR simulation training preceding actual welding proved instrumental in this enhancement. Notably, students who underwent AR training showcased markedly improved welding quality compared to previous cohorts, who did not take part in AR simulation training.

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There was a notable improvement in the time taken by students to complete their welding tasks, with many finishing their assignments approximately one week ahead of schedule. This observed efficiency and proficiency among students underscored their ability to accomplish welding tasks more expeditiously while upholding quality standards.

Demonstration by the TWI trainer

The maturity of students also witnessed a remarkable upswing, attributed to their exposure to technical terminology and theoretical classes during the two-week AR training period. By acquainting students with industry-specific jargon and offering insights into addressing welding defects, their comprehension deepened. This comprehensive approach not only enhanced weld quality, but also ensured students were better equipped for their transition into industrial practice or employment.

Additionally, the utilisation of materials and welding accessories experienced a remarkable reduction of approximately 20% compared to previous levels. This reduction encompassed various facets, including consumables, base materials and the number of gas cylinders required for welding. Such improvements signify more efficient resource utilisation, delivering cost savings and environmental benefits as a result.

Furthermore, the execution of AR technology within MAIPs uplifted training syllabi and approaches led to unprecedented levels of effectiveness and engagement. Through interactive tutorials, immersive simulations, and real-time performance analytics, students are better prepared for subsequent traditional training offering a more dynamic, personalised, and impactful learning experience for the cohort of trainees.

Although TWI is already offering augmented reality training in Malaysia, augmented reality training systems complete with TWI training course content are being considered for roll out elsewhere, including in the Middle East and the United Kingdom.

Benefits

As demonstrated, the benefits of augmented reality training include reducing the time and costs taken to get welders certified, with training time in a real-life welding shop reduced by 56%.

Welders still require real-world physical welding training, but this can be delayed until the trainee is ready. This is not only important in closing the skills gap and delivering more certified welders to industry, but also reduces accidents by 84% compared to training under real-life welding conditions.*

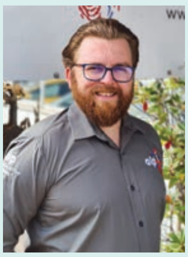
Training in progress and an array of demo test pieces

While augmented reality won't replace the need for real-world physical welding practice, it can certainly speed up the learning process, as well as offering additional monitoring and training data benefits, ensuring that skilled welders can be delivered to industry sooner.

It is also hoped that the introduction of these augmented reality systems will appeal to the next generation of welders by delivering training in a more appealing environment, while utilising the latest technologies.

To find out more please email TWI's business development manager, Johnathan Gan Han Seong at john.gan@twi-gtc.com

**Statistics: University of Esslingen, Germany.*



AIP WELDING SUPPLIES – ON A MISSION TO BRING YOUNG PEOPLE INTO WELDING

An interview with Kim Hunt, Director, AIP Welding Supplies Ltd

WJM: What brought you into welding and how do you promote the welding industry?

I started working in Engineering through a link course with Bridgwater and Taunton College back in 2005 where I 'got the bug'. I then proceeding on to an apprenticeship in 2007 with Berry & Escott Engineering where I progressed and gained the experience and knowledge to start AIP Welding Supplies in late 2015 and have been loving the work side of my life ever since. Over the last 9 years AIP has grown into a company known for its expertise and customer-focused service. We are working alongside some of the biggest and most sought-after colleges in the region to encourage the next generation of welders into the industry.

WJM: You have a thriving business, what is your personal motivation to work to bring young people into welding and share your experience?

From a young age I struggled with English in school, being diagnosed with dyslexia at 10 years old. School was hard to enjoy due to the lack of support offered. I did, however, seem to have a knack for problem-solving and discovering how things worked, allowing me to get into more hands-on subjects and I focussed on these strengths in maths, PE, design technology, science and engineering. As I got older and entered the working world of welding and fabrication, I also found that having OCD meant my attention to detail, planning and the drive to get thing perfect became an advantage as I was able to work to an extremely high level of accuracy and finish. The workshop is my 'happy place' and where I go to escape if I require some time to myself. I have had a few life-changing experiences in my adult life which still affect me mentally, something which seems to affect quite a lot of men in this industry. I can quite easily say that being in such a diverse industry (and not in a 9-5 job) has helped, since every day is different.

My own personal experiences are what helps drive AIP in the areas of the industry that seem to be overlooked. I work alongside charities that help people struggling in life. I run bootcamp talks at colleges and schools on the fabrication industry, where it could take you in life and what career paths would best suit their interests. I make sure to include a segment on mental health and say that it is ok to talk either openly or privately if the avenues are there for them to reach out to, but also I want to raise awareness about understanding other's battles in life. I will speak openly about my journey as I feel it allows others to feel that they are not alone and hopefully they can relate to it and take those first steps to move ahead.

WJM: What led you come up with the concept of reaching out and engaging with young people who are disaffected with the education system?

As touched on above I didn't have the best educational experience but I got through due to having some strengths in other areas, and I was able to conform to the requirements of the educational system even though I didn't agree with it, even at a young age. Students being 'naughty' and 'disruptive' weren't failing, they just couldn't conform to the system, yet they thrived when outdoors or in a more active environment. There is no information or direction being offered to place them in careers where they would thrive, such as welding and fabrication. I was lucky enough that I knew what I wanted to do when leaving school.

This has led us into building and investing into a show van which allows students to have a view at what welding is all about. We have a VR welding simulator where they can have a go at welding without the hazards, PPE for them to try on and dress up as a welder and equipment that is used in the industry. We also have some metal artwork demonstrating what welding and fabrication is all about. The hardest challenge has been getting the secondary schools to actually get involved with it.

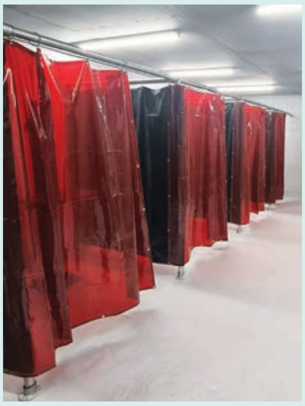
WJM: Have you had experience of teaching 'challenging' young people?

This year I was fortunate enough to be introduced to a wonderful women called Emma who works within the Somerset Carers Hub and has helped us connect with Schools that teach 'challenging' students. We have visited and engaged with five different schools across Somerset this year and are arranging more as we speak, and we have connected and worked with students from the ages of 10 to 16 years old, all with their own individual personalities and living with their own life hurdles. We have had a success rate of around 98% engagement overall and the feedback has been brilliant with some students now looking into a career in welding and fabrication.

WJM: What mechanisms do you use to engage with these young people, and what are the most effective?

I try to keep things light-hearted and tend to move around when speaking with the students to try and keep their focus on me rather than standing still and them getting distracted. I will engage with them from the offset by asking questions related to welding but also interacting with them on their hobbies and interests to see if I can create a link to keep their engagement high. Questions from the students that require a factual answer are met with praise and encourage them to engage again. We then get them up into the van and playing with the VR system, which is always a big hit and has the students challenging their teachers to have a go.

Virtual reality welder training equipment at AIP



Welder training booths at AIP

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WJM: Have you found that doing a practical 'hands on' activity has improved the young people's engagement and developed other functional skills?

Offering the practical side of the experience with VR welding has definitely heightened the interest and engagement of the students and we have found that a whole class is more likely to get involved, compared with just a few when no practical experience is offered.

WJM: What visible signs are there that you are being successful and do you have plans to extend the provision?

We launched the demo van at the beginning of this year and have seen bookings and interest grow month on month with feedback from the schools being nothing but brilliant and in their words 'what these students need'. So we have invested again and have set up three new workshops at our Bridgwater location. One setup is solely to give an insight into welding and what it entails, and this is aimed at younger students and the less abled. This setup has a VR welding simulator, 55 inch TV, sofa, coffee table, work station and mood lighting… because we are trying to educate, but not in a classroom style layout. The second is our full, top of the range welding bays. These are aimed for young teens and upwards who wish to experience welding for real and for people who wish to learn welding as a career. We run courses and qualifications from here as well getting people ready for jobs requiring certificates. The third is our motorsport area. Here we have our donor car that we will be building and modifying for track events. We encourage car enthusiasts to come and get involved including those who would normally not have the opportunity to do so or can't due to circumstances such as being less mobile and unable to lay down on a piece of cardboard on the driveway to work on their pride and joy. Here we show techniques on how to work on bodywork, exhausts, intercoolers, turbos and structural parts of the vehicle, demonstrating how to produce new parts or repair existing ones.

WJM: How is the project funded, and have you managed to get sponsorship, and if so is it sufficient or do you require more help?

The project has been fully funded by myself. This is because every avenue I have investigated (or been recommended by others) has led to a dead end. Most state that, due to us being a business they are unable to help. This has been really frustrating as we are doing this as a not-for-profit service and to give back to the industry and to help to bring the next generation into the trade.

QUICK LINKS - BRAZING, SOLDERING AND DIFFUSION BONDING

Articles on the Internet

Brazing and Soldering

This article looks at some of the differences between fusion welding and makes comparisons to brazing and soldering including advantages and disadvantages of each of the three joining types. https://www.twi-global.com/technical-knowledge/faqs/welding-brazing-and-soldering

This article looks specifically at some of the advantages and disadvantages but also includes details on silver soldering and aluminium brazing.
https://www.wcwelding.com/soldering-and-brazing.html

This article looks at the mode of operation of brazing, including temperatures, heating requirements and the role of capillary attraction or capillary action which makes brazing unique compared to fusion welding. https://www.twi-global.com/technical-knowledge/faqs/faq-what-is-brazing

This article looks at some of the basics of brazing and soldering but also looks at joint design and fit up tolerances required for brazing, as well as different joint types and the effects of heat input as well as flame types and filler metals.
https://metallurgicalexpertise.wordpress.com/2020/04/21/brazing/

This article looks at the comparisons of fusion welding and brazing, as well as selecting the correct joining process.
https://lucasmilhaupt.com/EN/Brazing-Academy/Brazing-vs-Welding.htm#:~:text=In%20a%20brazing%20operation%2C%20you,a%20brazed%20joint%20is%20made

This article shows the 6 essential steps in order to make successful brazed joints. https://www.thefabricator.com/thewelder/article/tubepipefabrication/6-steps-to-successful-brazing

This article looks at a number of different factors related to brazing including the properties of a successfully brazed joint, as well as terms associated with the brazing process including brazing filler metals as well as metallurgical problems in brazed joints.
https://www.jmmetaljoining.com/technical-about-brazing

This article covers some of the basics of other articles above but also delves into torch brazing, induction brazing, and resistance brazing, furnace brazing and dip brazing.
https://fractory.com/brazing-explained/

This article focuses on soldering and highlights soldering in electronics and also offers a free 17 page Ebook (PDF) – "Learn How To Solder".
https://www.makerspaces.com/how-to-solder/

Diffusion Bonding

This article looks at the fundamentals of diffusion bonding and highlights a furnace that is used for such a process as well as some details related to materials which can be diffusion bonded.
https://www.twi-global.com/what-we-do/our-processes/diffusion-bonding

This article looks at some of the applications of diffusion bonding technology and highlights the main benefits, as well as showing a specialist company who provide diffusion bonding services to UK industry.
https://www.heatric.com/heat-exchangers/features/diffusion-bonding/

This article looks at the principles and process as well as its advantages and challenges.
https://bortec-group.com/glossary/diffusion-bonding/

Videos on the Internet

The following videos show a range of different brazing, soldering and diffusion bonding techniques.

Brazing

https://www.youtube.com/watch?v=WeRPdVDCLyk
https://www.youtube.com/watch?v=TQP8EBQRvr0
https://www.youtube.com/watch?v=iyBWJMiof5k
https://www.youtube.com/watch?v=_MISR0hfB00

Soldering

https://www.youtube.com/watch?v=Qps9woUGkvI
https://www.youtube.com/watch?v=m_w7KXHCewU
https://www.youtube.com/watch?v=NQwGUACUr34

Diffusion Bonding

https://www.youtube.com/watch?v=7o9CfeS8cxs
https://www.youtube.com/watch?v=ZfFo3b918qo
https://www.youtube.com/watch?v=69aWXWaBsik

Compiled by Mark Cozens

FUNDAMENTALS OF SOLID-STATE DIFFUSION BONDING

Amir A. Shirzadi, The Open University , Cambridge Joining Technology.

Introduction

Solid-State Diffusion bonding (SSDB) is a joining process wherein the principal mechanism is interdiffusion of atoms across the joint interface at an elevated temperature of about 50%-90% of the melting point of the material in the Kelvin scale. The International Institute of Welding (IIW) has adopted a modified definition of solid-state diffusion bonding, proposed by *N. F. Kazakov* who is credited as the pioneer in the field [1].

"Diffusion bonding of materials in the solid state is a process for making a monolithic joint through the formation of bonds at atomic level, as a result of closure of the mating surfaces due to the local plastic deformation at an elevated temperature which aids interdiffusion at the surface layers of the materials being joined."

The SSDB process requires applying compressive loads on the joint interface for a time ranging from a few minutes to a few hours depending on the material. The higher the bonding pressure the shorter the bonding time, however, the pressure is limited by the amount of plastic deformation permissible on the components. The diffusion bonding of most materials has to be carried out in vacuum (normally below 10^{-3} mbar) or in an inert gas (argon or nitrogen) in order to reduce oxidation of the joint surface at elevated temperatures. Given the absence of a liquid phase, precise surface preparation is required to ensure minimum gap between the mating surfaces.

It is literally impossible to establish a full contact in interatomic scale by pushing the parts against each other. Even highly polished surfaces contain peaks and troughs and come into contact only at their peaks, resulting in a very low contact areas compared to the entire mating area. Besides, the presence of tenacious native oxide layers affects the ease of diffusion bonding by blocking metal-to-metal contact. Apart from a few exceptions where oxide films dissociate at the bonding temperature (e.g. titanium and silver), achieving a metallic bond in alloys with chemically stable surface oxides (e.g. aluminium and its alloys) can be a challenging task.

Mechanism of SSDB

The mechanism of bond formation during SSDB of the alloys with stable surface oxide can be classified into two main stages [2,3]. In the early stage, the asperities or surface peaks yield and deform plastically under the applied compressive force. As the micro-deformation proceeds, more metal-to-metal contact is established because of local rupture of the thin and brittle oxide films. Figure 1 schematically shows the end of this stage, when the bonded area is still less than 10% of the entire surface and a large volume of voids and surface oxide remain at the joint interface.

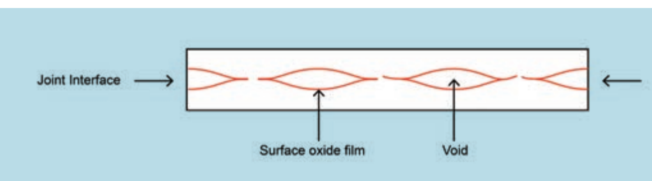

Figure 1: Schematic presentation of joint interface at early stages of solid-state diffusion bonding

In the subsequent stage of diffusion bonding, the thermally activated mechanisms lead to void shrinkage and this increases the bonded areas. According to the *"Diffusion Hypothesis"*, the difference in the energy level of the surface atoms and that of the bulk atoms is the main driving force behind the interatomic diffusion across the joint interface [1].

Figure 2 shows how the use of higher bonding temperatures and/or longer times expedited the annihilation of the voids, hence increased bonded area fraction.

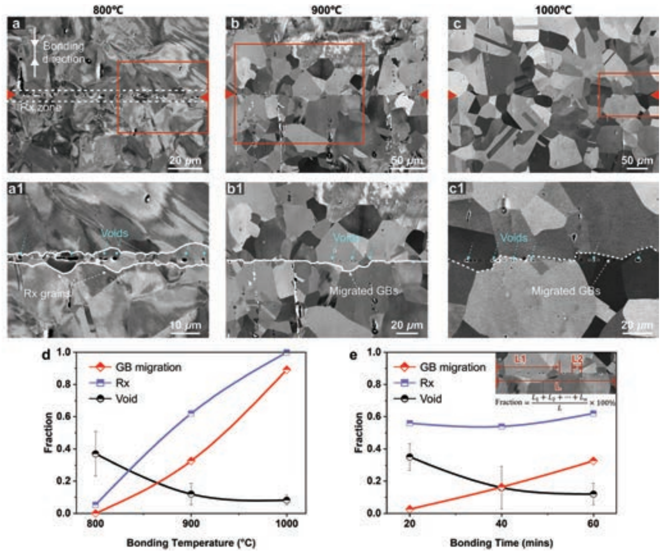

Figure 2: Effect of increasing bonding temperature and time on the reduction of interfacial voids due to recrystallisation (Rx) and grain boundary (GB) migration during diffusion bonding of stainless steel 316L [4]

The joining of dissimilar materials with different thermo-physical characteristics (e.g. aluminium to steel) which is not possible by conventional fusion welding, has been done by solid-state diffusion bonding. Metals, alloys, ceramics and powder metallurgy products also have successfully been joined by solid-state diffusion bonding. However, diffusion bonding dissimilar alloys may result in the formation of undesirable and brittle intermetallics if the bonding temperature and time exceed the optimum levels. In some case interlayers are used to reduce the formation of brittle intermetallics.

Approaches to overcome surface oxide problem

As mentioned above, the presence of surface peaks and troughs (e.g. machining or grinding marks) and native oxide films hinder bringing two faying surfaces within interatomic distances and establishing metal-to-metal contact. The surface waviness and roughness can be improved by polishing and lapping of the faying surfaces. The presence of surface oxide films is a far more challenging issue and this why most of the research work in the field aims to minimise or eradicate the effect of stable surface oxides.

The majority of surface oxide films are brittle and very thin (a few nanometre on a freshly polished aluminium), therefore

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they rupture when the alloy is subjected to a large amount of plastic deformation during SSDB (normally 40% or more). The disruption of the oxide promotes metal-to-metal contact and increases joint strength. Clearly this approach has limited applications due to the substantial deformation of the parts being joined.

Some active alloying elements, such as magnesium and lithium in aluminium alloys, can interact with and break up the continuous and amorphous surface oxide at an interface to form an array of discrete particles. A good correlation between bond strength and the extent of broken oxide was observed, leading to the conclusion that the greater the content of these elements; the greater the disruption of the oxide layer and consequently the higher the bond strengths [2].The effects of active elements in interlayers, inserted in joint, have widely been researched – see [2] for more on interlayer-assisted diffusion bonding.

Several surface preparation methods have been developed which are based on the chemical and non-chemical removal or modification of surface oxide films prior to SSDB process. Using such approaches, excellent solid-state bonds in various alloys have been achieved. As shown in Figure 3, if the surface oxides are removed or modified sufficiently, the bond lines become virtually invisible as the microstructures of the joint interfaces are identical to those of the bulk alloys [5].

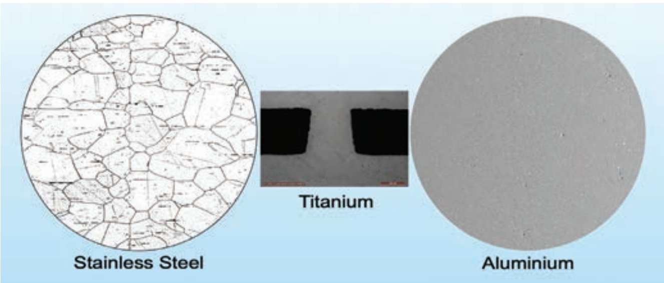

Figure 3: Virtually defect-free bond lines in the diffusion bonded structural alloys

More recently, a new technology is developing to minimise the bonding time and improve the bond integrity by applying cyclically pulsative forces [6]. Alternative approaches include removing surface oxide in high vacuum followed by bonding without exposure to atmosphere.

The complexity of an apparatus capable of in-situ surface oxide removal and bonding renders very limited applications for this method. Interestingly, SSDB is a very promising method for joining materials in space due to ambient high vacuum.

Advantages of SSDB

As demonstrated above, SSDB has the ability to produce high quality and monolithic joints without large defects or porosity [2]. Using optimum bonding parameters (mainly temperature, pressure and time) the joints can have strength and ductility comparable to those of the parent alloy.

Conventional welding of dissimilar alloys or metal-to-ceramic is not possible due to their different thermo-physical characteristics. Capability of joining un-weldable materials is one of the most attractive features of SSDB.

SSDB allows fabrication of high precision component without a need for subsequent machining. Laminated Object Manufacturing (LOM) using diffusing bonding is one of the fastest growing techniques.

Apart from the capital investment, the consumable costs of SSDB are considerably low since no electrodes or flux are required.

Solid-state diffusion bonding is a more environmentally-friendly process than fusion welding processes which generate ultraviolet radiation and gas emission.

Limitations of SSDB

The stringent surface requirement is the most limiting factor. Any excessive oxidation or contamination of the mating surfaces can compromise the joint strength considerably. Therefore, pre-bonding preparation of the mating parts takes much longer times than with conventional welding processes.

The capital investment is very high particularly for bonding large components. For the same reason and due to long bonding times, the viability of this process for mass and cheap production is questionable.

Modelling SSDB

Analytical and more recently numerical modelling of SSDB can considerably reduce a need for costly and lengthy experimental trials [7,8]. For instance, a suitable range of bonding temperature and time can be estimated by conducting a basic analytical modelling. Generally optimisation of bonding pressure requires numerical simulations using Finite Element Modelling and so forth. However, none of the analytical or numerical models take the effect of oxide film in account. Therefore, application of these models remains limited to bonding the metals without stable surface oxides.

Diffusion bonder

A diffusion bonder is essentially a hot press which operates in vacuum. The bonding pressure and temperature are controlled independently. Radiation, conduction or induction heating can be used to heat the parts. Figure 4 shows the main components of a diffusion bonder with an induction heating system. The parts are placed between the lower and upper platens of the bonder surrounded by the water-cooled copper coil. The load is applied by a hydraulic or electric motor actuated piston. The load cell under the lower platen and a thermocouple in touch with the parts measure the load and temperature continuously and provide feedback to the control system. A diffusion or turbo-rotary vacuum pump, backed up by a rotary vacuum pump, is used to evacuate the chamber down to 10^{-3} mbar or lower.

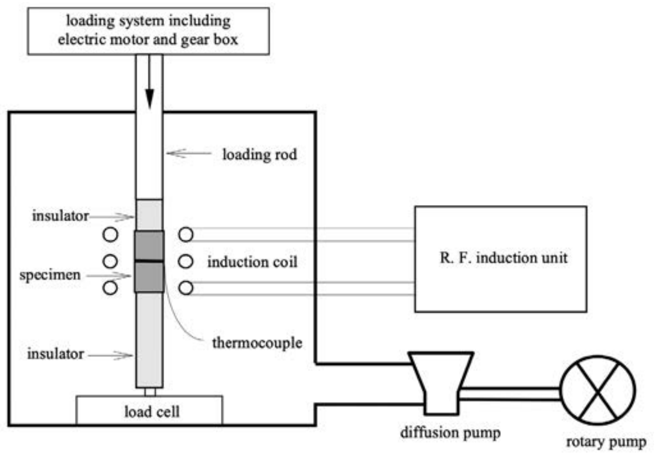

Figure 4: Schematic diagram of diffusion bonder and its peripherals

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[4] Wei Wang, Daniel S Balint, Amir A Shirzadi, Yaping Wang, Junyi Lee, Lee Aucott and Jun Jiang (2023): Imparted benefits on mechanical properties by achieving grain boundary migration across voids, Acta Materialia Vol. 256, 1 Sept. 2023, 119103; https://doi.org/10.1016/j.actamat.2023.119103

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[8] Hill A. and Wallach E.R. (1989), "Modelling solid-state diffusion bonding", *Acta Metallurgica*, Vol. 37, No. 9, 2425-2437.

Dr Amir Shirzadi has a PhD from the University of Cambridge and holds several patents in Diffusion Bonding. He has established a research lab at The Open University where he develops novel methods for joining un-weldable materials. He is also the Director of Cambridge Joining Technology and Fellow of TWI and IoM3.

THE SCIENCE OF VACUUM BRAZING: ENSURING STRENGTH, RELIABILITY, AND PERFORMANCE IN JOINT DESIGN

Adrian Goodbrand CEng. VFE.

Image: Thermal survey and accuracy test

Introduction

In manufacturing, many applications require the joining of parts where joint geometry prohibits direct access. In such applications, brazing is often used because it allows joints to be fused together without needing direct access to the joint surfaces. This technique is particularly valuable in industries such as aerospace, medical devices, nuclear, and defence, where components can have complex geometries. The criticality of these applications requires components to be reliable under harsh conditions, such as high temperatures, while maintaining minimal distortion and stress to preserve dimensional and functional integrity. Vacuum brazing provides the optimal conditions for producing highly reliable joints in these demanding applications.

VFE has over 34 years of experience in the furnace industry having installed, serviced, or optimized more than 60 brazing furnaces. Joint design is crucial for ensuring reliability, but even well-designed joints can fail if the correct joining techniques and specifications are not followed.

This article explores vacuum brazing, how it works, and the key design considerations for vacuum brazing furnaces, including control systems and instrumentation necessary to create the right atmosphere for the process, ensuring joint integrity.

Understanding Vacuum Brazing

Vacuum brazing is a unique, flux-less process of joining two or more metals, ceramics, or even metals to ceramics. Typically, a filler metal is used, which can be in the form of a metal preform, wire, or paste. Metal alloys can also be used instead of pure metals, with eutectic alloys being particularly effective for brazing since they co-exist at the eutectic temperature and behave similarly to pure metals. The vacuum brazing process can occur under complete vacuum, partial pressure, or even ultra-high vacuum environments, achieving a clean, bright, and oxide-free finish.

The filler metal, having a lower melting point than the adjoining metals, melts and flows into the joint, where it then solidifies to create a bond. When it becomes a liquid, the filler reaches a temperature at which its surface tension is lower, allowing it to wet a greater surface area and fill the joint correctly.

The liquid spreads by capillary action within the joint cavity between the metals, creating an intermediate layer, as illustrated in Figure 1 below.

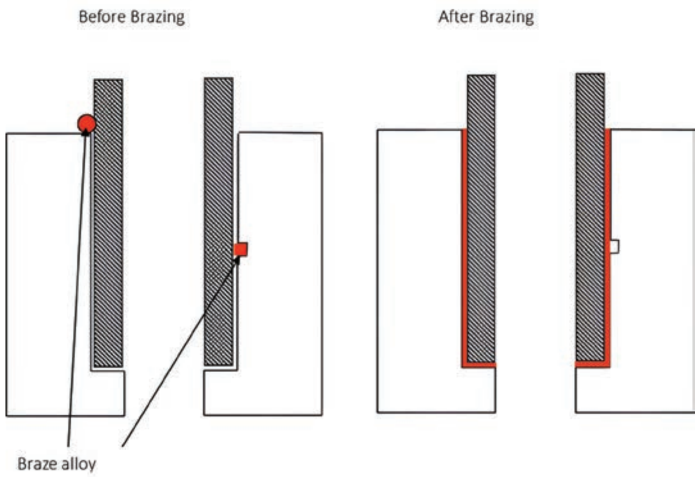

Figure 1: Capillary action in brazing

Obtaining the right joint tolerances is critical for successful vacuum brazing. The gap must be neither too small, making the bond difficult to fill, nor too large, which could result in a weak joint with gaps or porosity.

As the brazing alloy or filler melts at a lower temperature than the substrate (the metals being joined), the mechanical properties of the substrate are not adversely affected. A perfectly brazed joint requires a clean surface, oxide free, without traces of processing oils or greases, to ensure good wettability. This allows the alloy or filler to be drawn onto the surfaces to be joined.

To achieve a high-quality brazed bond with properties such as stress resistance and corrosion resistance, it is essential to create a highly controlled environment. For maximum joint strength, the gap clearance should be as parallel as possible, with the gap between mating surfaces held within 0.03 - 0.08mm at brazing temperature (which may vary depending on the alloy used). The chart shown in figure 2 illustrates the relationship between braze gap and the tensile strength of a joint.

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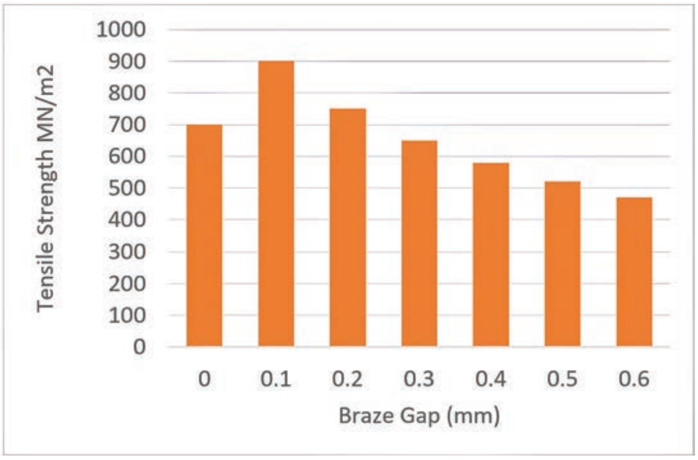

Figure 2: Relationship between braze gap and tensile strength of a joint

Why Vacuum Brazing?

Vacuum brazing is crucial for joining components where high joint strength and flawless quality are required, especially in critical applications. Several factors highlight how a vacuum environment contributes to creating strong, high-quality joints:

Elimination of Oxidation:

In a vacuum environment, the absence of air (and thus oxygen) prevents the formation of oxides on metal surfaces. Oxides can act as barriers to the wetting and bonding process, weakening the joint. By eliminating oxidation, the metal surfaces remain clean and free of contaminants, ensuring better adhesion of the filler metal.

Enhanced Wetting and Capillary Action:

The vacuum environment reduces surface tension and promotes better capillary action of the molten filler metal, allowing it to flow more smoothly and cover the joint area completely thus enhancing wettability. This improved wetting enables the filler metal to penetrate microscopic gaps and irregularities in the joint area, resulting in a more uniform and stronger bond.

Removal of Volatiles and Contaminants:

The vacuum environment helps remove volatile substances and contaminants that may be present on the metal surfaces or within the filler material. This outgassing process ensures that the joint area remains clean and free from impurities.

Enhancing Temperature Uniformity:

Vacuum brazing ensures even heating of the components and the filler metal. This uniform temperature distribution helps form a homogeneous alloy at the joint, resulting in consistent mechanical properties across the entire bond. This consistency ensures no weak spots, contributing to the overall strength and reliability of the brazed component.

Minimisation of Residual Stresses:

The vacuum furnace allows for controlled cooling rates, minimizing the development of residual stresses within the joint. Residual stresses can lead to cracking or weakening of the joint over time. By carefully controlling the cooling process, vacuum brazing produces joints that are more stable and durable under operational conditions.

High Purity Environment:

While vacuum brazing primarily uses a vacuum to achieve these benefits, sometimes an inert gas like argon or a reducing gas like hydrogen may be introduced at low pressures. This further enhances the purity of the environment, especially for metals that are highly reactive.

Design Considerations of vacuum furnace:

To successfully achieve the enhanced brazing capabilities using vacuum, it is imperative to use the right vacuum furnace equipment. The following design factors should be considered while selecting a vacuum furnace for your process.

Cleanliness:

The hot zone of a vacuum furnace can be constructed with either graphite insulation or multiple layers of metal reflective shielding, such as molybdenum/lanthanum for the internal shields, molybdenum for the intermediate shields, and stainless steel for the external shields. The selection is determined by the required vacuum level for brazing the specific workpiece and whether it reacts with carbon, ultimately ensuring a clean brazing environment.

Temperature:

The hot zone can reach operating temperatures ranging from 650 °C for brazing aluminium components to 2200 °C for ceramics and more exotic materials. High-temperature refractory metals such as molybdenum are used to construct the hot zone, allowing it to reach temperatures between 900 °C and 1400 °C. For even higher temperatures, tungsten is employed, accommodating ranges from 1500 °C to 2200 °C.

The development of high-purity carbon fibre insulation has made graphite hot zone construction more common in 90% of applications, covering the temperature range of 900 °C to 2200 °C. Graphite is a more thermally efficient insulating material, so if the workpiece does not react with carbon and does not require a vacuum more powerful than 1×10^{-5} mbar then graphite is often chosen. This preference is due to its energy savings and ease of maintenance compared to an all-metal hot zone.


Figure 3a: Furnace with all-graphite hot-zones Figure 3b Furnace with all-metal hot zones

Temperature Uniformity:

The hot zone heating must be controllable with the ability to fine-tune the temperature as required. Maintaining uniform heat in the chamber is crucial for vacuum brazing. Typically, vacuum furnaces should not vary by more than 5 °C from the set temperature in either direction, and in some cases, a variance of only 3 °C is required to minimize distortion or to comply with the Aerospace Material Specification AMS2750, Pyrometry, published by SAE International.

Vacuum:

The ability to create and maintain a high vacuum in the vacuum furnace is crucial for successful brazing. Three stages of pumping are utilized to ensure a high vacuum is maintained during furnace operation.

The initial vacuum stages are achieved using mechanical pumps, reaching a vacuum level in the range of 10^{-2} to 10^{-3} mbar. The first stage typically involves a rotary vane vacuum pump or a dry, oil-free screw vacuum pump. The second stage usually employs a positive displacement rotary lobe pump, known as a roots booster pump. To reach the desired operating vacuum level for brazing, an oil vapour diffusion pump is used, typically achieving a vacuum level of 10^{-5} mbar.

Additional enhancements to the vacuum system can be implemented, such as incorporating a hot water system in the furnace chamber to remove moisture from surfaces and improve the vacuum level. Alternatively, a cryogenic baffle can be added to trap moisture and further improve the ultimate vacuum. Additionally, the cryogenic baffle can reduce chamber pump down time by up to 75%.

Figure 4: A combi vacuum pumping system for initial vacuum stages with a roots booster at the top and dry screw backing pump at the bottom

Hydrogen:

The use of hydrogen is significant due to its ability to actively remove oxides from metal surfaces, ensuring clean and oxide-free interfaces necessary for a strong joint. Vacuum furnaces can be designed to introduce either a small bleed of hydrogen at partial pressure (0.1-1 mbar abs) or a full reducing atmosphere of hydrogen (1 bar abs) to improve brazing quality.

Once the right vacuum furnace is selected based on the design considerations discussed above, it is essential to have a control system that is user-friendly and tailored to the process requirements, along with a set of properly calibrated instruments. Process control becomes a mandatory requirement to create the right environment for brazing and to ensure that the process recipe is followed accurately.

Controls & Instrumentation:

The controls and instrumentation of vacuum furnaces are critical design features that ensures the process conditions meet strict requirements, whether it involves producing compliant aerospace parts or pushing the boundaries of furnace capability to develop new brazes.

The diversity of the furnace instrumentation and controls package needs to be tailored to suit the application and quality control requirements, whether it is controlling various temperature set points, removing volatile contaminants using vacuum, or preventing the vaporization of elements within the material. Modern digital vacuum furnace control systems serve as primary user interfaces for operators and engineers, providing a high level of supervision over the system and process. These systems offer various control features:

- Simple yet powerful graphical profile editor.
- Monitoring and issuing of process commands, such as controller setpoint changes.
- Displaying current running status with numerical and graphical presentation.
- Allowing manual intervention by authorized users.
- Displaying system alarms and diagnostic data.
- Recording all process data and user actions in a secure database.
- Providing the ability to search the database and view, print, or export historical records.
- Ability to connect to a network or production management system.

These features enable operators to optimize furnace performance and enhance overall equipment effectiveness (OEE).

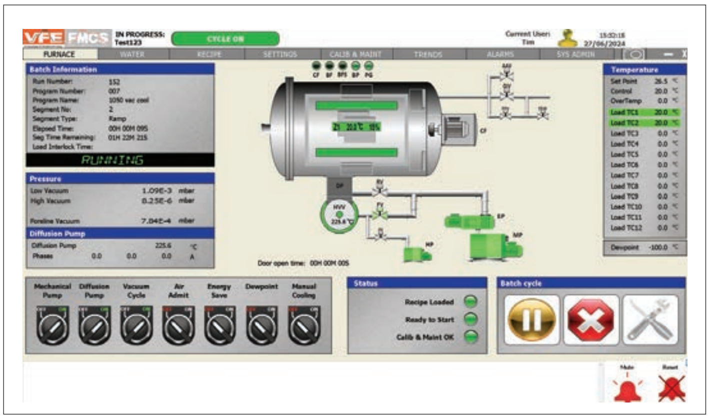

Figure 5: Main overview screen of the furnace displaying real-time vacuum and temperature information as well as operational status

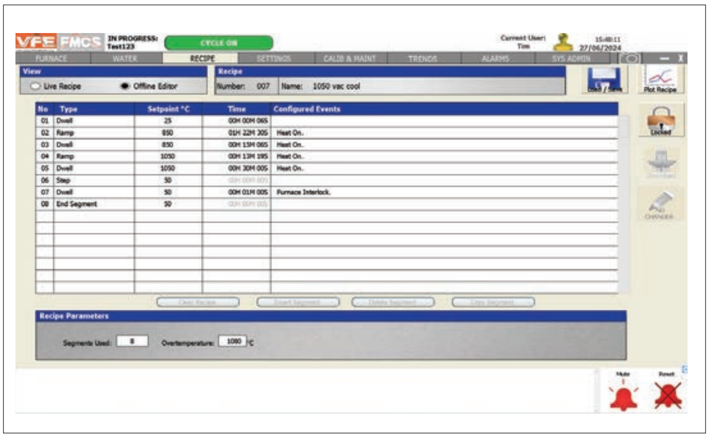

Figure 6: Recipe load and edit screen, where furnace recipes are designed in segments for time, temperature, and event control

In critical applications like brazing aerospace components, adherence to quality standards is paramount. One such standard, AMS2750, sets stringent requirements for vacuum furnace operations. While originally designed for aerospace applications, AMS2750 has become a benchmark for quality in various industries. AMS2750 outlines pyrometric requirements for equipment used in the thermal processing of metallic materials. It significantly impacts control system design and covers various aspects, including:

- Temperature sensors
- Instrumentation
- Thermal processing equipment
- System accuracy tests (SAT)
- Temperature uniformity surveys (TUS)
- Reporting
- Quality assurance provision

Compliance with AMS2750 ensures that vacuum furnace operations meet the highest quality standards, particularly in critical industries where precision and reliability are essential.

Conclusion

Vacuum brazing offers unparalleled advantages in producing strong, reliable joints across various industries. As technology continues to evolve, the role of vacuum brazing in achieving precision engineering solutions will only grow. With careful attention to process control and quality assurance, vacuum brazing remains a cornerstone of modern manufacturing, enabling the creation of advanced products for many critical applications.

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BACK TO BASICS #9: WELDING PREHEAT

WHY DO WE NEED IT AND HOW DO WE APPLY IT?

EUR ING Gene Mathers CEng MSc DipIIM FWeldI.

Image: Pipe welding with flexible ceramic preheating elements under insulation. Courtesy of depositphotos.com

Introduction

Welding preheat is rarely a mandatory requirement in national and international specifications. It can be expensive and time consuming so is it necessary? The consequences of *not* applying an adequate preheat when it *is* necessary, however, can be very expensive if not catastrophic.

Applying heat to a joint prior to welding may be used for a variety of reasons e.g. to reduce the risk of lack of fusion defects when welding high thermal conductivity metals such as copper or aluminium or to minimise distortion. This article, however, will focus on preheat when it is applied to carbon and low-alloy steels, the primary reason for which is to reduce the risk of hydrogen-induced cracking (also termed cold cracking) or, to a slightly lesser extent, to control the microstructure. This cracking occurs in the heat affected zone of the weld after welding, frequently delayed by hours or days after the fabrication has cooled.

This article will discuss why we need to preheat ferritic steels, provide sources of guidance on suitable preheat temperatures and on methods of preheating along with its control and monitoring.

The Need for Preheat

To prevent heat affected zone hydrogen cold cracking

So why may it be necessary to apply welding preheat to ferritic steels? Steel undergoes a *phase transformation* – the crystal structure formed by the iron atoms at ambient temperature changing from a *body-centred cubic* (BCC) arrangement to a *face-centred cubic* (FCC) arrangement above approximately 720 °C, reverting to BCC as the temperature falls. This rearrangement of the iron atoms from a BCC configuration to an FCC configuration and the reverse on cooling takes time to occur. There may be insufficient time during cooling from welding temperatures for this change to take place and hard, brittle microstructures, mainly in the heat affected zone (HAZ) can be formed. These hard structures result in an increased risk of hydrogen cold cracking and a reduction in toughness, both obviously undesirable. With many steels these hard structures can be avoided by slowing the cooling rate and this may be achieved by applying a suitable preheat temperature throughout the welding operation.

In short; preheating is intended to avoid the formation of undesirable microstructures, high HAZ hardness and heat affected zone hydrogen cracking.

High alloy steels

Only a very small number of steels may require such rapid cooling rates to harden that preheat is not necessary. The general rule is that, as the carbon and/or alloy content increases, hard brittle microstructures are more easily developed and it becomes necessary to slow the cooling rate by applying an appropriate preheat. So, where do we obtain advice on the circumstances where a suitable preheat temperature is recommended?

There are a number of application standards that contain guidance on preheat temperatures for a range of high alloy steels, such as 2CrMo, 9CrMoV and 12CrMo. These include ASME 1.cl A100.4, ASME VIII Appendix R, AWS D1.1 Table 3.2 and BS2633 Table 5.

Creep resisting and low temperature steels

EN 1011-2 includes Section C.4 which is 'Avoidance of hydrogen cracking for creep- resisting and low temperature steels'. Tables C.5 and C.6 give recommended preheating temperatures for creep resisting steels and low temperature steels respectively. Minimum preheating temperatures can be selected based on steel alloy type, the thickness and the hydrogen scale appropriate to the welding process. A sample from table C.5 is presented below:

Table C.5 — Creep resisting steels — Minimum preheating and interpass temperature

Steel type	Thickness	Minimum preheating and interpass temperature			Maximum interpass temperature
		Scale – D Hydrogen ≤ 5 ml/100 g	Scale – C Hydrogen 5 ≤ 10 ml/100 g	Scale – A Hydrogen > 15 ml/100 g	
	mm	°C	°C	°C	°C
0,3 Mo	≤ 15	20	20	100	250
	> 15 ≤ 30	75	75	100	
	> 30	75	100	Not applicable	
1 Cr 0,5 Mo	≤ 15	20	100	150	300
1,25 Cr 0,5 Mo	> 15	100	150	Not applicable	
0,5 Cr 0,5 Mo 0,25 V	≤ 15	100	150	Not applicable	300
	> 15	100	200	Not applicable	
2,25 Cr 1 Mo	≤ 15	75	150	200	350
	> 15	100	200	Not applicable	

Table 1: Sample information from Table C.5 from BS EN 1011-2

TMCP or quenched and tempered steels

With high strength steels manufactured by the thermo-mechanical controlled processes (TMCP) or quenched and tempered steels such as S/P690, S/P960 etc then advice on suitable preheat temperatures are best obtained from the steel supplier, either directly or via the company's website.

Detailed procedure for determination of suitable preheat temperatures for carbon, carbon-manganese and low alloy steels.

Many methods have been proposed for calculating suitable preheat temperatures and examples of some of these are given in IIW documents IX-1602-90 and IX-1631-91. This article will review the recommendations in EN 1011-2 Arc Welding of Ferritic Steels Annex C Section C.2 only. This Section is titled 'Method A for the avoidance of hydrogen cracking in non-alloyed, fine grained and low alloy steels'. It details the method by which a suitable preheat temperature can be calculated, is based on extensive trials and experience and is focused on carbon, carbon-manganese and low alloy steels with a maximum carbon content of 0.25% and an alloy content of approximately 3% maximum. There is more detail on the validity range of this method for the principle alloying elements in clause C.2.1 of the standard. EN 1011-2 Section C.2 requires four pieces of information to determine the recommended preheat temperature: the carbon equivalent, the welding process heat input, the thicknesses to be joined and the welding process hydrogen content. Once these numbers have been established reference can then be made to a series of graphs from which the temperature can be determined.

The carbon equivalent

The carbon equivalent value CE, is a measure of the *hardenability*, the ability to form hard microstructures, of a steel and is calculated using the IIW formula:-

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

The CE is calculated using the composition percentages for each of the elements above taken from the material test certificate. If a certificate is not available then the maximum carbon equivalent permitted by the material specification should be used.

The welding process heat input

The welding process heat input (Q) is calculated using the formula:-

$$Q = k\,\frac{U \times I}{v} \times 10^{-3}\ kJ/mm$$

where: k is the thermal efficiency
U is the arc voltage in volts
I is the welding current in amps
v is the travel speed in mm/s

The factor "k" reflects the amount of heat lost by the welding process; see Table 2.

Welding Process	Process No	k
Submerged arc welding	12	1.0
Manual metal arc welding	111	0.8
MIG and MAG welding	131 and 135	0.8
MCAW and FCAW welding with gas shield	136 and 137	0.8
TIG and plasma welding	0.6	0.6

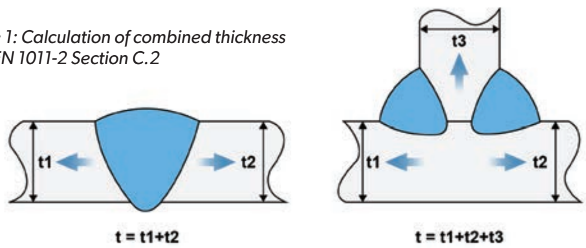
Table 2: Thermal efficiency factor k from EN 1011-1 Table 1

It is advisable to take the lowest heat input value from the welding procedure specification, which will often be the root pass which, in addition to the final capping pass, is the weld run most likely to result in cold cracks. EN 1011-2 Section C.2 also contains tables for heat input during MMA welding, relating electrode diameter and run-out length (ROL) to heat input, obviating the need to calculate heat input. There are four tables listing the heat input for a range of electrode efficiencies (Tables C4.1 – Table C.4.4). Table C3 in the standard gives the heat input for a range of MMA welded single pass fillet weld sizes.

Combined thickness

The combined thickness is a measure of the chilling effect of heat being conducted away from the joint and is determined by the number of conduction paths i.e. the number of pieces of steel combining to form the joint.

Figure 1: Calculation of combined thickness as in EN 1011-2 Section C.2



A butt weld has two paths for heat conduction and a fillet weld has three as shown in Figure 1 so a combined thickness of a butt weld is $t_1 + t_2$, and a fillet weld $t_1+t_2+t_3$. The thicker the components then the greater will be the heat loss, requiring an increase in preheat temperature. An additional inference is that a preheat temperature that is adequate for a butt weld may not be sufficient for a fillet joint – and don't forget that this applies not only to structural welds but also to temporary attachments and tack welds!

The welding process hydrogen content

The final decision concerns the potential hydrogen content of the weld metal (termed diffusible hydrogen content) which is normally expressed as millilitres of hydrogen per 100 grammes of weld metal. (ml/100 g). Table 3 lists the likely hydrogen potential of the common arc welding processes but these should be treated with some caution as contamination of a shield gas or improperly stored and handled consumables may result in higher than expected weld metal hydrogen. Many consumable suppliers provide information of hydrogen content on the consumable packaging or in consumable data sheets. If the hydrogen potential is unclear, the advice of the supplier should be sought.

Process	Hydrogen potential (ml/100 g)
TIG	< 3
MAG	< 5
MMA (basic electrodes)	< 5
MMA (rutile electrodes)	<15
SAW	<15
FCAW (rutile)	<15
ESW	<15

Table 3: Hydrogen potential of arc welding processes

Section C.2 identifies five hydrogen scales, A to E, A being the highest at over 15 ml/100g of hydrogen.

Hydrogen content ml/ 100g of deposited metal	Hydrogen scale
High: >15 ml	A
Medium: 10 ml - 15 ml	B
Low: 5 ml - 10 ml	C
Very low: 3 ml - 5 ml	D
Ultra-low: < 3 ml	E

Table 4 Hydrogen scales (annotated) from EN1011-2 Table C.2

Determining the preheat level

Having established the above four factors it is then possible to turn to one of the thirteen graphs in Annex C from which the recommended preheat temperature can be obtained. Illustrated below are two graphs copied from the annex. All the graphs are of the same format: row 4 is the hydrogen scale, row 5 the carbon equivalent value which ranges over the thirteen graphs from 0.30 to 0.70 CE. The vertical axis is the combined thickness (in mm) and the horizontal axis (labelled 2) is heat input (in kJ/mm). The preheat level (labelled 3) is shown by the fields in the graph. Let us have a look at how this system works. Assuming that we have a carbon steel with a CE of 0.43, a 40 mm thick plate fillet weld giving a combined thickness of 120 mm, an FCAW process using basic wire with guaranteed hydrogen scale C then Figure C.2.c is the appropriate graph. [See the table on the next page which shows the combinations of Carbon Equivalent (labelled 5) and the hydrogen scale (labelled 6) for which this figure is valid]. With a heat input of 1.2 kJ/mm the recommended preheat temperature is 75 °C.

Assuming the same conditions: a CE of 0.43, a combined thickness of 120 mm and a welding heat input of 1.2 kJ/mm *but* a rutile FCAW wire with a hydrogen scale B the appropriate graph is Figure C.2.d. This recommends a preheat temperature of 125 °C, a 50 °C increase, illustrating the importance of the control of weld metal hydrogen if preheat temperatures are to be kept as low as possible.

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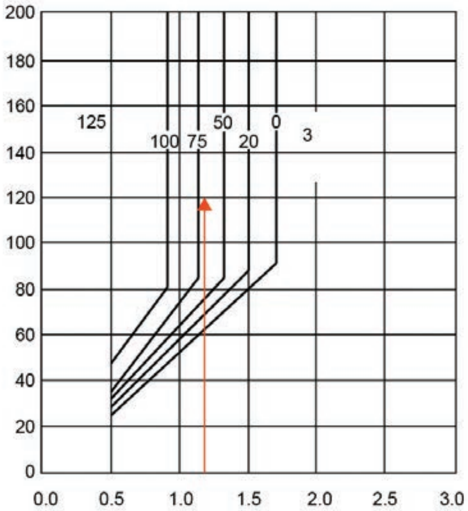
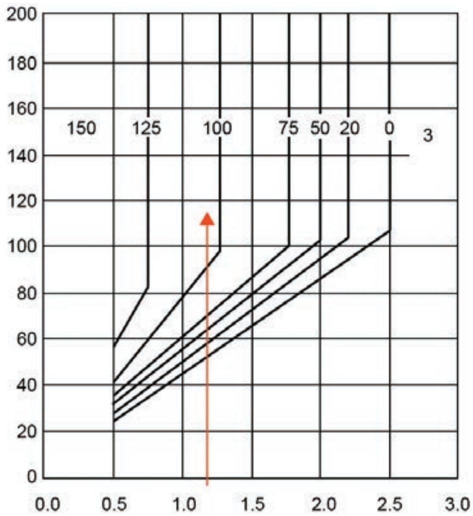


4	A	B	C	D	E
5	0.38	0.41	0.43	0.48	0.50

Figure C.2 c)



4	A	B	C	D	E
5	0.41	0.43	0.45	0.50	0.52

Figure C.2 d)

Figure 2. Extracts from EN 1011-2 Annex C2

Note that the preheat temperature is always taken from the curve to the left of the plotted point and if the production steel value falls between two of the CE figures in line 5 the higher value is taken.

Preheating Methods

The simplest method of applying preheat is with a manually operated oxy-gas torch. It can be used to heat complex or rotating components but, particularly if thick components are to be welded, is time-consuming and achieving and maintaining the correct temperature relies upon the competence of the operator. Monitoring and recording of the preheat temperature can also be a problem. However the equipment is simple, readily portable and self-contained and is widely used. A word of caution – a pepper-pot torch should be used for preheating, never an oxy-gas cutting torch as this can lead to localised overheating.

Radiant ceramic gas heaters, similar to a domestic gas fire and illustrated in Figure 3, are an improvement on manual gas heating. There is no direct flame impingement on the component and, as can be seen in the illustration, automatic monitoring and control can be achieved using thermocouples linked to recording equipment and motorised gas control valves. The equipment is bulky and not readily portable. It is also necessary to have a reliable gas supply and is therefore not truly suitable for site use. This figure, at the top, shows a sliding thermocouple, with lagging removed (for illustrative purposes). This permits live monitoring of the temperature whilst the vessel is being rotated.

Figure 3: Preheating using radiant gas heaters during internal cladding of a pressure vessel

A common method of preheating, capable of being used in both the workshop and on site, is ceramic electrical resistance heating elements, as shown in Figure 4. (These are shown here without insulation for illustrative purposes).The elements can be obtained in various sizes and are flexible, enabling compound shapes to be preheated. Heating rates are faster than those achieved with gas preheating and this has benefits with respect to both productivity and reliability. They may also be used to post weld heat treat the joint on completion of welding. Thermocouples can be used to monitor and control both the preheat and post weld heat treatment temperatures.

Figure 4: Ceramic electrical resistance elements being used for the internal welding of a pressure vessel head

The final method is high frequency induction heating as shown in Figure 5. The equipment is expensive and not readily portable but is gaining popularity because of its ability to rapidly achieve both preheat and post weld heat treatment temperatures.

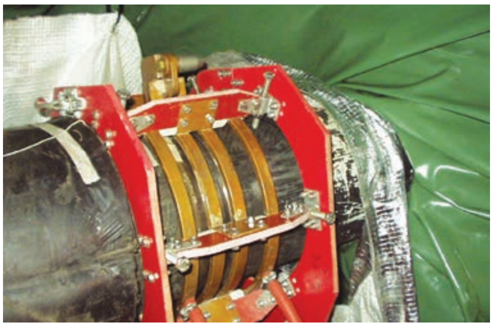


Figure 5: Induction heating clamp

Both sides of a joint should be heated and, if possible, the heat should be applied to the reverse side of the joint so that the heat is conducted through the full thickness of the component. It is recommended that the temperature is measured some 75 mm from the joint and two minutes after the heat source has been removed to ensure that the component is at a relatively stable temperature. BS EN ISO 13916 contains advice on the application and maintenance of preheat and interpass temperatures.

Measurement, Recording and Control

Temperature indicating crayons, commonly referred to as "Tempilstiks™" (a branded product) have been used for many years to determine a component's temperature. Whilst simple to use they are designed to melt at a specific temperature and therefore can only be used to confirm that the preheat temperature has been exceeded. Often two temperature indicating crayons are used during welding with the lower temperature crayon melting to confirm minimum preheat and higher temperature crayon remaining unmelted to confirm maximum interpass temperature has not been exceeded.There are several methods by which the actual temperature can be measured. Contact and optical pyrometers are readily available and relatively inexpensive. Optical pyrometers may give false readings as the condition of the radiating surface can affect the results and it is advisable to calibrate the pyrometer against a representative surface.

Thermocouples are most useful when close control and monitoring of the preheat temperature is required. As mentioned above, they can be used to control motorised gas valves, electrical resistance elements and HF induction coils giving precise control of temperature and to provide a record via chart recorders or a data logger. Thermocouples are generally capacitor discharge welded to the component making it problematic if the item is to be rotated. As shown in Figure 3 it is possible to use sliding thermocouples embedded in a hardened steel carrier – these must be calibrated.

Conclusion

Although preheat is not mandatory it becomes an essential variable once a welding procedure is qualified. However, BS EN ISO 15614-1 permits a reduction in preheat temperature of 50 °C, ASME IX a reduction of 55 °C, but in both cases this reduction from the qualified preheat temperature must be justified by additional testing or, for example, by calculating a lower preheat as described above.

Post heat, which is maintaining or boosting the preheat on completion of welding and holding that for a defined period of time, may be used to reduce the risk of cold cracking in crack sensitive alloys or thick section carbon-manganese steels by allowing any hydrogen to diffuse out of the joint. It may also be helpful if a partially filled joint is to be cooled or to shorten the delay time before carrying out NDE. Typically keeping a weld at between 200 °C and 300 °C for 3 or 4 hours has been found to be effective.

References *(editions stated are those current at time of writing)*

BS EN 1011-2: 2001. Welding. Recommendations for welding of metallic materials – Arc Welding of Ferritic Steel. British Standards Institution.

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BS 2633:1987. Specification for Class 1 arc welding of ferritic steel pipework for carrying fluids. British Standards Institution.

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ASME B31.1 – 2022. Power Piping.

ASME BPVC.IX 2023: BPVC Section IX – Welding, brazing and fusing qualifications.

APPLICATIONS OF SOLID-STATE DIFFUSION BONDING

This article outlines five categories of applications of Solid-State Diffusion Bonding (SSDB).

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Category 1: Bonding alloys and composites which are prone to deterioration and decomposition at high temperatures, e.g. when close to their melting points during fusion welding processes.

Nickel and cobalt based superalloys exhibit outstanding strengths at high temperatures. The exceptionally high creep resistance and toughness of superalloys are attributed to their complex microstructures. Great care is required during casting, forming and heat treatment of them to ensure obtaining and maintaining the required microstructures. For the same reason, fusion welding processes can significantly damage the microstructure of the superalloy at and adjacent to the weld line, resulting in inferior mechanical properties.

Diffusion bonding, with or without an interlayer, can be carried out at temperatures well below the melting point of superalloys and therefore the original microstructure and mechanical properties of the superalloy are maintained. Figure 1 shows that near-perfect joints, free from microstructural segregations and defects, can be achieved by diffusion bonding process.

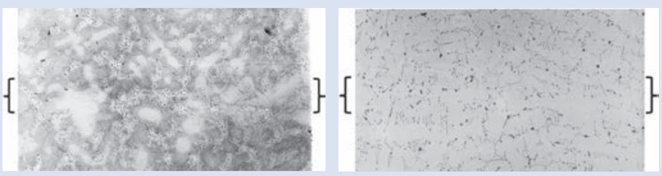

Figure 1: Virtually invisible joints in diffusion bonded nickel superalloy C1023 (left) and cobalt superalloy PWA647 (right). Braces show approximate locations of the joints [Ref. 1]

Diffusion bonding has a large number of applications in the aerospace sector. Example cases are: the fabrication of titanium-based fuel tanks for fighter aircrafts and laminated fan blades for large turbofan jet engines as shown in Figure 2.

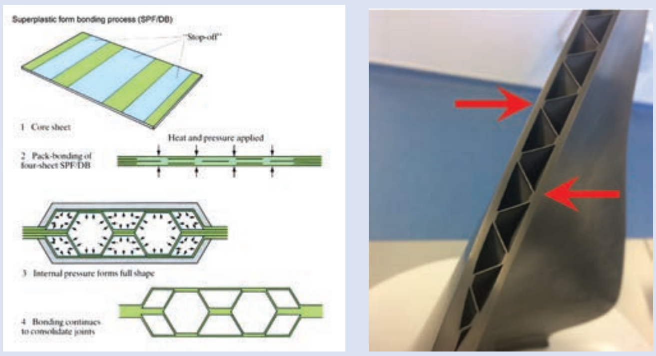

Figure 2: Large fan blades for jet engines are fabricated by diffusion bonding followed by superplastic forming

Category 2: Joining dissimilar alloys with different thermo-physical characteristics, e.g. aluminium to steel which have about 900 °C difference in their melting points.

Joining dissimilar alloys has many applications for fabricating complex bi-material components which allows one component to exploit the benefits of two different materials. For instance, key structural materials used in manufacturing aircrafts are aluminium, titanium, steel and superalloys which are not weldable to each

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other using conventional welding processes. Figure 3 shows examples where diffusion bonding led to successful joining of dissimilar alloys. The example shown are:

i. Top left: creep-test piece, after failure, made of stainless and high temperature resistant steels

ii. Top right: bonded steel-titanium rods which have been subjected to bending and torsion loads

iii. Bottom: steel-aluminium flanges used in ultra-high vacuum X-ray tubes.

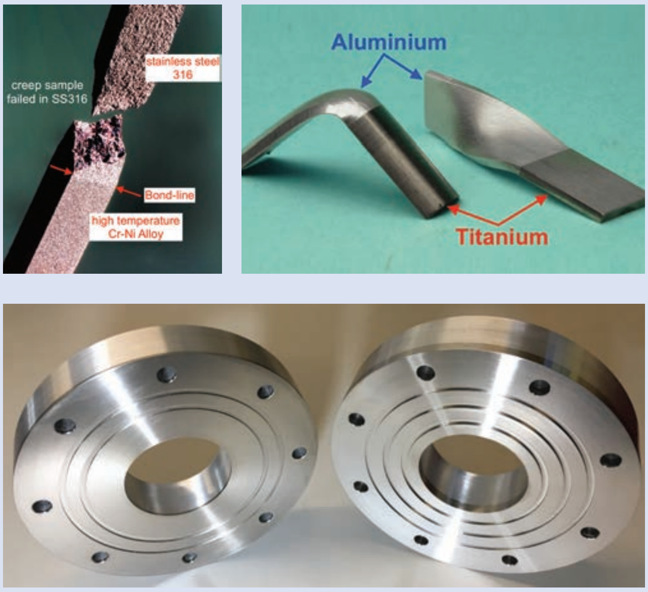

Figure 3: Bi-material components made by diffusion bonding

Category 3: Joining alloys and composites to ceramics, e.g. sapphire to titanium.

There are many engineering applications for joining ceramics and metals using the most common joining method, which is brazing using commercial filler metals. However in certain cases, where a direct joint is required, without a filler metal, then solid state diffusion bonding could be the only option. Figure 4 shows a sapphire diffusion bonded to an aluminium alloy as a part of an optical product. Joining sapphire to titanium and steel is also of interest in manufacturing inspection windows of Tokamak fusion reactors.

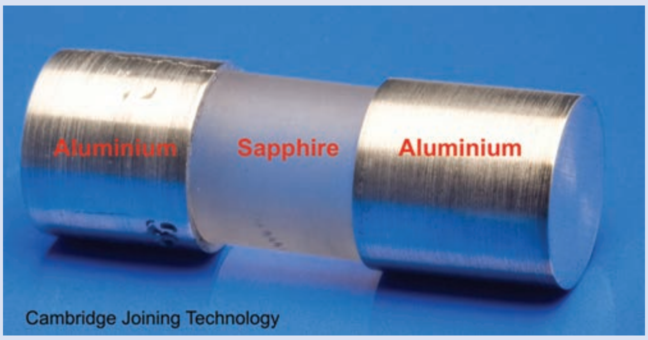

Figure 4: Direct Diffusion bonding sapphire to aluminium without a need for interlayer or brazing filler metal

Category 4: High-precision joining components where the required dimensional tolerances cannot be achieved by post-bonding machining, e.g. microwave filters and duplexers.

Although there are many options for welding structural alloys such as steels and aluminium alloys, extremely close dimensional requirements can be achieved only by solid-state bonding processes. For example, in microwave filters and duplexer used in telecommunications the formation of any fillet at the joint interface would deteriorate the quality of the output signals. Figure 5 shows a high-precision mould, free from any fillet or undercut, made by diffusion bonding stainless steel.

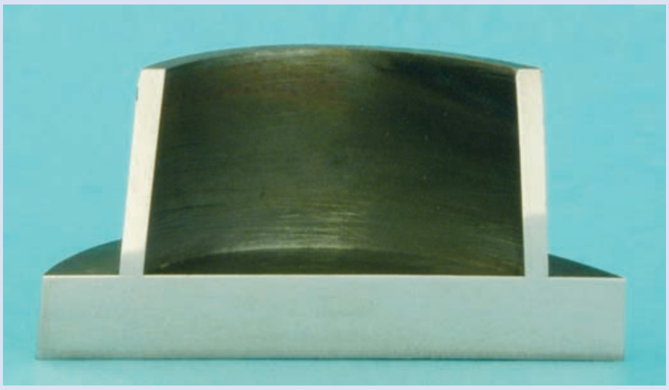

Figure 5: Cross-section of a stainless steel tube, diffusion bonded to a steel plate without the formation of any fillet at the joint

Category 5: Additive Manufacturing (AD) or more precisely Laminated Object Manufacturing (LOM) by diffusion bonding, e.g. Printed Circuit Heat Exchangers (PCHEs).

Perhaps the largest application of diffusion bonding by volume is in manufacturing compact laminated heat exchangers. The chemically etched plates containing channels are stacked in a certain order and diffusion bonded at the same time. This family of heat exchangers, also known as Printed Circuit Heat Exchangers (PCHEs), are considerably smaller and more efficient that conventional "shell & tube" heat exchangers. Figure 6 shows compact heat exchangers, with integrated leak-detection system, made by solid state diffusion bonding of stainless steel without using any interlayer or flux.

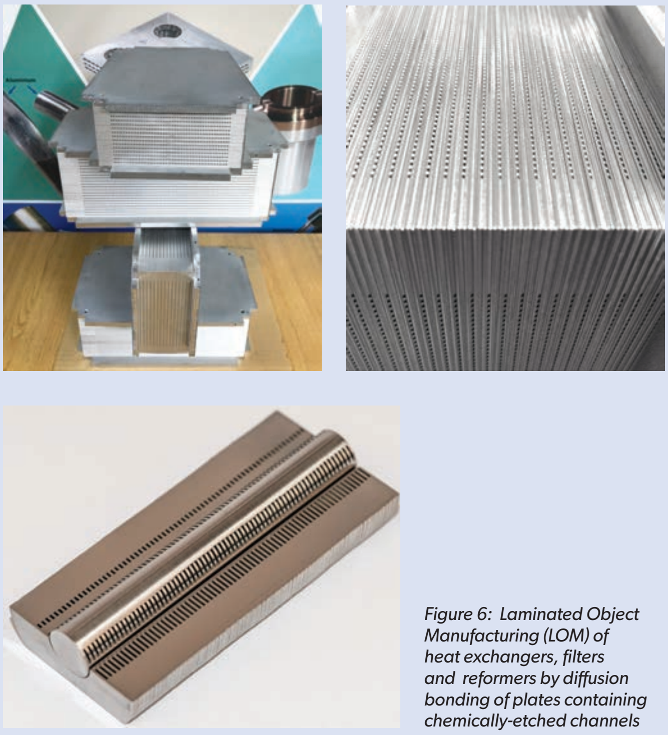

Figure 6: Laminated Object Manufacturing (LOM) of heat exchangers, filters and reformers by diffusion bonding of plates containing chemically-etched channels

Reference:

[1] Shirzadi A.A. and Wallach E.R., New method to diffusion bond superalloys, Science and Technology of Welding and Joining, 2004, Vol. 9, No. 1, pp 37-40. (80%) - https://doi.org/10.1179/136217104225017125

AN INTRODUCTION TO VACUUM BRAZING OF ALUMINIUM

Robin Andrews. Director, Davis Scientific Treatments Ltd.

Aluminium heat exchangers

The vehicle market is forecast to become the largest market for use of aluminium and its alloys. Specific transport applications include electric vehicle battery housings, replacing more expensive and heavier copper. Uses of aluminium alloy heat exchangers involve air conditioners, HVAC and refrigeration equipment, and the alloys feature widely in the aerospace industry.

Heat exchangers are devices in which the heat generated by a device is transferred away to a fluid medium, such as air or a liquid coolant. This dissipates the heat in order to maintain device performance.

Both aluminium and copper are very good conductors of heat. However, aluminium has light weight, corrosion resistance, and low cost: these factors make it an increasingly desirable material for heat transfer applications and it is readily shaped into foil, sheets or fins.

Brazing of aluminium alloys

Brazing is a metal joining technique frequently applied to aluminium components, where a metal alloy filler is used for bonding which is heated above its melting temperature, but below the melting point of the metals being joined.

The liquid filler alloy, at the soak temperature, is drawn into the gap between the closely fitting surfaces at the joint interface by capillary action. It is important to achieve surface "wetting" and effective capillary action and this is dependent on the quality and cleanliness of the joint mating surfaces. Furthermore, it is essential to minimise joint clearance.

Brazing, when performed correctly, produces excellent joints, especially when fixing thin-walled, compact assemblies. However, aluminium and its alloys require extremely careful control, especially since the brazing temperature is very close to the melting point of aluminium. Many of the problems associated with aluminium brazing are related to the complexity of the temperature rise and cooling profile. Manufacturers do not want premature melting of the brazing alloy, or localised areas of heat, creating hot spots. Heating has to be made evenly across the base metals.

If the brazing process is not done correctly the high brazing temperature, relative to the melting point of the base aluminium alloy significantly lowers its strength. The potential softening effects must be considered when alloy and filler material are chosen.

Another difficulty occurs when brazing aluminium to other metals. Owing to differences in thermal expansion rates stresses are set up in the area of the joint during heating and subsequent cooling.

Aluminium readily forms a tough oxide film during brazing and means must be found to minimise the presence of oxygen atoms during the process. Brazing in a high vacuum furnace is hence desirable.

Vacuum brazing of aluminium

DST has carried out extensive R & D work in aluminium brazing over many years, using vacuum furnaces. This eliminates most of the risk of oxidation and contamination which otherwise is a risk when the braze filler melts and flows into the gap between mating parts. Vacuum brazing is a high-quality jointing technology which results in assemblies with extremely strong joints.

Successful vacuum brazing requires a short process cycle; that is a fast pumping and heating furnace cycle. Temperature uniformity throughout the furnace chamber must be obtained at soak temperatures.

Good vacuum furnace design and manufacture is critical to successful aluminium brazing. With such furnaces, the vacuum brazing operation is highly repeatable, which is necessary for volume production and DST's experience has led us to designing and building our own bespoke furnaces.

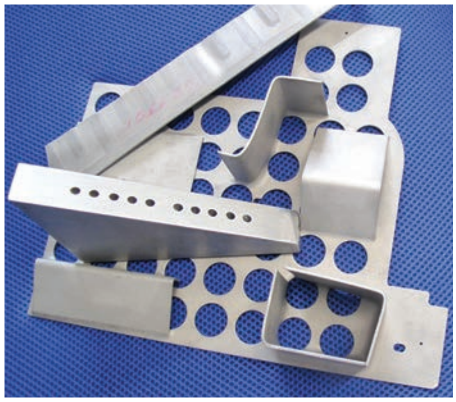

Figure 1: Aluminium alloy components joined by vacuum brazing

Setting up a vacuum brazing procedure

Below are listed the technical considerations for each brazing operation.

- The design and manufacture of a high performance vacuum furnace.
- The types of aluminium alloy and other metals being brazed.
- The methods to be used to obtain sufficient cleanliness of parts.
- The appropriate types of braze filler materials.
- The potential use of "cladding" on aluminium sheets.
- The choice of filler paste or foil for brazing.
- The design and manufacture of 'fixturing.' This is necessary to present parts into a stable sub-assembly, with close joint separation, ready for brazing. It will also determine if one obtains a successful temperature profile in the furnace.
- The parameters for the heating temperature rise.
- The settling profile at braze soak temperature.
- The dwell time at soak temperature.
- The parameters for the cooling temperature fall.
- The use of oxygen reduction methods, e.g. magnesium pellets, their type and amount.
- The need for and parameters for annealing after the brazing operation
- The process and requirements for inspection of final joint, to assess integrity, strength and uniformity.
- The sectioning of joint, and hardness testing.

Developing the complete procedure for each brazing trial is an empirical and experimental process. Systematic analysis of the process parameters and judgement of success or failure leads to the establishment of reliable parameters for production.

Research and Development work at DST

DST's aim is to overcome difficulties in making strong joints between aluminium alloy components, (and other metals) by using a specially constructed high vacuum furnace. However there are many aspects to the aluminium brazing process and DST's experience is that successful parameters can only be determined by continuous development.

HYBRID ELECTRO-SLAG CLADDING

A MAJOR IMPROVEMENT IN PRODUCTIVITY

Pallav Chattopadhyay, Lincoln Electric EMEA and Gene Mathers, Consultant.

Introduction

For many years there has been a requirement in the oil and gas industry for vessels clad with Ni-625 to achieve a cladding chemistry with a maximum iron content of 5% at the clad surface. This has been accomplished in the past by using a two-layer submerged arc strip cladding process (SAW), although single layer electro-slag cladding (ESC) has been able to deposit Ni-625 with an iron content as low as 6%. The hybrid ESC process (H-ESC) developed by Lincoln Electric has enabled less than 5% iron to be reliably achieved at a travel speed some 50% greater than that of conventional electro-slag cladding. This has been made possible by using a 60 mm x 0.5 mm thick strip, a neutral flux and the addition of metal cored (MCW) hot wires. Addition of the hot MCWs to the molten weld pool is regulated by a digital control system to limit the dilution level and achieve clean cladding chemistry, coupled with at least a 50% higher welding speed and nearly double the weld deposition rate (up to 42 kg/hr for 60 x 0.5 mm strip and two 1.6 mm diameter wires) compared to the standard ESC technique. Similarly, H-ESC offers a unique solution in case of high-speed single layer austenitic stainless steel (SS) cladding wherein only one single 308L composition strip is used along with neutral flux. The desired deposited chemistry is easily achieved for typical austenitic SS grades 308L, 316L, 347 & 317L by using a suitable MCW chemical composition. Such a solution would help fabricators to achieve the desired weld chemistry with a high speed single layer cladding technique.

Conventional strip cladding processes:

The two conventional strip cladding processes – submerged arc (SAW) and electro-slag (ESW) strip cladding are compared below.

SAW strip cladding

SAW strip cladding (Figure 1) utilises an arc that runs back and forth at high speed along the strip, depositing weld metal onto the base material. Because this is an arc welding process, there will be a relatively deep penetration into the base material resulting in high dilution levels of ~ 20%. Deposition rates are in the region of 12-14 kg/hr for 60 x 0.5 mm strip but is restricted by the amount of current that can be applied without increasing dilution. Care must also be applied to the overlap area as any residual slag will not be re-melted and will result in slag entrapment and lack of fusion. For a similar reason, often it is not recommended for lane closures of rolled clad plate in the area where the roll cladding meets the base material.

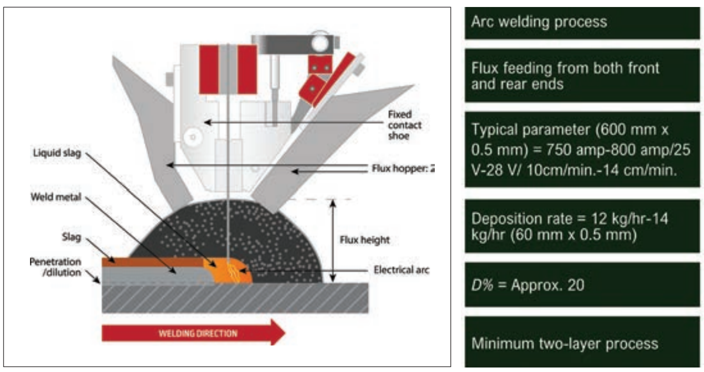

Figure 1: Schematic of conventional submerged arc (SAW) strip cladding process

Since dilution is high in SAW strip cladding, it is necessary to apply a buffer or barrier layer using strips of richer chemistry before applying the second or subsequent layer(s) of the final required chemistry.

Electro-slag strip cladding (ESW)

The conventional ESW technique (Figure 2) utilises a conductive flux and is an arc-less resistance welding process. The process initiates with a short-lived arc forming between the continuously fed strip and the base metal, The flux is conductive due to the presence of special constituents which support the passage of a current at lower voltages and the arc is extinguished. The heat, which is required to melt the strip and continue the process, is generated by the resistance to the flow of current through the conductive flux. Since a concentrated arc is absent in this process, there is less penetration into the base material. As a result, the process is characterised by a low dilution level of 6 - 12%. The ESW process thus has significant advantages over SAW cladding being capable of providing an acceptable cladding composition in a single layer, halving both the welding duration and consumable consumption compared with the two layer SAW method.

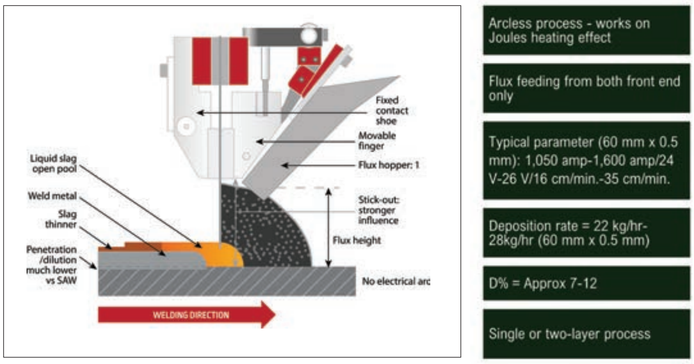

Figure 2: Schematic of conventional electro-slag (ESW) strip cladding process

The differences between these two processes are summarised in Table 1

	SAW strip cladding	ESW strip cladding
Flux feeding	Both front and rear side	Only front side
Heat source	Arc energy	Joule's resistance heating: $H=I^2R$
Flux consumption	High (typical 1:1)	Low (typical 1:0.6)
Dilution, %	18-20	7-12
Welding speed, cm/min.	10-14	15-18 (normal)/24-35 (high)
Deposition rate, kg/hr 60 mm x 0.5 mm	12-14	22-30
Weld metal quality	Higher oxygen content in weld metal	Cleaner chemistry with lower oxygen content
Number of layers to reach clean undiluted chemistry	Minimum two layers	Single or two layers

Table 1: Comparison between SAW & ESW Cladding processes

Productivity comparison of SAW and ESW

While most of the existing arc welding processes can be utilized to deposit layers of cladding, strip cladding with the submerged arc or the electro-slag welding processes are the most attractive choices for applications requiring large surface area coverage due to substantially higher deposition rates and more importantly, higher surface area coverage rates than the conventional arc welding processes. Figure 3 shows a comparison of deposition rates for most of the commonly used weld cladding processes.

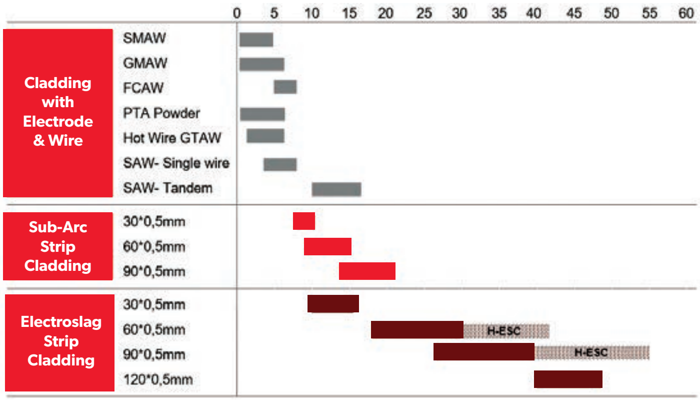

Figure 3: Comparison of Deposition Rate for different Welding processes (kg/hr)

It is clear from Figure 3 that ESW is the most productive welding process for cladding applications and therefore is the most efficient and productive process.

Dilution

Since corrosion resistant cladding material (e.g. Ni alloys or stainless steel) rely for their corrosion resistant properties on a closely controlled chemical composition there is always the issue of dilution of the cladding from a ferritic base material that needs to be considered as another important factor in selecting the optimum cladding process.

Dilution is normally calculated using the formula given in Figure 4 below:-

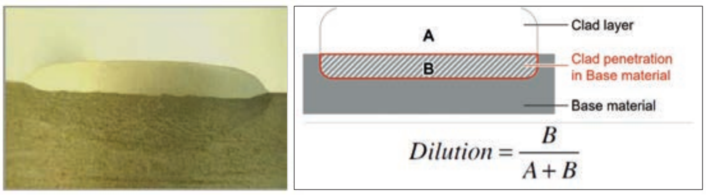

Figure 4: Dilution

It is clear from the formula that reducing the dilution makes it easier to achieve the desired weld deposit chemistry. With a very low dilution process it is possible to achieve the required deposit chemistry in a single layer. Table 2 provides a comparison of typical dilution rates for different welding processes:

Welding Process	Typical Dilution %
Shielded Metal Arc Welding (SMAW)	25-30
Flux Cored Arc Welding (FCAW)	20-25
Submerged Arc Welding (SAW) - Wire	25-35
Submerged Arc Welding (SAW) – Strip : 60*0.5mm	18-20
Electro-slag Welding (ESW) – Strip : 60*0.5mm	7-12

Table 2: Comparison of dilution % for different welding processes

As can be seen from Table 2 ESW is the most attractive cladding process from a dilution point of view and is therefore the most widely applied for cladding work in oil & gas industry applications.

Hybrid electro-slag strip cladding (H-ESC):

Hybrid ESW strip cladding is a new variant of the conventional ESW cladding process developed and introduced into the market in 2015 by Lincoln Electric. In addition to the strip and flux as used in the conventional ESW cladding processes, hot metal-cored welding wires (H-MCW) are added to the molten pool as the third constituent in this technique. Only neutral non-alloy containing flux is used. Whilst the majority of the early development work was carried out using 60 mm wide strip a fabricator has successfully hybrid ESW clad a hydro-processor vessel using 90 mm wide strip.

The addition of multiple H-MCWs to the molten pool absorbs the excess energy from that required to establish the weld pool thereby controlling dilution with the base material. Over-alloyed MCW wires can also compensate for the loss of alloying elements. As a result, this technique is able to achieve the desired deposit composition in a single layer with dilution levels below 5% Fe in a Ni-alloy 625 deposit.

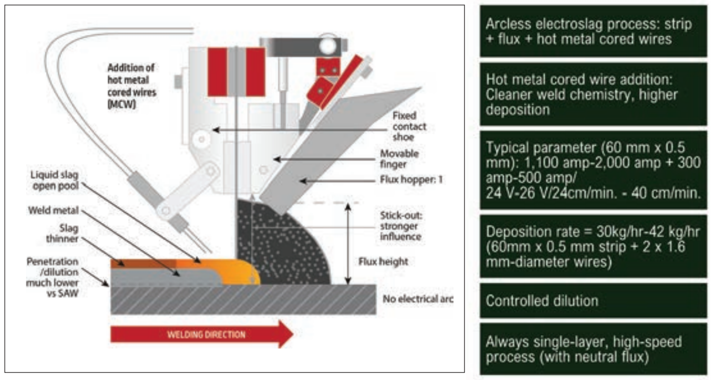

Figure 5: H-ESC strip cladding technique

Melting of strips and multiple H-MCWs make this technique more productive compared to both conventional and high speed ESW cladding with a 50 to 90% higher deposition rate.

The higher deposition rate, coupled with use of high speed neutral flux , also enables the process to increase the cladding travel speed by 50-100% compared with conventional ESW cladding.

The addition of H-MCWs allows one standard 308L composition stainless steel strip to be used with the other alloying elements (e.g. Nb to achieve 347, and Mo for 316L deposits) coming from the alloyed wire. Similar results have been obtained with nickel based alloy strips.

A specially designed, advanced digital welding controller cum data logger developed by Lincoln Electric plays a very important role by controlling and monitoring critical welding parameters.

Productivity comparison - cladding by SAW or ESW processes and H-ESW

A contract completed by one of the authors, shown in Table 3.1 below, highlights the potential cost savings achievable using the conventional ESC single layer process compared with two-layer submerged arc strip cladding. The data in the table details the results from ESW cladding with 60 mm wide strip of three Ni alloy 625 clad vessels intended for offshore use. The maximum allowable iron content of the cladding was specified in the contract as 12%. This was readily achieved in a single, 4.5 mm thick layer, actual dilution being in the region of 7%. Cladding parameters were a current of 1050 amps and a travel speed of 160 mm/min. (The H-ESW technique could fulfil a requirement of max 5% Fe in a single layer).

The cladding consumable weights for two layer submerged arc strip cladding are approximate. They are calculated from the combined surface areas of the vessel strakes and hemispherical heads, clad with 60 mm wide strip. The time savings given for Vessel A are based on standard SAW cladding parameters of 650 amps, a travel speed of 120 mm/min and the calculated surface area.

Vessel Identification	Diameter (metres)	Overall Length (metres)	Cladding Process (tonnes approx.)	
			ESW	SAW strip
A	3.5	11	6.15	~12
B	3.0	10	4.2	~8
C	3.0	13	5.5	~10
		Total (tonnes)	15.85	~30
		Weight saving	~14	
Approximate cladding times vessel"A"	ESW 95 hrs		Calculated time saving on cladding vessel and heads only ~500hrs	
	SAW 2 layers 604 hrs		Consumable cost savings - 3 vessels - approx. 14 tonnes Ni625 @ £45/kilo - £630,000	

Table 3.1: Illustration of the benefits of electro-slag vs submerged arc cladding. The SAW cladding data are estimates only

continues on page 26

The data in Table 3.1 for the vessels illustrates the substantial reduction in cladding material, and for vessel A the associated time and cost savings that can be achieved by moving from SAW cladding to conventional ESW cladding.

The implementation of high speed or hybrid ESW cladding, as given in Table 3.2 and Table 3.3, will result in additional major gains in productivity and reduction in costs.

	Cladding:	SS 308L	Approx. Surface Area 3940 mm²						
Process			ESW 1 Layer – Normal Speed	ESW 1 Layer – High Speed	H-ESC	Savings vs Normal Speed		Savings vs High Speed	
	Layer thickness	[mm]	4.5	4.5	3.5	1	22%	1	22%
	Welding speed	[cm/min]	18	33	35	17	94%	2	6%
Consumable	Weldmetal	Total kg	140,067	140,067	108,941	31,126	22%	31,126	22%
Time	Welding time	[min/m²]	95.8	52.2	49.3	46.5	49%	2.99	6%
		Total [Hour]	6,290	3,431	3,235	3,055	49%	196	6%

Table 3.2: Comparison of ESW at normal speed, ESW at higher speed and H-ESC

Table 3.2 shows a comparison of the processes: ESW at normal speed, ESW at higher speed and H-ESC for cladding vessels with 308L weld metal. It shows the savings of H-ESC measured in welding time and weight of weld metal relative to the two ESW levels.

	Cladding:	Ni 625	Approx. Surface Area – 2 Vessels 894 m²			
Process			ESW 2 Layers – Conv. High Speed	H-ESC	Savings vs Conv. High Speed	
	Layer thickness	[mm]	7	5	2	29%
	Welding speed	[cm/min]	27	27		
Consumable	Weld metal	Total kg	55,682	39,773	15,909	29%
Labour	Welding time	[min/m²]	127.7	63.9		
		Total [Hour]	1,902	951	**951**	**50%**

Table 3.3: Comparison of H-ESC relative to conventional ESW

Table 3.3 shows a comparison of H-ESC relative to conventional ESW at high speed in terms of consumable consumption and welding time for cladding using Ni 625 cladding weld metal. Cladding in a single layer is a very common practice due to the relatively lower dilution level and is achieved either by using over-alloyed strip or a combination of over-alloyed strip coupled with alloyed flux.

Summary of findings

Extensive tests have been carried out using the H-ESC process for different nickel and austenitic stainless steel cladding alloys to conclude the following:

a) The cladding metal is fully homogeneous in chemistry across the deposited strip width and through the cladding thickness since there is only a single, well agitated molten pool.

b) It has been confirmed by extensive ultrasonic examination that there is no lack of bond between the cladding and the base material as well as between the clad beads.

c) 180° side bend tests as per ASME Section IX requirements in both the as-welded and PWHT'd condition have not exhibited any lack-of-fusion between the cladding and the base material, between overlapping runs or at stop/start positions. Through-thickness fissuring was also absent.

d) The cladding is fully corrosion resistant in accordance with ASTM G28A for Ni alloys and ASTM A 262 Practice E for austenitic stainless steel in the as-welded and PWHT'd condition.

e) Austenitic stainless steel cladding delta ferrite contents of between 5FN and 8FN are readily achievable. (FN = ferrite number).

f) Hardness values in weld metal and HAZ of C/Mn and 2CrMo base materials are well within specification acceptance limits.

Conclusions

The H-ESC technique has the following benefits over other cladding techniques:

a) It provides greater flexibility in chemistry and delta ferrite control by means of easy adjustment of the metal cored wire composition without any need to change the strip composition.

b) A single layer cladding solution is always available. This not only saves overall weld metal cost and cladding time, it also eliminates all associated NDE cost and time required for the inspection of the additional layers.

c) It operates at much higher relative welding speed. For example typical welding speeds are 27-32 cm/min for Ni alloys and a minimum 35 cm/min for austenitic stainless steels as compared to 16-18 cm/min in normal-speed conventional ESW cladding. The higher speed not only helps fabricators to reduce their labour costs, it shortens the floor-to-floor time, allowing the cladding of more components, substantially increasing productivity.

d) It operates at a significantly higher deposition rate, typically 38-44 kg/hr as compared to 22-24 kg /hr in normal speed conventional ESW cladding for 60 x 0.5 mm strip size.

e) The working capital cost for fabricators is reduced due to a shorter delivery time for one standard austenitic stainless steel strip and flux clad vessel.

The H-ESC technique introduces multiple hot metal cored wires in the molten electro-slag weld pool. As a result, this hybrid ESC process offers the ability to control dilution while increasing both the welding speed and the deposition rate.

H-ESC makes it possible to reach stringent undiluted cladding chemistry in a single layer for all of the commonly used Ni and stainless steel alloys. it is possible to reach <5% Fe in a single layer Ni-625 alloy deposit with a cladding travel speed of 27cm/min or reaching a minimum 40% Ni content in Ni-825 alloy in a single layer 4 mm thick deposit with a welding speed of 32 cm/min.

H-ESC makes it possible to purchase one single composition strip (e.g. 308L), alloyed wires and a neutral flux to deposit all of the common austenitic stainless steels such as SS308L / 316L / 347 and 317L in a single layer with a welding speed above 33 cm/min.

About the Authors

Gene Mathers has over 50 years of experience in the fossil fired and nuclear power generation industries. He is currently working as a welding engineering consultant having worked for a number of engineering companies and latterly as Principal Consultant with TWI Ltd.

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RESISTANCE SPOT WELDING IN AUTOMOTIVE REPAIR

A discussion between Welding and Joining Matters (WJM) and Neil Pulsford, Managing Director of GYS in the UK.

Introduction

WJM wanted to look into resistance welding in automotive repair so we caught up with GYS who are the largest manufacturer of Spot Welders in Europe for body repair.

Figure 1: GYSPOT Pti Genius motorised boom in action

GYS: Working closely with car makers and repairers places us in a unique position and this drives the development of the repair equipment. We see the requirements from the car maker, from new construction methods and steels used and the need to develop solutions. It is our challenge and to some degree our responsibility to use the technology and our knowledge to provide products that increase safety, and efficiency. Safety can be by providing some automation to reduce the chance of error, and efficiency by reducing time needed, and reducing maintenance by designing in better reliability. These come together as the car maker will often ask us to test repair processes to ensure that a new vehicle can be repaired by the equipment in use.

WJM: What are the current technology drivers for you?

GYS: The requirements for resistance welding in automotive repair move in parallel with vehicle body evolution. There are two overriding factors that drive this development, first safety, and second impact on the environment.

Safety is addressed by complex structural design and the adoption of a variety of steels to address the different behavioural requirements of the car body structure in an accident. Environmental considerations of CO_2 emissions and fuel consumption drive the need for weight reduction. This quest is then addressed through selection of materials to construct the car body. Hence we now see high strength steels/boron steels in use for direct occupant protection and softer steels on the periphery of vehicles for energy absorption.

Figure 2 summarises the change of steel and materials used over the last 20 years.

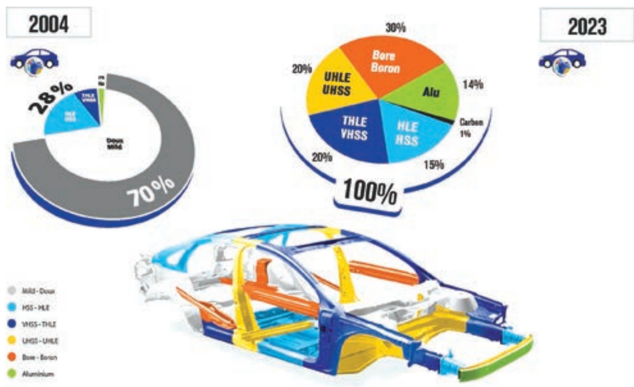

Figure 2: The change in car body materials from 2004 (70% mild steel) to 2023 (a wide range of steels and other materials)

WJM: How has the equipment used in repair developed to meet these challenges.

GYS: Let's have a look at the latest spot welding equipment in use in automotive repair in body shops today (Figure 3). The equipment must have the functionality to deliver the correct weld result with efficiency, to enable the technician to carry this out safely and in a time-efficient manner. The requirements for this equipment are complex, covering electronic, mechanical and data functionality.

WJM: What are the functional requirements and parameters for the equipment?

GYS: When performing a spot weld, there are three process parameters to achieve the optimum strength of the weld: welding current, clamping force and time.

Figure 3 (right): The latest generation spot welder, the 'GYSPOT Pti Genius'

Welding Current

Spot welding requires currents significantly higher than other types of welding, the process using the heat created by the resistance of the steel when a current is passed through it to fuse two or more pieces of steel together. The current required to create the optimum spot weld depends on the number of sheets to be joined, the thickness of the sheets, and the type of steel to be welded but, typically required currents are in the range of 7,000-13,000 A.

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Clamping Force

Correct clamping force is necessary to allow the current to flow through the multiple sheets to be joined; too little force and the current will not pass without arcing, too much force and the sheet could be deformed.
In body repair work forces of up to 550 daN are used to clamp steel together and this clamping force is exerted by the electrodes through which the current will pass. This force is achieved by using an adjustable hydro-pneumatic ram.

Time

The current used to create the weld must be applied for a precise amount of time to produce the correct weld measured in milliseconds with typical times being in the range of 300-500 ms. If the current used is too high or applied for a fraction of a second too long the repair will not be to specification and would be potentially unsafe.

WJM: How do you choose the correct parameters?

GYS: Here we start to see how technological development in the design of the equipment is advancing the quality and functionality of the repair.

In the past a technician would be expected to program the spot welder with each of the parameters (current, force and time) based on a simple table created for different thicknesses of steel.

Modern cars have added complexity as they use many different types of steel. Often two or more different types must be joined, meaning the responsibility could lie with the technician to analyse all of the sheets before setting the correct parameters, and the chance of error leading to a sub-optimal repair is very present.

The solution lies in software; modern spot welders have been designed to weld modern materials. The latest technology spot welders are equipped with software which offers an AUTOMATIC mode to determine the correct parameters with no input required by the operator.

Many spot welders also have a semi-automatic or synergic mode, this means that the technician can enter a small amount of information (material thickness and material type) for the welder to determine the correct parameters.

WJM: Is there any quality record of the joints performed?

GYS: Each spot weld performed (whether in automatic or manual mode) can be recorded and saved digitally against a job reference number. The spot welder records the actual parameters achieved during the weld and a repairer can prove that the spot welds performed were at the correct parameters and completed successfully. This data can be stored on mobile devices such as SD Cards or USB Drives, with the latest machines now transferring the data via a Wi-Fi connection.

WJM: What are the notable features of modern equipment?

GYS: Current capacity, max pressure applied and ergonomic factors are important and these are illustrated by the features of a modern piece of equipment in Table 1.

Features / Performance	GYS PTi Genius
Max Current A	14500
Max daN	550
Power cable length	8 metres
Gun cable length	6 metres
Maximum C arm depth	1,000 mm
Gun weight	11.3 kg (G1 arm inc.)
Number of Arms Available	11
Traceability Data Transfer	WiFi / SD Card

Table 1: Specification data for GYS PTIG machine

Cooling

The high power used for resistance spot welding creates a lot of heat. The electrodes get very hot very quickly, so if multiple welds are performed in quick succession a very efficient cooling system is required. A low conductivity liquid coolant is pumped to the tips of the electrodes and alongside all cables to maintain a safe temperature throughout the welding process. The spot welder will typically house a 30 litre capacity coolant tank with an electric pump to circulate the coolant.

Use of inverters, replacing transformers

Traditionally spot welders were manufactured with a transformer, but since around 2004 these have been replaced with inverter technology to meet higher power requirements and much more efficient use of power.

Inverter spot welders can be designed in two clear configurations, relating to the location of the inverter:

Inverter located in welder body: When the inverter is located within the body of the spot welder, the extremely high welding currently must be carried along the cables to the electrodes mounted in the gun. The benefit is that the gun is much lighter, (typically around 6 kg). The drawbacks are that the cable length is limited, (maximum 2.5 m) and they are much thicker and heavier (so more difficult to handle). Also, special technology is required to minimise the magnetic field created.

Inverter located in the gun: When the inverter is located in the gun, a lower current is carried along the cables, meaning less heat created, and there are less power losses. The benefits are that the cable length can be much longer (up to 6 m) and they are thinner and lighter, and there are no concerns around magnetic fields. The drawback is that the gun is heavier, (around 11 kg) offset by the reduction in cable weight.

WJM: How do you address the challenge of getting access for the welding head to the right location?

GYS: The location of spot welds on the body of a vehicle presents many challenges, meaning that equipment manufacturers have to be increasingly innovative to overcome the problem.

Arms of different shapes and sizes have been designed to allow technicians to access even the most difficult to reach welds. Access depth of up to 1 meter is now possible, meaning even floor pans in commercial vehicles can be replaced. Recessed flanges are no longer an issue due to the availability of a gun attachment which configures a C-Gun to an X-Gun (Figures 4 and 5).

Figure 4: A C-Gun configuration

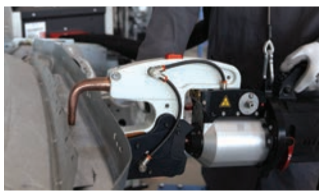


Figure 5: An X-Gun configuration

Access is also an issue where there is a small space between the electrodes, even when fully open – around 20mm. The answer to this problem is twofold:

• A retractable electrode offering up to 80mm between electrodes, resolves most issues. (Figure 6)

• Where even more access is required, the arm can be hinged to offer maximum space. (Figure 7)

Figure 6: Gun with a retractable electrode

Figure 7: Gun with hinged arm electrode

Changeable arms – design improvement

It is necessary to exchange the C-arm depending on where the weld is positioned on the vehicle, meaning that the huge current used to create a spot weld must pass through a detachable joint.

This joint used is a mechanical joint between two aluminium components, the end of the C-arm joining to a base plate mounted on the C-gun. This is a wearable joint with a manual locking adjustment requiring ongoing maintenance. Historically this has been a maintenance and reliability weak point. The conductivity can be improved using a copper lubricant to ensure better transfer of current, also the pipes carrying coolant to the electrode tips must also be manually detached and re-attached each time an arm is changed.

The latest technology spot welders have solved this weakness through the introduction of an innovative arm joint, consisting of two mated brass contact plates (Figure 8). These plates form part of a maintenance-free locking mechanism which eradicates the need for adjustment and also the coolant pipes are integrated into the new connection, meaning that the technician must simply maintain a clean connection area to achieve perfect current conduction every time.

As the welds on vehicles can be in many positions, it necessary to use the C-gun in many different positions too. The C-gun can be supplied with a gyro to allow 360 degree rotation, meaning welds can be completed at any angle.

Figure 8: Innovative arm joint

Overhead arm assembly

Spot welder C-guns generally weigh between 6 kg to 12 kg, meaning prolonged use can cause fatigue for the technician. Manufacturers have developed many designs to support the weight of the C-gun while in use, usually consisting of an overhead arm and a cable reel with sprung tension.

The latest designs now incorporate an electronically controlled and hinged overhead arm, allowing the best possible experience for the technician – weightless use of the C-gun in almost any position.

Spot Counter software

For consistent and safe welding performance, it is important for the contact tips to stay in good condition. The software on the latest spot welders includes a counting function, which displays a notification to the technician when a certain number of welds have been made (typically 50 – 200), to clean or replace the tips.

MEMBERSHIP UPDATE

NEW QUALIFICATIONS AWARDED
15 MARCH TO 14 JUNE 2024

Name	Member Grade	EngC Registration
The following members have been awarded FWeldI		
DORÉ, Matthew	FWeldI	CEng
The following members have been awarded MWeldI and/or the Engineering Council registration as indicated		
BAILEY, Jacob	MWeldI	CEng
HERRON, Stephen	MWeldI	CEng
KHAN, Saad	MWeldI	CEng
LAVIS, Carl	MWeldI	CEng
MCBRIDE, Stephen	MWeldI	CEng
PATIL, Siddharth	MWeldI	CEng
RUMAHORBO, Dormauly	MWeldI	CEng
SAKTHIVEL, Karthik	MWeldI	CEng
GUHJAHR, Jhonattan	MWeldI	CEng
HOYOS PULGARIN, Elizabeth	MWeldI	CEng
PANCESCU, Costel	MWeldI	IEng
OBIOHA, Charles	MWeldI	IEng
OWUSU ASAMOAH, Kwadwo	MWeldI	IEng
DREW, Thomas	MWeldI	EngTech
KASRAVI, Navid	MWeldI	
RAFIEEYE, Ali	MWeldI	

The following members have been awarded TechWeldI and/or the Engineering Council registration as indicated		
ABBOT, Rachel	TechWeldI	EngTech
DOWN, Ryan	TechWeldI	EngTech
FAIRS, Richard	TechWeldI	EngTech
SIMMONDS, Neil	TechWeldI	EngTech
SMITH, Barry	TechWeldI	EngTech
STRANDT, Rhys	TechWeldI	EngTech
THORNE, Ian	TechWeldI	EngTech
WELLS, Matthew	TechWeldI	EngTech
O'HANLON, Paul	TechWeldI	EngTech
SOBRAL, Antonio	TechWeldI	EngTech
AYERS, Jacob	TechWeldI	
JANARDHANAN PILLAI, Mahadev	TechWeldI	
MORGAN, Alex	TechWeldI	
ROEST, Marcelino Clemens	TechWeldI	
WARD, Warren	TechWeldI	
WARDROP, Craig	TechWeldI	
The following members have been awarded Associate with Interim Engineering Council registration		
HOLLIDGE, Sam	AWeldI	IEng-I
We send our congratulations to all the members listed above		

DECEASED MEMBERS

Name	Member Grade	EngC Registration
Graham Hutt	SenMWeldI CEng	1983
John Bailey	AWeldI	1978
John Smith	MWeldI	1993
Michael Fuller	FWeldI	1968
Roy Biddulph	FWeldI	1970

It is with great sadness we mark the deaths of these members:

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.

GUEST EDITORS - NICK LUDFORD AND PAUL BROOKER; TWI LTD

Dr Nick Ludford has spent over 18 years at TWI leading projects for TWI's Industrial members; developing joining solutions for engineering problems using brazing, soldering and diffusion bonding processes. Prior to joining TWI he completed a PhD investigating the use of oxide-oxide ceramic matrix composites. In his current role as section manager of both the Thermal Processing Technologies and Arc Welding and Engineering sections he is responsible for coordinating both day to day support to Industrial members as well as identifying future industrial trends and how TWI aligns to these. He has developed a range of different vacuum brazing processes for clients and is the co-inventor of a patent related to the diffusion bonding of aluminium and its alloys. He believes that the transition to net zero and a potential hydrogen-based economy will present exciting challenges and opportunities for the brazing and welding community, including skills development and training.

Paul Brooker is a consultant in the Thermal Processing Technologies section at TWI and has over 45 years' experience developing vacuum brazing and welding solutions for industry. Previous roles have included Site Manager at Bodycote running heat treatment, vacuum brazing and electron beam welding technologies and Managing Director at Creative Instrumentation Ltd during which he supported a range of industrial sectors with process development and troubleshooting related to vacuum brazing, TIG welding and electron beam welding. Given his broad industrial experience, Paul is also the manufacturing support manager at TWI with a focus on transferring applied research and development into solutions ready for uptake by industry. This includes assessing the suitability of different joining solutions and inspection techniques in conjunction with colleagues, to inform design activities as part of product development cycles.

JOHN HILL, DIRECTOR OF TECHNOLOGY AT TWI AWARDED OBE

John Hill, TWI's Director of Technology, has been awarded an OBE in the King's Birthday Honours List. This was in recognition of his services to SMEs, the research institutes sector, local economic development and to higher education.

With a career spanning over 45 years John joined PERA, the Production Engineering Research Association, in 1988 as a Chartered Engineer, specialising in engineering polymers and composites. While there he rose to become its Director of Technology in 2000 and its Chief Executive in 2008. In the 90s he built an international network of research institutes focused on helping thousands of small firms to innovate, providing the money and the scientific expertise for them to develop hundreds of innovative new products. Between 2000 and 2015, he developed management techniques for helping small firms grow faster and for longer, piloting these first in the East Midlands, then establishing a national small firm growth coaching programme. This went on to help 20,000 small firms accelerate their growth, creating 75,000 jobs. After a spell in government where he was responsible increasing exports from small firms nationally, he moved on to become Director of Business & Skills for the Cambridgeshire & Peterborough Metro-Mayor. While there he saw the challenges facing his home city, Peterborough. A higher education "cold spot" with only 32 per cent of the population having degree level qualifications, compared to a national average of 43 per cent John developed an idea to help solve this problem. Over a 30 month period working with a wide range of partners he helped raise £80m to build what has become the multi-award-winning ARU Peterborough. John joined TWI in 2022 as Director of Membership and he is currently serving as Director of Technology.

See the full press release at: https://www.twi-global.com/media-and-events/press-releases/2024/john-hill-director-of-technology-at-twi-awarded-obe

LOYAL SERVICE AWARD WINNERS 2024

The Welding Institute have announced that the 2024 Loyal Service Award Winners are as follows:

Service to Branches

Daniel Clark	East Midlands Branch
Miles Goodwin	South Western Branch
Steve Beech	East Midlands Branch
Stuart Ward	Scottish Branch

Service to Membership Education and Registration Committee (MERC)

Joanna Nicholas
Philippa Moore
Stephen Norrish

The awards will be presented at an event later in the year.

DR HASAN CAGLAR IS THE WINNER OF ROLLS ROYCE - RICHARD DOLBY AWARD 2024

Left to right: Paul Woollin, Richard Dolby, Hasan Caglar (Winner) Rucha Kanade (Runner up) Matt Haslett

Dr Hasan Caglar AWeldI Interim CEng has been announced as this year's winner of the Richard Dolby - Rolls Royce Award.

The Richard Dolby - Rolls Royce Award is presented biennially by The Welding Institute's Young Members Committee. A cash prize of £1,000 is awarded to any young Member (under 35 years of age) that can show success and enthusiasm for welding, joining and/or materials engineering at an early stage in their career. Hasan won the award for his presentation on Debonding of carbon fibre veil interleaved adhesively bonded GFRP joints via Joule heating.

A panel of judges from Rolls Royce (Professor Gary Jones), TWI (Dr Paul Woollin), the Younger Members Committee (Matt Haslett) and Richard Dolby assessed the finalists for the award on the 3rd July 2024. Hasan has a BSc from Ozyegin University in Istanbul; MSc from Koc University in Istanbul and a PhD from Nanyang Technological University in Singapore. He was previously employed as a Project Leader at TWI Cambridge and is currently working at Cranfield University as a Research Fellow.

INTRODUCING THE WJM EDITORIAL PANEL...

Welding and Joining Matters has been developed by the Editorial Panel over the last four years, with its first issue in April 2022. There have been a number of changes to the Panel from the founding group but the Panel that compiled this issue are the following, together with our guest editors and contributors.

Gene Mathers

Gene has over 50 years experience in welding engineering. Gene qualified as a metallurgist and his interest in welding was sparked whilst working for a heavy pressure vessel and boiler manufacturer. He obtained an MSc in welding engineering and then worked in the power generation and nuclear industries. Gene became Head of the School of Welding Technology at TWI then Principal Consultant. Nominally retired Gene continues to provide welding consultancy services.

Julian French

Julian French is a Partner with London based consultancy Sandberg LLP. Julian specialises in the welding, testing and coating of structural steelwork and is chairman of the TWI Technical Group for Structures and infrastructure. Julian sits on various committees for BSI, BINDT and UK steelwork specifications.

Hugh McPhillips

Hugh has been involved with Fabrication & Welding Training and Consultancy for over 50 years and is Chair of AWFTE. Hugh sits on Professional Board, and is President of the South Western Branch with South Wales Branch of the Institute. He is author of two books on welding and fabrication, and is technical director for Metaverse Learning's Fabrication & Welding virtual environment programme.

Dave Reeves

Dave Reeves is a Welding Engineer working in offshore and pipeline engineering. He is a member of Professional Board, MERC and International Members Working Group and Chair of the Structural Integrity Technical group when not doing his day job of Pipeline Technology Manager for Saipem Romania.

Miles Goodwin

Miles was brought up in and worked in the civil engineering/petro-chemical industries. He became involved in teaching welding related subjects in Further Education and taught in three colleges. Miles moved into skills training for Welder Certification, along with developing Welding Procedure Qualifications and all relevant technical work. He is a member of Professional Board.

Stephen Webster

Steve's career was in the steel industry, working largely at Swinden Laboratories in Rotherham where he ran the Structural Integrity and Welding Departments. His involvement in those fields resulted in his association with TWI and the Welding Institute over many years. Steve served on the Research Board, the Council and Professional Board as vice-Chair and subsequently Chair.

David Millar

David began his career as a Welder at the Govan Shipyard Glasgow in 1975, progressing to become the yard Welding Engineering Manager in 1995. In May 2020 David became the Worldwide Business Development Manager for Gullco International, providing technical support for Gullco's staff in the Americas, UK, Middle East, Far East and India.

Chris Worrall

Chris is TWI's Technology Fellow for 'Composites; structural integrity and joining', leading developments and responding to technical challenges from member companies. Prior to that Chris worked in Japan lecturing and working in composites across many industries and previously worked in the UK on testing and failure analysis. Chris is Chair of The Welding Institute Technical Group for Polymers and Composites.

Alan Denney

Alan Denney is a metallurgist and welding engineer with 50 years experience in the world of structures, offshore engineering, pipelines and process plant. Alan is currently the editor of the Journal, is programme secretary and a Past-President of London Branch of the Institute and is the Technical Group Co-ordinator for the Institute.

Nadine Earp

Nadine joined TWI Ltd in 1990 and first worked in the International Institute of Welding Secretariat and moved in 1996 to the TWI Training & Examination Services co-ordinating their global marketing activities. In September 2021 Nadine moved to The Welding Institute and is currently Business Development Team Manager.

Hafiza Rahman

Hafiza is currently Digital Marketing Degree Apprentice at The Welding Institute, having joined in 2022, where she works marketing The Institute's events, the Technical Groups and personal membership and its benefits.

Kate Day

Kate Day has a degree in environmental science and worked for 30 years in environmental management. She joined The Welding Institute Professional Membership Team in 2016 where her role focuses on the support and development of our membership volunteers, our Branches and our global regional networks.

The Panel sources the articles, writes some of them and does the first edit of external contributions. Working on the Panel is an active role and a job for people who like to make a difference and make the necessary extra effort to do that. We also invite guest editors to bring their expert knowledge and fresh ideas to the journal and we also draw on a group of regular contributors. We have an hour-long meeting every week in which we compile the journal. The role requires industry knowledge, contacts and commitment. We would like to diversify and improve the age profile, so if you know that you want to make that difference please contact us at: **WJMeditorial@ theweldinginstitute.com**

YOUNG MEMBERS' ACTIVITIES

Welding with chocolate at Teesside STEM events

Younger members of the Teesside branch have been very active in encouraging an interest in engineering at schools in the Teesside area. Quality Engineer Callum Pennock and Quality Apprentice James Bell, both of whom work for Jacobs at their Stockton-on-Tees offices, have been very proactive in local STEM events.

Welding with chocolate has proved to be one of the most popular stands at the STEM events. Apart from the opportunity to sample broken Milky Bars, the children learn about the strength of materials (the weight that a single Milky Bar can support), the significant increase in weight supported when they weld four Milky Bars into a box section, and the importance of welding to join materials.

Tension mounts as James Bell increases the weight on a box girder of welded Milky Bars while Callum Pennock prepares to catch the pieces when it fails

Whilst our older members have done some excellent STEM work, our younger members help the children relate to engineering, and welding in particular, with a modern and dynamic career opportunity. It is their inspiration and enthusiasm that will hopefully drive the aspirations of the next generation to become welding specialists.

YOUNGER MEMBERS NEWS

My name is Aaron Kirkbride and I'm one of The Welding Institute's Young Members Representatives (YMR) who form the Young Members Committee (YMC). I previously represented the Northumbria, South-Western and most recently, the East-Midlands branch, which covers, primarily, Derby and Nottingham areas and extends across to Hull.

Chaired by Sean Evans (you can find his interview in issue 7 of WJM) the YMC was formed to engage and network with those at the early stages of their careers, including welders, engineers, inspectors, apprentices, metallurgists or any role related to welding. As Sean put it, the YMC is a group of individuals who have a passion for welding/ engineering and want to help share that passion with others in the industry. This is done through knowledge-sharing opportunities, helping with the recruitment of younger members and supporting the branch network of The Welding Institute. The term, 'Young Members' does not necessarily represent age or level of competency, but rather refers to those who's careers in welding are at an earlier stage.

As a member of The Welding Institute, you should hopefully know about your regional branch; most branches are incredibly active and host a range of monthly meetings, both in person and online, which, if attended, count towards your Continuous Professional Development (CPD). The meetings include technical talks and site visits, which are all relevant to welding but are normally in specialist areas, and are extremely valuable to our members as they offer a glimpse into different areas of welding and its applications. The YMC are here to help develop your welding career, whichever stage you're at, and we can offer support and guidance for professional membership and registration, such as mentoring. The YMC are looking to actively engage with young members, to give you the most out of your membership. Your branch committee members, and your regional YMR, are members of The Welding Institute just like yourself. As a member of The Welding Institute, you should be receiving regular updates about your local branch events, but if you have any questions about how the YMC can support you, or even get involved yourself, please contact us through the YMC email at **ymc@twi.co.uk**.

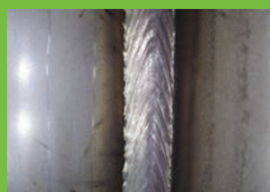
SOUTH WESTERN BRANCH WITH SOUTH WALES BRANCH

Presentation on welding of duplex stainless steels and developments in consumables by Peter Stones of ESAB

At a meeting of SWB held in February 2024 Peter presented the characteristics and properties of duplex stainless steels, a history of the development of new grades, an explanation of the PRE number and how it relates to the categorisation and properties of different duplex grades, and then moved on to an explanation of the importance of using the correct welding parameters. Before listing several examples of where duplex grades have been used in a selection of different industries, we learnt of the benefits of the unique duplex grade, Exaton 22.8.3.LSi, which is the only standard duplex grade with added silicon.

Standard duplex grades have a 0.5% silicon content, whereas Exaton 22.8.3.LSi has 0.8%. The additional silicon, as an added deoxidiser, provides better weld metal fluidity, so that the weld pool wets into the toes of the weld for complete fusion, and produces a smooth, flat weld bead.

Standard ER 2209



Exaton 22.8.3.LSi

Peter explained that, according to ASME II C FSA-5.9, the maximum permissible silicon content of AWS 2209 / ISO 22 9 3 L is 0.9%, so the Exaton 22.8.3.LSi can be substituted in an existing WPS where 'standard' duplex is required. It also has the same PRE number as standard duplex and the Yield Strength/ proof strength (Rp0.2) is the same at 580 MPa (ksi).

BRANCH NEWS

TEESSIDE BRANCH

Presentation by Hydrogen Safe on safety training for hydrogen and related activity in the Teesside area

With its potential to play such a big part in the push towards carbon zero, hydrogen is undoubtedly the hot topic in so many industries. This is certainly the case in the welding and joining business where the development of hydrogen carrying materials, and joining them together, is an existential challenge. The wider issues around hydrogen itself brings extended challenges when dealing with its production, handling, transportation, storage and use. As with the petrochemical industry, many of the safety considerations are similar but hydrogen has specific characteristics that require particular knowledge and awareness to adequately and safely manage them.

In mid-March, the Teesside Branch was given an online talk by specialist training organisation, Hydrogen Safe of Manchester. Hydrogen Safe currently run a number of courses from a half day ‘Hydrogen Awareness’ course to a four day Level 1 ‘Hydrogen Safety and Awareness’ course (advised to be the UK’s first Ofqual registered hydrogen qualification, through TLM).

Liz Simon, Hydrogen Safe’s Green Energy Partnerships Director

After an introduction from Hydrogen Safe’s founder, Andy Lord, the main presentation was provided by Elizabeth (Liz) Simon, Hydrogen Safe’s Green Energy Partnerships Director. Whilst Liz started by extolling the virtues of hydrogen, she went on to outline the challenges facing the country to overcome the skills gaps, at all levels, that will need to be plugged before we can progress to meet the targets outlined by government in their Hydrogen Strategy. Liz reviewed the ‘Hydrogen Rainbow’, outlining the various ways in which hydrogen is commonly produced and the differing carbon credentials represented by each rainbow colour. We also looked at the potential demand for hydrogen in the coming years, expected to be some 20% to 35% of energy consumption by 2050, and the numbers of jobs that this will support in the future.

Once the general overview of hydrogen had been covered, Liz continued with a review of the hydrogen related work in the Teesside area. This probably came as a bit of a surprise to many of us who had no idea that so much work was already underway or planned on Teesside. This included hydrogen production plants to proposed pipelines for offshore storage and carbon capture facilities.

This was a thoroughly interesting and informative presentation and our thanks go to Liz, Andy and the Hydrogen Safe team for their time and expertise.

TEESSIDE BRANCH – 69th ANNUAL DINNER

The Teesside Branch held its 69th Annual dinner and awards presentations on the 26th April 2024, the dinner was well supported by local sponsors, and there were around 150 people in attendance, the event at the Middlesbrough FC Riverside Stadium all of whom had a great night out.

Figure 1: The top table. From left to right: Vince Dawkins - Branch Chairman, Don Atkinson - Branch President Josh Daniels – Comedian, Kevin Dunn - Branch Vice-chairman, Robert McGowan - Chief Executive Officer Paralloy (Industry Speaker), John O’Brien - General Manager TWI certification and Strategy (TWI Speaker).

Awards

During the event the Branch made presentations to the award winners from local colleges, the winners were:

Apprentice of the year

Winner: Jamie Hutchinson (on the right), works for Wilton Engineering and attends Hartlepool College.

Practical welder of the year

Winner: Luke Edmondston (on the left) works for Rainham Industrial Services Ltd and attends Middlesbrough College.

Student of the Year

Winner: Stephen Keogh (on the right) works for Owben Engineering and attends Newcastle College.

The attendees enjoyed a great evening of after dinner speakers, and were entertained by comedian Josh Daniels, with everyone now looking forward to the Branches 70th anniversary dinner next year.

AUSTRALIA BRANCH

Wonder reef - the world's first floating off-shore reef dive site area

Dean Terry of Inspection & Weld Tech, Australia gave a talk to the Australian Branch in May 2024 on Wonder Reef and has provided this summary of his talk for publication in Welding and Joining Matters.

The Wonder Reef project was developed to provide an ecotourism diving experience by providing 32,000 cubic meters of new reef habitat and thus benefit marine life whilst satisfying the human desire to get up close and see marine life first hand.

To say that this project sunk is actually a good thing, considering the project was to manufacture an underwater structure. Wonder Reef is the world's first floating (but completely submerged), offshore reef dive site and was built to withstand an eighteen-metre wave height in the open ocean off Australia's Gold Coast.

It was a challenging design concept that called on many years of experience. Inspection & Weld Tech were amongst a small group of local businesses brought together to manufacture the unique structure for Subcon, lead contractor to the Queensland State Government and the city of Gold Coast.

Figure 1: Padeye fabrication

ISM Manufacturing, a small family-owned business based in Maryborough was awarded the contract to manufacture the reef structure. They, together with a small group of skilled trades and support services, proved the capability of regional businesses to manufacture this world class steel structure.

Figure 2: A foundation unit awaits transportation to the dockside for concreting

Each of the nine units are comprised of steel pipe and plate ranging in thickness from 10 mm to 60 mm plus a ballast foundation with over one-metre thick sections of concrete. Placed in 30 m of water, each foundation anchors a flute unit which floats some 22 m above it. The foundations and suspended flutes are connected by 10 m of 60 mm chain making each unit weigh approximately 80 tonnes. The entire design was developed into shop drawings by local Maryborough business, The Drawing Office.

Figure 3: A buoyant flute unit is loaded onto a trailer for despatch to the dockside

Steel assembly was by submerged arc welding (SAW) and gas-metal arc welding (GMAW) processes, with construction to Australian pressure standards, requiring ultrasonic testing (UT) and magnetic particle testing (MT) plus pressure testing to ensure that the flutes would float. Movement of all the components from the ISM Manufacturing facility in Maryborough to the Gold Coast 340 km away was the responsibility of local business Warren Haulage who specialise in transporting oversize loads.

Assembly of the bases, chains and flutes was completed on the barge at the dockside. Each assembly spanned 20 m in height and were positioned 2 km off The Spit, Main Beach on the Gold Coast in 30 m of water using a 600 tonne shearleg floating crane barge. The location is now a thriving area with marine life and coral taking up residence, monitored by researchers at Griffith University and recreational divers adventuring via charter.

Further information is available at:

https://www.wonderreef.com.au/
https://www.youtube.com/watch?v=9O562IyLb-I&t=1s

Apart from the involvement with Wonder Reef, Inspection & Weld Tech has provided contract services of welding co-ordination and non destructive testing to support the manufacture of a diverse range of rolling stock, mining equipment, structural and pressure equipment for over 20 years.

FOR ALL YOU WELDERS AND WELDING EXPERTS OUT THERE…

QUIZ time

A quiz on preheating of steel

a) Is preheat a mandatory requirement in application standards?
b) Do austenitic steels require preheating?
c) Where can advice on the preheat temperature required for creep resistant steels be found?
d) Why is preheat required for ferritic steels?
e) What are the four factors that need to be considered when deciding if preheating is required?
f) What is the most important factor when deciding if preheating is necessary?
g) What are the principal methods for applying preheat?
h) Why may a temporary attachment require preheating when the adjacent butt weld doesn't?
i) When welding high strength steels is the weld metal composition significant?
j) Is it allowable to reduce the preheat temperature from that given in the relevant PQR?

Answers can be found on page 49.

5th CONFERENCE ON CRACKING PHENOMENA IN WELDING AND ADDITIVE MANUFACTURING - CALL FOR PAPERS

5TH CONFERENCE ON CRACKING PHENOMENA IN WELDING AND ADDITIVE MANUFACTURING - MARCH 12-14, 2025, UNIVERSITY WEST, TROLLHÄTTAN, SWEDEN.

IIW along with its organising partners, University West, the Ohio State University and Böhler welding have announced the 5th International Conference on Cracking Phenomena, at University West in Trollhättan, Sweden on 12th-14th March. The purpose of the conference is to gather international experts to discuss cracking phenomena associated with welding and additive manufacturing, from both a scientific and practical standpoint.

Topics include solidification and liquation cracking, ductility-dip cracking, reheat and stress-relief cracking, hydrogen-induced cracking, weldability testing, simulation and modelling, measurement and quantification, and remedial measures.

The conference is for academics and industrial researchers to present and highlight their most recent findings in the field and others with this an interest in cracking phenomena. It is organized by a distinguished panel from Ohio State University, Voestalpine Böhler Welding and University West.

The registration fee is 300 Euro (incl. VAT) which includes a copy of the proceedings, lunches, a cocktail reception and post-workshop tour.

Abstracts of 200-300 words should be submitted through the conference website prior to 1 December 2024. (https://www.hv.se/om-oss/event-och-konferenser/cracking-phenomena-in-welding-and-additive-manufacturing-2025/)

For enquiries email: asun.valiente@hv.se

INTERNATIONAL THERMAL SPRAY CONFERENCE AND EXPOSITION 2025 – CALL FOR PAPERS

The International Thermal Spray Conference 2025 (ITSC 2025) will be held in Vancouver, Canada from 5th – 8th May 2025 focusing on "Sustainable Innovations in Thermal Spray Technology: Pioneering a Greener Future."

ITSC 2025 is an event for thermal spray professionals and will feature: Technical sessions, the exhibition, an industry forum focusing on practical demonstrations, a 'young professionals' section with its awards and recognition programme, and networking time and events with other professionals. ITSC 2025 will highlight new topics and discussions related to the theme, "Sustainable Innovations in Thermal Spray Technology: Pioneering a Greener Future."

Details are available at:
https://www.asminternational.org/itsc-2025/

The Call for Papers is now open. Authors interested in participating should submit original, previously unpublished abstracts of 100-150 words (in English) via ASM's online abstract service. https://www.asminternational.org/itsc-2025/cfp/.

INTERNATIONAL CONFERENCE ON RESIDUAL STRESSES 2025 – CALL FOR PAPERS

12th International Conference on Residual Stress (ICRS-12) for 20th – 23rd October 2025, in Detroit, Michigan.

Proposals are invited for papers covering scientific and engineering aspects of residual stresses including prediction, measurement, control, and effects of residual stresses. Topics covered may include the formation of residual stress fields, their characteristics, and their influence on distortion, material response to loading, damage initiation and propagation, component performance, life and failure. This conference will be co-located with the ASM International Materials Applications and Technologies (IMAT) 2025 Meeting and will benefit from joint sessions and access to the exhibitors.

Further information can be found at:
https://www.asminternational.org/icrs-12/

Abstract Submission will begin in August 2024 with a deadline of 21st February 2025.

10th INTERNATIONAL CONFERENCE ON ADVANCES IN MATERIALS, MANUFACTURING & REPAIR FOR POWER PLANTS: 15th -18th OCTOBER 2024

The 10th International Conference on Advances In Materials, Manufacturing and Repair for Power Plants, organised by the Electric Power Research Institute (EPRI) in partnership with ASM International, will be held in Bonita Springs, Florida, in the period 15th - 18th of October 2024.

This conference takes place about every four years and is an ideal opportunity for those in the power generation industry to benefit from an insight into the latest in materials and related technologies.

Registration is open now and can be made at https://www.asminternational.org/epri-2024/ where there is a full outline of the programme along with sponsorship opportunities and other details of the event.

FORTHCOMING TECHNICAL GROUP MEETINGS AND WEBINARS

16 October 2024	**Professional Members' Day including: Hydrogen for Power – Materials Behaviour and Associated Challenges** Time: 9:00 am – 4:00 pm (UK time) **In-person** at TWI Ltd, Cambridge	**Technical Groups**
24 October 2024	**Additive Manufacture of Pressure Equipment** Time: TBC **In-person** at Cranfield University	**TG2/TG8** Welding and Joining Processes/ NDT and Condition Monitoring
5 November 2024	**Environmental Fracture Toughness Testing** Time: TBC	**TG6** Structural Integrity
14 November 2024	**Back-to-basics: TIG Welding** Time: TBC	**TG2** Welding and Joining Processes

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

REFURBISHMENT AND RE-USE OF STRUCTURAL STEEL

David Brown of the Steel Construction Institute summarises his presentation on the developing practice of reusing steel members which was given at a Technical Group 1 meeting held in March 2024.

The drive to lower embodied carbon

No-one in the developed world can be unaware of the discussion about greenhouse gases, climate change and limiting the increase in average global temperatures. This article will not debate whether the science is correct, or where the responsibility lies, but simply acknowledges that there is an immediate drive to reduce the contributions to the problem. It seems unlikely that the average increase in global temperature will be limited to 1.5 °C – the challenge is now to limit how far that target is exceeded.

One of the large contributions to greenhouse gases is construction, and within that, the manufacture of cement and steelwork. In common with many industries, the steelwork sector has a "decarbonisation roadmap", leading to "carbon zero" in 2050. This is an ambitious target, heavily dependant on reducing the carbon in manufacture.

Manufacturing steel using an electric arc furnace is good – less carbon is involved in this recycling process. Unfortunately this does not solve the global problem, since the demand for steel outstrips the volume that can be produced from scrap by a factor of approximately three. Specifying steel produced by an electric arc furnace may make a particular project look attractively low in terms of carbon, but someone, somewhere must meet their demand from the more carbon-intensive blast furnace process to manufacture new steel.

Producing buildings with low embodied carbon is not an option – authorities such as the Mayor of London and clients are setting targets for maximum embodied carbon, and those limiting values are set to reduce still further over the next few years. The Institution of Structural Engineers have published a hierarchy of steps to reduce carbon, which starts with not building new construction at all. If construction must proceed, then the next opportunity is to refurbish and adapt existing buildings – and to reuse steelwork rather than scrapping it.

Table 1 shows the relative contributions to "equivalent" greenhouse gases for different steel options. It will immediately be observed that reused and refabricated steel has a very attractive low carbon content compared to new steel.

Steel source	kg of CO_2 equivalent per tonne of steel
Blast furnace	2400
Electric arc furnace	500
UK average content	1740
Reused steel	50

Table 1: Typical carbon contribution by manufacturing route in comparison with reused steel

Recovered steel

Engineers have always recovered and reused steel in a piecemeal fashion. If steel is to be recovered and reused in a wholesale manner, certain pieces of infrastructure must be in place:

- Carefully recovered steelwork. Demolition usually proceeds without too much concern, with steel recovered for scrap. Careful recovery is more akin to dismantling and will involve initiating a comprehensive inventory of the recovered members.
- A stockist prepared to hold the recovered material (Figure 1), who pays more than scrap prices for it and makes a business selling it on.
- Companies willing to re-fabricate. This is not as straightforward as might be imagined. Recovered steelwork is generally imperfect and often has attachments welded to it. Modern fabrication equipment relies on numerically controlled rollers, clamps, sensors, saws and drills – which often cannot readily accommodate anything other than a new steel section.
- Engineering design rules. What additional rules are required – if any, for the structural design?

Figure 1: Recovered steel members (Courtesy: Cleveland Steel & Tubes Ltd)

All the above sits alongside a knowledge of the original material – what design grade is the steel and – in some cases, what is its Carbon Equivalent Value, and what is its Charpy impact value?

One significant hurdle is that the construction industry is today used to CE marked products – so can recovered steel be CE Marked? Certainly "yes" says the industry bodies. The governing requirement is the Execution specification which allows the use of "other" steel – as long as certain essential characteristics are declared. Those characteristics are determined and declared by the inspection and testing undertaken by the stockholder.

Design guidance

Back in 2019, SCI published P427, covering the assessment, testing and design principles for structural steel reuse. Interest in reuse was increasing and the industry embraced the guidance with enthusiasm. P427 has become widely accepted and is the model for a European set of requirements under preparation.

The publication established the concept of 20T "groups". Same project, same function, same member means that the members of the 20T group were probably the same design grade. P427 required that every single member was hardness tested (Figure 2), simply to confirm that the members of the group really did appear to be of the same family. The actual steel design grade could be calculated from the hardness test results or by limited destructive testing from members of the group. Conservative limiting values are in place, since it is well known that the yield and ultimate strength of steel of a certain grade is always higher – and sometimes a lot higher – than the specified minimum.

Figure 2: In-situ (portable) hardness testing (Courtesy: EMR)

Practice since 2019 has demonstrated that the relationship between hardness testing and design grade is poor. Perhaps it is the preparation of the surface, or the test procedure, but a comparison of the relationship between hardness and strength measured by destructive testing shows a complete scatter with hardly a line of best fit to be seen. The same is observed if the hardness testing is completed by a laboratory. A higher grade (which is more valuable) is often demonstrated by destructive tests, so this is the route that some stockists are starting to adopt.

P427 has a significant limitation to its scope. Steel used in construction prior to 1970 is excluded. This is because the industry has reliable manufacturing data from 1970, on which the average, minimum and maximum strengths used to identify the steel grade are based. In 2023, P440 was published, which provided supplementary guidance for steel used as early as 1931. This date was chosen to mirror the first issue of BS 449, which was the first widely used steel design code in the UK. For anyone interested in materials, the changes in design rules and associated material standards between 1931 and 1970 are illuminating. Back in the 30s, welding was not even mentioned – connections were riveted, not bolted. It was not until after the second world war that the structural steel world paid much attention to impact toughness. The design rules for buckling varied considerably – some would be thought rather optimistic compared to the rules today. It seems that unrestrained beams were not common, as the early rules were very basic. Some recommendations follow from those features:

- A conservative buckling curve for flexural buckling and lateral torsional buckling is recommended, presented in the same way as the Eurocode.
- That bolted connections are preferred to welded, reflecting the original form of construction.
- That impact properties are likely to be very variable, if at all.
- That comprehensive testing may be required.

Current practice

Reused steel is all the rage as one of the ways to reduce embodied carbon. It is almost essential to say that one's project includes at least some reused steel. Multiple "stock matching" tools have been developed, which compare the new member list from a building design with the recovered steel available at a stockist and identify suitable reuse candidates. Some flexibility is encouraged to allow slightly different sizes to be used – although not too overweight as the carbon advantage is being wasted. It has become clear that stock matching at the early designs stage is not workable – no-one wants to pay to secure the stock so early in the process and the stock may have changed when the actual fabrication commences. Better practice is to set the steelwork contractor a reuse target – say 10% of the building to be from reused steel, with some flexibility and perhaps guidance on where reused sections may be used.

To make reuse really work, the industry must engage. Structural engineers are used to assuming they have a new piece of steel, and some appear to be reluctant to make decisions on the suitability of particular members, but this is essential. A recovered piece of steel is unlikely to be perfect (Figure 3), but:

- Maybe it could be used upside down, where defects to what was the top flange no longer matter, and are not seen.
- A penetration through the web might be important near the support, but maybe is not important elsewhere.
- A defect in the flange might be important near midspan, but not elsewhere
- A defect in a tension flange does not make a beam buckle.

These sorts of assessments are well within a structural engineer's competence and must be made or else the vast majority of recovered imperfect steelwork will still be scrapped.

Figure 3: Steelwork during demolition and recovery (Courtesy: Elliott Wood)

And now – the welding

As a structural designer writing in a TWI Journal, it may be a little provocative to suggest that in many instances, precise carbon equivalent values don't really make much difference. This is the problem when structural engineers are introduced to BS EN 1011-2 and then think they might know something about welding! The vast majority of welds to structural steelwork are for end plates and cleats. In very many cases, the welds will be 6 mm or 8 mm leg length fillet welds, so relatively small. With the sorts of combined thicknesses and heat inputs with modest size welds on relatively thin material, perhaps there is little risk, even with higher CEV. It is absolutely clear that for larger welds on thicker material, a proper assessment is essential.

Thankfully, since all structural steelwork in the UK must be CE marked, the steelwork contractor must have access to a Responsible Welding Coordinator, who knows more about the subject than a misguided structural engineer. The SCI guidance strays into the RWC's parish by suggesting that they may wish to undertake trials, or increase inspection, and of course will be concerned about the CEV. Steel produced in earlier decades may be more susceptible to lamellar tearing, so cruciform joints are best avoided by the designer and the RWC.

Conclusions

Reused steel is just one part of the campaign to reduce embodied carbon in construction. Efficient design and fully utilised structures is an equally important contribution. Reusing steelwork brings its own demands to know the provenance of the members and testing to know what material is being designed and fabricated.

David Brown is a technical specialist at the Steel Construction Institute, usually working on structural design, connection design, advice and training. He is one of the authors of both P427 and P440.

STANDARDS UPDATE

The following updated standards have been issued during the period February to May 2024:

Welding of Thermoplastics

BS EN 12814-7:2024
Testing of welded joints of thermoplastics semi-finished products. Tensile test with waisted test specimens.
Supersedes BS EN 12814-7:2002

Welding of metals

BS EN IEC 60352-9:2024
Solderless connections. Ultrasonically welded connections. General requirements, test methods and practical guidance.

BS EN ISO 3834-6:2024
Quality requirements for fusion welding of metallic materials. Guidelines on implementing the ISO 3834 series.
Supersedes PD CEN ISO/TR 3834-6:2007

BS EN ISO 9692-2:2024
Welding and allied processes. Joint preparation. Submerged arc welding of steels.
Supersedes BS EN ISO 9692-2:1998

BS EN ISO 14373:2024
Resistance welding. Procedure for spot welding of uncoated and coated low-carbon steels.
Supersedes BS EN ISO 14373:2015

BS EN ISO 15610:2024
Specification and qualification of welding procedures for metallic materials. Qualification based on tested welding consumables.
Supersedes BS EN ISO 15610:2023

BS EN ISO 15611:2024
Specification and qualification of welding procedures for metallic materials. Qualification based on previous welding experience.
Supersedes BS EN ISO 15611:2003

ISO 15614-5:2024
Specification and qualification of welding procedures for metallic materials. Welding procedure test. Arc welding of titanium, zirconium and their alloys.

BS ISO 17607-5:2023
Steel structures. Execution of structural steelwork. Welding.

Products

ISO 10544:2024
Cold-reduced steel wire for the reinforcement of concrete and the manufacture of welded fabric.

Published Documents

PD 5500:2024
Specification for unfired fusion welded pressure vessels.
Supersedes PD 5500:2021

PD CEN/TR 16862:2023
Plastics welding supervisor. Task, responsibilities, knowledge, skills and competence.
Supersedes PD CEN/TR 16862:2015

STANDARDS ON BRAZING

The designation BS indicates it to be a British Standard under the control of the British Standards Institution. Where the designation includes EN this indicates it to be a 'European Norm' under the control of the European Committee for Standardisation (CEN). Where the designation includes ISO this indicates it to be internationally agreed under the auspices of the International Organization for Standardization (ISO).

British Standard	Title
BS EN ISO 17672:2024	Brazing. Filler metals.
BS EN ISO 18279:2023	Brazing. Imperfections in brazed joints.
BS ISO 22688:2020	Brazing. Quality requirements for brazing of metallic materials.
BS EN 13134:2000	Brazing. Procedure approval.
BS EN ISO 5179:2023	Investigation of brazeability with spreading and gap-filling test.
BS EN 14324:2004	Brazing. Guidance on the application of brazed joints. Currently under review.
BS EN 12799:2000	Brazing. Non-destructive examination of brazed joints Currently under review.
BS EN ISO 13585:2024	Brazing. Qualification test of brazers and brazing operators. Currently under review.
BS EN 12797:2000	Brazing. Destructive tests of brazed joints Currently under review.
BS ISO 11745:2022	Brazing for aerospace applications. Qualification test for brazers and brazing operators. Brazing of metallic components.
BS EN ISO 18496:2021	Brazing. Fluxes for brazing. Classification and technical delivery conditions.
BS EN ISO 4063:2023	Welding, brazing, soldering and cutting. Nomenclature of processes and reference numbers.
BS EN ISO 3677:2024	Filler metal for brazing. Designation.
BS EN 3875:2017	Aerospace series. Metallic materials, Filler metal for brazing. Technical specification.
BS EN 16602-70-40:2023	Space product assurance. Processing and quality assurance requirements for hard brazing of metallic materials for flight hardware.
BS EN 4632-001:2008	Aerospace series. Welded and brazed assemblies for aerospace constructions. Weldability and brazeability of materials - General requirements.
BS EN 4632-002:2008	Aerospace series. Welded and brazed assemblies for aerospace constructions. Weldability and brazeability of materials - Homogeneous assemblies aluminium and aluminium alloys.
BS EN 4632-003:2010	Aerospace series. Weldability and brazeability of materials in aerospace constructions - Welding and brazing of homogeneous assemblies of unalloyed and low alloy steels.
BS EN 4632-004:2012	Aerospace series. Weldability and brazeability of materials in aerospace constructions - Welding and brazing of homogeneous assemblies of high alloyed steels.
BS EN 4632-005:2009	Aerospace series. Weldability and brazeability of materials in aerospace constructions - Homogeneous assemblies of heat resisting Ni or Co base alloys.
BS EN 4632-006:2013	Aerospace series. Weldability and brazeability of materials in aerospace constructions - Homogeneous assemblies of titanium alloys.
American Standard	**Title**
ASME BPVC Section IX-2023	Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators.

INFORMATION SERVICES - DIGITAL BOOK NEWS

Three ebooks on brazing and soldering are new to the TWI Digital Library.

P.M. Roberts's **'Introduction to Brazing Technology'** introduces the fundamentals of the brazing process including joint design, filler metals and brazing with flames. It also provides straightforward guidance, informed by 50 years of experience, for the effective brazing of metal joints.

'Recent Progress in Lead-Free Solder Technology: Materials Development, Processing and Performance' discusses the development of lead-free solder materials, technologies and processes as a reference point for researchers.

'Lead-Free Soldering Process Development and Reliability' discusses thirteen aspects of lead-free soldering to provide an updated review of solder technologies and address issues in production.

Together, all three books introduce and describe the recent industry developments and ongoing research being made in the areas of brazing and soldering, covering new and key topics providing valuable insight into the area.

Members can access these and around 200 more ebooks through the TWI Digital Library. Logon at Technical Knowledge - Engineering and Materials Joining Library - TWI (twi-global.com)

YOUR THOUGHTS ON THE JOURNAL – A REQUEST FROM THE EDITORIAL PANEL

The Welding Institute
ESTABLISHED 1923

The April 2024 issue of Welding and Joining Matters was provided in hard copy to all Institute members resident in the UK, as a special event. This was to publicise the availability of this new journal in hard copy. The feedback has been very positive, and many members have requested that they receive a hard copy of the journal in the future. Several members were previously unaware that the journal existed, so the exercise was doubly beneficial.

The editorial panel would be delighted to receive more feedback from members with their opinions and thoughts on past articles, and ideas on topics for future articles and journal themes. For example, we are trialling a regular compilation of relevant training establishments, and we offer classified advertisements in a range of presentation styles to individuals and companies. We would like to know if these will be of benefit to members.

The journal's editorial panel and the content contributors provide their services for free as volunteers. We would like to receive offers for assistance with the sub-editing of the articles to get them in the right 'voice' and form for printing. If you have a journalistic flair, then do let us know. We welcome contributions from younger members and the entire diverse membership of the Institute. Articles may be purely technical but also may be on a specific project of interest, a particular difficulty that has been overcome, external involvement that promotes the institute (e.g., STEM events), a personal journey in the industry, etc. The scope is wide and varied, so long as there is a connection to welding and joining. If you have anything that you would like to share with other members, then please get in touch with us at **WJMeditorial@theweldinginstitute.com**

Professional Affairs Group have entries in the database for every member recording their correspondence address and their last expressed preference to receive hard copy or electronic copy of the journal. If you wish to update your information please email ***theweldinginstitute@twi.co.uk***

PROFESSIONAL MEMBERSHIP – QUICK LINKS

Introduction

Professional membership of The Welding Institute provides many opportunities such as webinars, branch meetings, and technical groups as well as many other benefits. But being a professional member is also about supporting and encouraging non-members to join the Institute and mentoring those who join membership - in both the short and longer term. One of the great membership benefits seen by many, are the networking opportunities that professional membership brings and in contributing to the topics and issues relating to the work of the welding community which enables you to grow as an individual - both technically and professionally. Being a professional member gives a number of opportunities, some of which are highlighted in the following links.

Professional membership really does matter - now and in the future of our industry!

The Welding Institute

Welcome to The Welding Institute:

https://theweldinginstitute.com/

An overview of professional membership:

https://theweldinginstitute.com/membership

The difference between Professional Membership and Registration:

https://theweldinginstitute.com/membership/membership-and-registration

Membership Grades can be found at:

https://theweldinginstitute.com/membership/membership-grades

Application Process and Subscription Fees:

https://theweldinginstitute.com/membership/application-subscription-fees

Contact the Membership Office:

https://theweldinginstitute.com/contact-us

Engineering Council matters

Standards

https://www.engc.org.uk/standards-guidance/standards

Registration and the Engineering Council's UK Spec

https://www.engc.org.uk/standards-guidance/standards/uk-spec

Continuing Professional Development

https://theweldinginstitute.com/continuous-professional-development-(CPD)

Membership of the Institute of Rail Welding

http://www.iorw.org/membership

Compiled by Mark Cozens

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APPLICATION AND PROBLEMS OF SOLDERED JOINTS OF COPPER PIPEWORK IN DOMESTIC WATER SYSTEMS

Dr Zuojia Liu, Midland Corrosion Services Ltd.

Background

Soldered joints have been widely used in domestic water systems particularly for copper pipe connections over thousands of years, due to their reliability and durability. The early soldering techniques often involved the use of filler alloys of tin and lead as solder, which melt at relatively low temperatures compared with the base copper metal. Since the industrial revolution in the 18th and 19th centuries, soldered joints became a standard method for joining copper pipes in domestic and industrial plumbing systems.

From the 20th century soldering techniques continued to evolve with improvements leading to the adoption of lead-free and water-soluble solders which comply with the modern safety standards such as ASTM B828 and HSE requirements. Although solder joining techniques are very well developed pitfalls and failures still occur, often requiring extensive investigation to establish the root cause.

Common causes of failure

The common issues associated with solder joints on copper pipes are discussed below:

1. Corrosion: If flux deposits or residuals are not properly removed after soldering, or excessive flux has run and penetrated through the joint, it can lead to corrosion over time. Once corrosion is triggered, the joint can be weakened and perforated, causing leaks.

2. Leaking joints: Improperly soldered joints can result in leakage. Mostly this happens if the pipe and fitting surfaces are not adequately cleaned before soldering. It can also occur if the solder does not properly fill the joint due to insufficient heat or flux, an incorrect soldering technique or if the pipes and fittings are not properly aligned during the soldering process.

3. Overheating or underheating: Soldering requires precise heating of the joint. Overheating can damage the pipe or fitting, leading to weakened joints. Underheating may result in incomplete solder flow creating weak spots that are prone to leakage.

4. Contamination of water supply: Historically, solder joints used lead-based solder, which poses health risks due to potential lead contamination of drinking water. Also, lead containing water may affect the copper pipe, potentially facilitating the development of corrosion.

5. Skill and experience: Effectively soldering copper pipes requires skill and experience. An inexperienced individual may create defects or poor quality of soldered joints resulting in a weak, low strength and defective pipe connections.

6. Expansion and contraction: Copper pipes expand and contract with changes in temperature. Poorly soldered joints may fail over time due to thermal stress cycling.

7. Compatibility issues: Copper pipes should be compatible with the type of solder and flux used. Incompatible materials may result in weakened joints and leaks.

Corrosion as a cause of failure - general

Failure of soldered joints in copper pipes due to corrosion is still a regular occurrence. It can occur due to the following common types of corrosion.

1. Under deposit corrosion/flux corrosion attack
2. Erosion corrosion
3. Galvanic corrosion
4. Pitting corrosion
5. Microbially influenced corrosion
6. Environmental affected corrosion

Points 2 to 6 are also applicable to crimped joints, which is another popular joining technique for copper pipes nowadays.

Under deposit corrosion/flux corrosion attack only occurs on soldered joints and is one of the most common failure mechanisms in soldered joints in copper pipework systems. It is the subject of this case study.

Under deposit corrosion/flux corrosion attack – case study

Under deposit corrosion/flux corrosion is usually caused by excessive flux run or residuals remaining at the soldered joint; hence it is also referred to as flux corrosion attack. This type of corrosion can rapidly develop especially when older-style fluxes containing ammonium chloride (NH_4Cl) and/or zinc chloride ($ZnCl_2$) were used. The conditions beneath the flux deposits can be very acidic leading to a high corrosion rate.

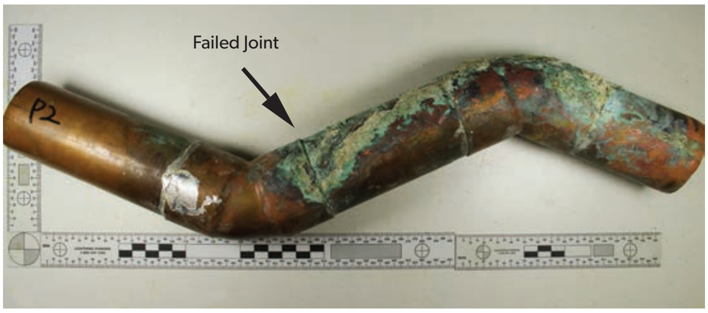

Figure 1: A domestic cold water copper pipe which has suffered leaks from soldered joints. Copyright MCS Ltd

The failure in question is shown in Figures 1 to 3 which exhibits leakage failure from soldered joints of a domestic cold water copper pipe. Before cleaning the bore, the joint was covered by a thick, green patina mixed with excessive flux residues, white and yellow deposits and blue crystals. The white and yellow deposits could have originated from the solder flux compositions while the blue crystals were most likely from the copper hydroxy product or copper sulphate. After removing the deposits, significant remanence of solder and flux run was noted at the joint, extending to the adjacent pipe bore creating a corrosion circle (Figure 2). Within the circle, irregular deep corrosion pits along with the flux residue were observed.

Figure 2: The copper pipe bore after sectioning. Copyright MCS Ltd

For flux corrosion attack under deposits the failure manifestation is mostly by pitting, which may not become obvious until the deposits are fully removed. 10% sulphuric acid is usually employed for cleaning, based on the recommendations of BS EN 8407 and ASTM G1. Microscopic examination is often required to inspect the surface and to establish the pitting morphology.

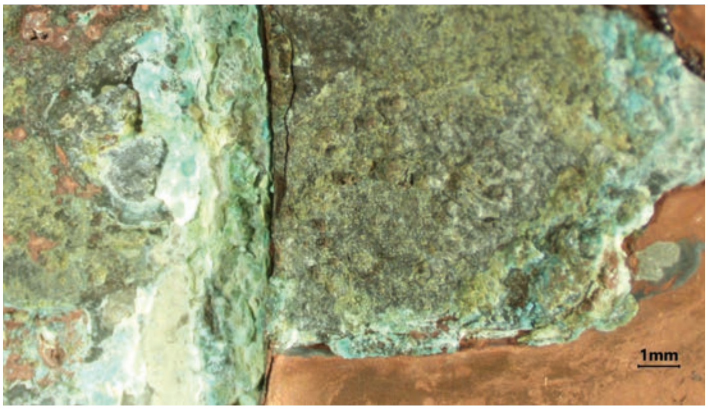

Figure 3: Microscopic images of the internal of the leak area before chemical cleaning (top) and after chemical cleaning (bottom). Copyright MCS Ltd

Sometimes subjective judgement has to be made between under-deposit corrosion and crevice corrosion as both are promoted by variations of oxygen concentration. Crevice corrosion normally occurs in stainless steel or carbon steel in which a passive film or iron oxide layer can form on the surface, and both mechanisms require consideration. Copper pipework surface does not generate a passive film indicating that concentration cell corrosion in copper is (perhaps) related only to under-deposit corrosion. Further, under the deposits, some aggressive agents such as chlorides, sulphates or even micro-organisms may be concentrated, enhancing the corrosion attack of the copper pipe.

In addition if there is no excessive flux penetration of the pipe joints but there are voluminous corrosion deposits it could still indicate under-deposit corrosion. In other words, excessive flux run through copper pipe joints can either be a predominant cause of corrosion or a mutual contributor.

Testing and analysis

In pipe joints that have suffered leakage failure it is appropriate to cut the pipes open for visual inspection of the pipe bore and the joint surface, to examine the deposits visually and look for evidence of excessive flux.

To identify whether corrosive agents have been concentrated under the deposits or fluxes the corrosion deposits should be carefully scraped off for X-ray fluorescence (XRF) analysis. An example result of XRF is displayed in Figure 4, which presents a trace for the corrosion deposits from the pipe under examination. The deposits consisted mainly of calcium, copper and chlorine. The presence of calcium indicated that the deposits contained calcium carbonate (limescale). The detection of chlorine is usually an indication of chlorides under the deposits. Both limescale and chlorides are aggressive to a copper surface and probably enhanced the corrosion rate and reduced the time to perforation.

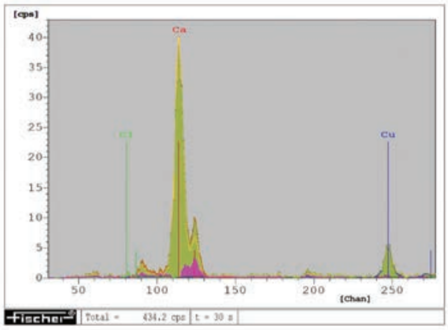

Figure 4: XRF spectrum analysis result from the deposit collected from the failed joint. Copyright MCS Ltd

XRF analysis is usually semi-quantitative whereas EDX (Energy dispersive X-ray spectroscopy) in a Scanning Electron Microscope (SEM) can be used to determine a fuller quantitative result including potential components such as silicon, sulphur, potassium, phosphate, lead etc. EDX analysis can identify accurately the content of each component. Analysis of the water chemistry is used to assess the corrosion condition within the pipework. The result is likely to shed light on the compositions of the corrosion deposits.

Microbiological analysis of water will determine whether there are micro-organisms present in the pipes. If micro-organisms are present they may have grown under the deposits and through the joints, their proliferation creating the risk of microbially influenced corrosion (MIC), accelerating the under-deposit corrosion.

Recommendations for domestic plumbing pipework

1. Always use lead free solder and adequate water soluble (dispersible) flux.
2. Corrosion caused by excessive flux attack is usually the result of poor installation practice. It is recommended that all work is done under appropriate supervision.
3. It is recommended to ensure the system is thoroughly flushed to the requirements of BS EN 806-4 after pressure testing to remove deposits and excess flux.
4. After commissioning it is suggested to avoid stagnation by ensuring that the pipework is used. If not in use the piping should be flushed regularly (at least twice a week) to introduce fresh aerated water into the system which allows the build-up (and maintenance) of a stable protective malachite layer on the bore of copper pipe.
5. A thorough disinfection regime/programme should be carried out to reduce or eliminate any bacteria/micro-organisms in the copper pipework system. This will protect against MIC which can thrive under corrosion deposits, especially at joints.

Corrosion is unpredictable but with appropriate controls based on the understanding of the possible mechanism, it can be prevented assuring the integrity and extending the remaining life of the copper pipework material.

References

BS EN 806: part 4. Specification for installations inside buildings conveying water for human consumption. Installation.

BS EN 8407: 2021. Corrosion of metals and alloys. Removal of corrosion products from a corrosion test specimens.

ASTM B828-16. Standard practice for making capillary joints by soldering of copper and copper alloy tube and fittings.

ASTM G1-03(2017)e1. Standard practice for preparing, cleaning, and evaluating corrosion test specimens.

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WIDE GAP BRAZING: AN INNOVATIVE WAY TO EXTEND THE LIFE OF HIGH TEMPERATURE COMPONENTS

Scott Nelson, Rolls-Royce Corporation, Materials Technical Specialist and Global Process Owner for Brazing.

Introduction – nozzle guide vanes

Since the development of Gas Turbine Engines nearly eighty years ago, the demand for decreased costs and increased performance has required components that can withstand higher temperatures and longer service lives. Modern turbine components, such as Nozzle Guide Vanes (NGVs), responsible for directing and harnessing the violently expanding gases from fuel combustion, are made of advanced nickel-base superalloys, cast using solidification techniques, like single crystallization, and are designed with intricate cooling features. These components are, consequently, expensive to produce and require long lead times with careful logistical planning.

Figure 1: A Trent engine under inspection. Credit: Gary Marshall. Copyright: Rolls-Royce Holdings plc, 2015

To further complicate the life cycle of a NGV, the harsh operating environment of the turbine section of a gas turbine engine results in a degradation in performance and a finite service life. When an NGV is removed for an overhaul interval, the story of its life is clearly visible: cracks from the thermal stress of numerous take-offs; erosion from the constant stream of hot, high-pressure gases providing thrust; and surface wear from the continuous vibrations from an engine in-flight. Through this punishing life, the carefully designed aerodynamic and cooling features of the NGV can no longer function effectively and the part must be retired from service.

Repair of nozzle guide vanes

To avoid the time, expense, and environmental impact required to replace a used part with a new one, repair technologies have been developed that allow these used parts to continue to help power our modern world. One such technology, Wide Gap Brazing (WGB), provides many NGVs this opportunity and Rolls-Royce continues to apply this process to new products and components in innovative ways.

WGB is a technology derived from nickel diffusion and transient liquid phase bonding and is used to repair high temperature nickel alloys in both aerospace and ground-based gas turbine engines. WGB filler materials consist of two primary components, a superalloy powder and a lower melting braze powder. During a vacuum furnace brazing cycle, the braze powder constituent will melt and melting point suppressants such as boron and silicon will begin to diffuse into both the component and the superalloy powder. This compositional shift raises the melting point of the braze and leads to isothermal solidification, effectively creating a population of microbrazes between the superalloy powder particles and the component. As the braze cycle continues, the diffusion of the melting point suppressants ensures a strong, thermally resistant repair is left in place without brittle eutectic intermetallic phases.

WGB methods can repair cracks with widths of up to 2 mm (0.080 inches), a significant increase compared to traditional braze joint clearances. This capability also allows for the restoration of areas worn away by fretting, erosion, and thermal mechanical fatigue. WGB materials and processes are coordinated to control the filler alloy flow and ensure chemical compatibility. WGB balances constituent powder mixes and furnace time/temperatures to achieve the required material properties and filler flow sufficient to achieve dimensional controls. This powder mixture composition is defined by how much the alloy needs to flow to complete the repair; a crack will need more flowability and a higher percentage of braze, where a dimensional restoration repair will need to stay in place and have a higher percentage of superalloy powder. WGB filler materials are used by all aerospace engine manufacturers and repair facilities internationally, with both proprietary and commercially available compositions.

Wide Gap Braze filler materials come in numerous forms to ease application including slurry, paste, paints, powders, flexible sheets and rigid (sintered) sheets. WGB slurry and paste are used to heal cracks and provide material for dimensional restoration of worn areas. The flexible and rigid sheets, machined to a precise shape or preform, provide a more repeatable and reliable method, in comparison to the paste, to apply the WGB. These preforms are known as a Braze Sintered Preforms (BSP) or Pre-Sintered Preforms (PSP).

Figure 2: A Royal Air Force C130 J powered by the AE2100 engine. Copyright: Rolls-Royce Holding plc, 2009.

Repairing the 'unrepairable'

Thus far, WGB repairs have been restricted to small cracks and minor wear damage, which leaves much of the population of damaged turbine vanes unrepairable. Due to the high component costs, unrepairable components are often stored waiting for suitable repair development, creating large populations in warehouses, and leaving operators and OEMs with the cost to store and replace them.

Figure 3: An engine run AE2100 NGV during with previously unrepairable damage as noted during initial inspection. Copyright: Rolls-Royce Corporation, 2018.

In recent years, the population of unrepairable nozzle guide vanes has continued to expand at an accelerated pace. To improve operational efficiency, commercial and military operators continue to push the envelope and run combustor temperatures to the upper end of their specified limits; while this may optimize mission performance, it also results in shorter operational lives of the turbine vanes. This type of damage can start as a small crack which breaches the pressure side of the airfoil and allows the hot combustion products to enter the internal cooling passage and disrupt the cooling air, which results in oxidation, melting, and physical damage to the airfoil and the internal cooling structure. This type of damage has previously been deemed unrepairable, but PSP developments, made through a research partnership between Rolls-Royce and AIM MRO, present a new opportunity.

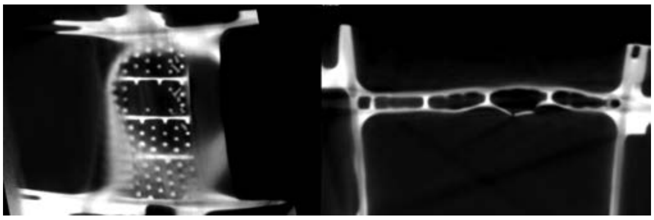

Figure 4: Radiographs of damage to NGV surface and destruction of internal cooling features in AE2100 engine. Copyright: Rolls-Royce Corporation, 2018.

The first application of this novel PSP repair was on a single crystal turbine NGV from the Rolls-Royce AE3007 engine, powering many small regional and corporate airframes. This damage presented as a small hole measuring 10 to 30 mm (0.4 to 1.2-inch) in diameter with cracks radiating towards the edges and platforms of the vane; the internal cooling passages were featureless. To repair this damage a milling tool was used to remove a specific amount of material corresponding to a preset patch preform. These patches comprised a single crystal specific composition and were made using a significantly higher ratio of superalloy to prevent sagging into the internal structures during brazing. WGB paste is also used adjacent to the patch and on the radial cracks before a cover preform is added. After brazing and heat treatment the airfoil is blended to match the required geometry. The final repaired component is returned to service extending the usable life for most previously unrepairable parts.

Repair of NGVs in the AE2100 engine

Other parts provided different challenges that required an even more novel solution. The internal cavity of the AE2100 turbine NGV component found on the internationally operated C130J is an equiaxed nickel superalloy component and features sets of sub-millimeter pins and rails to promote increased heat exchange and turbulate the cooling air. Damage on the airfoil, results in significant impact on the internal cooling geometry leading to a loss of cooling efficiency and potential for debris damaging components downstream. To repair this damage Rolls-Royce used an additive process developed by AIM MRO that produces high resolution 3D preforms. This involved adding layers of metal powder and binder on top of each other to create the desired shape. With this capability it is possible to design wide gap braze patches that include complex cooling features integrated into a patch to restore both internal and external features. The 3D preform patch is brazed much like the AE3007 repair method which is then blended to final configuration requirements.

This method resulted in a repair that successfully met all metrics set by the program including internal and external geometry, joint integrity, and cooling airflow. Evaluation of the repaired component showed that a controlled braze flow process, resulting in internal air passage with complex geometries, could feasibly be repaired using 3D sintered patches.

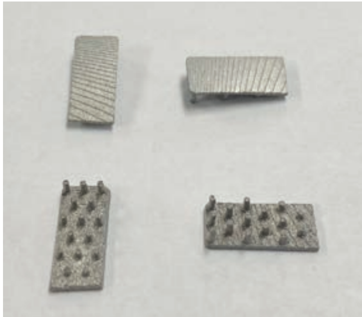

Figure 5: 3D preforms with cooling features designed and produced for the AE2100 NGV repair. Copyright AIM MRO Holding Inc., 2023

Figure 6: Leading edge 3D preform developed to replace a Trent XWB NGV with modern cooling features. Copyright AIM MRO Holding Inc., 2023

Work is still underway on the development of a new repair focused on the complete replacement of the leading edge of a damaged turbine vane airfoil from large civil engines powering airframes such as the Airbus A350 and Boeing 787. This repair requires a complex three-dimensional patch geometry with integrated cooling holes with internal cooling features and five-axis machining to remove the damaged material prior to braze replacement and blend the repaired area.

Summary

The successes of wide gap brazing and complex 3D braze preforms also provide opportunities for the future of wide gap brazing outside of the current repairs. Possibilities include using patches to alter material properties, repair or change cooling circuits, and manufacture or restore complex airfoils. As the engines get hotter and critical cooling pattern designs require more costly processes to produce the components, repair and manufacturing technologies must keep up. Additionally, the environmental impact of both manufacturing new components and the operation of less efficient aircraft engines must be mitigated for the benefit of our planet. Through our repair efforts, Rolls-Royce has shown that Wide Gap Brazing can provide the needed solutions by utilizing a balance of materials, processes, and 3D technology for both high-temperature turbine component service repair and new component manufacturing innovations.

Based on the feature article, "Additive Braze Preforms Take Turbine Repair to a New Dimension," by Scott Nelson and Justin Boreman published in the American Welding Society's October 2023 Welding Journal. Visit https://www.aws.org/publications/WeldingJournal.

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INDUSTRIAL APPLICATIONS OF BRAZING – THE CHALLENGES

Paul Brooker and Nick Ludford. TWI Ltd.

WJM joined our guest editors, **Nick Ludford** and **Paul Brooker** (who are profiled on page 30) to tap into their extensive industrial experience with brazing and to discuss some of the common challenges.

WJM: What are the most important considerations in applying brazing technology successfully in an industrial application.

Brazing has been around since approximately 3000 BCE when it was used in making jewellery so it has a lot of history and in modern usage it exists in many variants such as furnace, induction, vacuum, torch, inert and power beam brazing. However many of the challenges associated with brazing have not changed over the years such as part fit up, correct material selection, temperature and joint inspection.

When considering using a brazing process, the following points need to be considered at the design stage of the assembly: materials, joint configuration, joint clearances, service environment, component working temperature, the braze filler material (BFM), the development required, inspection criteria and certification requirements.

Brazing is an ideal process for joining dissimilar materials both in air, inert gas and vacuum environments. Choosing the correct brazing process is key to getting a repeatable manufacturing process and can affect the overall design and working life of the assembly.

Design for brazing

Material properties need to be taken into account very early in the design process of a part proposed for joining by brazing. Brazing can be the solution to joining materials that are not suitable to be welded due to compatibility of the materials being joined or if distortion may be an issue. When designing the parts for joining dissimilar materials we need to take into account the thermal expansion rates for each material in order to ensure we have clearance for capillary flow of the BFM into and through the faying surfaces to produce an acceptable level of joint fill. Too tight, and the BFM may not flow correctly into and within the joint and too large a gap and the BFM can drop through. In both instances, this is likely to result in joints that have a lack of fill. The most common mistake is that the clearance required is calculated at room temperature rather than the brazing temperature.

Selection of the braze filler metal

Once the assembly has been designed, the next step is to consider the working environment and operating temperature of the assembly to ensure you choose the correct braze filler metal (BFM) (BS EN ISO 17672:2024). The liquidus temperature of the BFM should be sufficiently high that it cannot re-melt during intended operation and also that the joint retains sufficient strength. Sometimes an additional limitation in selecting the BFM is when you need to keep the parts below a certain temperature, due to the potential of changing the characteristics of the component base materials through exposure to high temperatures.

A particular challenge related to applications in the nuclear industry is that there are certain elements in typical BFMs that are not allowed to be used in the specific service environment. Also, if the parts are being used in a corrosive or hostile environment this will affect the BFM to be used.

Brazing can also be used for joining different parts to build sub-assemblies which can then be formed into a final component in a process known as 'step brazing'. This involves starting with a high temperature BFM for the first joint, then changing the BFM for the next joint to one that has a lower liquidus temperature compared to the previous. This can be done multiple times, reducing the liquidus temperature of the BFM each time. There are sometimes issues with this method due to the number of times the parts have to go through a thermal cycle.

Application of standards to achieve performance and quality

For any brazing process the correct development programme and testing needs to be in place to ensure a reliable and repeatable process. This can be done applying the standards listed on page 38 in respect of brazeability and gap-filling, procedure approval, qualification of personnel, non-destructive testing and limits on imperfections.

WJM: What industrial challenges do you think will need to be addressed in the future.

Brazing will be a key joining process for the future development of new products. For example, with the growth of additive manufacturing (AM), there will be a requirement to join parts together to create larger, functional assemblies. This may be challenging due to the composition, microstructure and the surface finish of the AM component. TWI are currently doing development work funded by the Core Research Programme which is looking at these issues, in which we are evaluating BFMs and processes to produce a good joint.

The nuclear sector is also an area of growth due to the requirement for joining of less common and new materials as well as dissimilar materials which are required for the ITER build, STEP tokamak and small modular reactor (SMR) systems. Many of the current BFMs are not compositionally suitable and new BFMs will need to be developed to meet the ever-changing requirements during the build of these systems. Increasingly BFMs and brazing processes will need to be considered with respect to sustainability and environmental impact; reflecting industrial trends.

Another current concern is a loss of knowledge within companies involved in the brazing industry and achieving the skills in new employees. TWI has recently carried out a number of bespoke training courses on vacuum brazing to companies to help up-skill new staff to provide necessary knowledge and understanding of the brazing process.

WJM: Would you be able to share some common issues that occur related to brazing processes?

Common issues in torch brazing are:

Over-heating

This is a common fault which can result in the parts distorting or even partially melting. Using a burner nozzle that is too big for the application with the intention to heat the part up quicker is a common error.

Wrong filler

There was an instance years ago when a part was falling apart in service. After intensive investigation it was found that the braze filler material was re-melting due to the working temperature of the assembly. The solution was to replace the BFM with one with a higher liquidus temperature.

Flux selection

Using the wrong flux can result in poor wettability or in certain circumstances can react negatively with the materials being joined causing issues with the finished brazed joint. The point was made above regarding joint clearance and capillary action; if the clearance is not correct for the BFM, there is a potential that when the BFM capillaries through the faying area, it does not drive the flux out, which potentially can result in later corrosion

Fillet versus fill

There is the classic argument 'well it's got a good fillet so it must be ok', but when the joint is sectioned there is found to be insufficient fill and the parts fail. The reality is that if you apply BFM to the top of the joint as it capillaries into the joint it should leave a very small fillet and produce good fill.

Common issues in vacuum brazing are:

Heating rate

Many BFMs used in vacuum brazing have temperature suppressants, such as boron, to reduce the BFM's liquidus temperature. If you heat too slowly to the brazing temperature the boron diffuses into the material being brazed prior to the joint reaching the BFM's liquidus temperature, which increases the melting point of the BFM. This results in the comment 'the BFM did not reach brazing temperature', which is incorrect; it has been heated too slowly. The solution may be to increase the heating rate.

Brazing clearance

This is covered above but is also relevant here: always calculate your clearances at brazing temperature and not room temperature. In addition always consult the specification sheet for the BFM as the suitable gap size can vary between different BFMs.

BRAZING AND SOLDERING – A HISTORY AND PRINCIPLES

Shaun Meakin. Joint Managing Director of CuP Alloys (Metal Joining) Limited

Definitions

Brazing is defined as the joining of two metals by capillary flow by using heat with a filler rod whose melting temperature is above 450 °C but below that of the parent metals. The principles are the same with soft soldering except the joints are formed below 450 °C. Brazing is a skilful process but by sticking to the principles it is a skill that can be readily learnt.

Early beginnings

The use of brazing dates back to around 4000 BC in Mesopotamia, where the earliest recorded brazed joints were created. Archaeological discoveries show brazed artifacts, particularly jewellery and ornaments. These early joints were made predominantly using gold and silver alloys. These materials were very resistant to deterioration so have stood the test of time and are still admired today for their craftsmanship.

There is some evidence that around this time joints were also being made with tin and tin-based alloys, what we would now call soft soldering. But, because these alloys are not so resistant to corrosion from rainwater and the ground's natural chemicals, there have been much fewer artifacts discovered. Examples have been found in Egypt and Northern Europe from about 4000 years ago.

Figure 1: Image from Egyptian tomb showing a man brazing approx. 4000 years ago. Source: Nina M. Davies. Wikipedia. Creative Commons CC0 1.0 Universal Public Domain Dedication

continues on page 46

Throughout history, brazing continued to evolve, spreading across civilisations such as the Greek and Roman empires. In China and India, base metal brazing alloys emerged around four thousand years later, with the discovery of zinc and its combination with copper to create the first base metal brazing alloys. The creation of brass marked a significant milestone in the history of brazing. In approximately 2000 BC the Sumerians brazed bronzes and this is when the first evidence of flux being used is found. It wasn't until the mid-sixteenth century, facilitated by Dutch traders, that brass became an economically viable material in Europe. The term "braze" may have originated from "brass" highlighting its significance as a means of joining metals.

Arguably the biggest change in recent years was the banning the use of cadmium-bearing brazing alloys in the EU in December 2011. The addition of cadmium lowers the brazing temperature and the melting range of the alloy. To compensate it is necessary to add silver. For example, a 42% silver-cadmium bearing alloy melted at 610-620 °C. In terms of performance the nearest cadmium free alloy is 55% silver melting at 630-660 °C.

There are many brazing alloys in use today available as bare rods and wires, flux coated rods, flux cored rods and wires and preforms such as rings and paste. Materials range from gold and palladium alloys used in steel structures such as office furniture.

Silver brazing alloys predominantly contain 5-55% silver content which are used for brazing a variety of materials such as mild and stainless steel, and copper-phosphorus and silver-copper-phosphorus alloys used in, for example, joining copper pipes in refrigeration and air conditioning applications. Higher silver contents are used in jewellery where 65% silver is the lowest that can be used to retain the hallmark of the silver.

Why braze?

The reasons as to why we braze are the same today as 6000 years ago: It is a highly versatile process allowing both similar and dissimilar metals to be joined. The brazed joint is made at a relatively low temperature, well below the melting point of the parent metal(s) meaning the component is unlikely to suffer from discolouration, distorting or much worse, melting! The low temperatures allow very thin components to be joined and if done correctly the brazed joint are usually much stronger than the parent metals. (In stainless steel it is possible to produce joints with a tensile strength of 696 MPa (130,000 lb/in^2)). The brazing alloy may create a better colour match for example in jewellery.

Many of today's brazing alloys contain silver (silver brazing alloys). Although intrinsically these alloys are more expensive than, for example, welding alloys, the lower operating temperature reduces heating costs and the quick process leads to lower costs per joint.

The Role of silver solder

Silver solder emerged as a favoured brazing alloy in industries, leading to the range of silver solder used today. Silver solder offers numerous advantages, including the ability to join a wide range of dissimilar metals, strength, leak-tightness, and resistance to corrosion. Its low melting points allow for energy-efficient joints with minimal distortion, resulting in joints stronger than the parent materials.

Understanding brazing

Brazing is akin to soldering but conducted at higher temperatures. It involves drawing molten alloy into a controlled gap between two components by capillary attraction. This process, upon solidification, produces sound joints characterised by high integrity and strength. Unlike welding, the strength of brazed joints is not solely dependent on the filler metal or the parent materials. Brazing continues to be a vital metal joining technique, providing durable and reliable solutions for a wide range of applications.

The brazing process

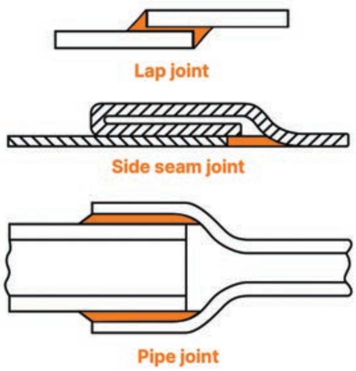
There are several stages to producing sound, leak free joints. All are meant to increase the opportunity of capillary flow of the brazing alloy over into the joint.

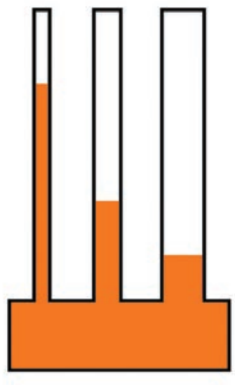
Surface preparation

Both pieces to be joined should be clean and free of rust, oil and grease. If pipes are cut, for example in refrigeration, they should be deburred. Do not clean by sandblasting or using any grit-based product such as emery cloth. Both these techniques can leave behind a residue that cannot be removed by flux.

Joint design

There are basically 2 types of joint design, butt and overlap and these and the variants on them are shown in Figure 2. Whichever type is used there must be a joint gap. The ideal joint gap is 0.05mm to 0.2mm, the narrower the gap the stronger the joint produced. As the strength of a brazed joint comes from the length of the inter-alloy areas formed during capillary flow into the joint, called the joint length, it is true that an overlap joint is stronger than a butt joint. However, the joint length of a butt joint can be increased by producing a scarf joint, cutting the parent meals at an angle. However, it should also be noted that a longer joint length does not produce a stronger joint and can lead to the alloy 'freezing' and building a crack into the back of the joint. The joint length should be no longer than 3 times the thickness of the thinnest part. For example a pipe joint (Figure 2) with a tube of wall thickness of 1 mm thick going into a 1.5 mm wall tube should overlap no more than 3 mm. If one part, (the 'female') is heated more than the other it opens up the gap and when cooled the residual stresses are in torsion, not shear.





Above: Figure 2: Examples of typical joint designs.

Left: Figure 3: The effect of gap on capillary action

Capillary action

Figure 3 represents an experiment using copper plates and water. It shows that capillary flow is not affected by gravity and the narrower the gap the greater the rate of capillary flow.

Fluxing the joint

Prior to assembly the joint area of both parent metals should be liberally fluxed. Either use a ready-made flux paste or mix powder with water and a couple of drops of washing-up liquid. The washing-up liquid helps as an extra degreaser and also aids the powder in suspension. There are many types of flux on the market today, including a flux that changes colour when brazing temperature is reached. Ensure you have the right flux for the parent metals you are joining. The flux acts in 2 ways, as an agent to dissolve oxides at the joint, and also as a barrier to prevent further oxides being formed. Additional flux may be added during the heating process by 'hot rodding,' warming the end of the rod and then dipping it into flux powder so some adheres to the rod itself. This should not be used instead of pre-fluxing. There are flux coated rods available now but these have a special coating of fast acting aggressive flux.

The exception to fluxing the joint is when brazing copper to copper such as refrigeration pipework. Here the use of a copper-phosphorus or a silver-copper-phosphorus rod does not require a flux as the phosphorus content acts as a fluxing agent, but only on copper to copper, and not with copper alloys such as brass.

Figure 4: Ensure plenty of flux is applied to the joint area

Heating the joint

The next operation is heating the parts. This requires the most skill as the heating must be correct; too little heat and the alloy won't flow, too much heat can exhaust the flux leading to voids in the joint. Excessive heat can also affect the parent metals through, for example, distortion.

There are many ways of heating the brazed joint. Most of the joints today are heated by a furnace, but this is in specialised applications such as in automated large batch production. It is most likely the joints will be heated by a hand-held gas torch, with gases such as acetylene, propane or 'MAPP' or its substitutes. Other less popular heating methods are induction or resistance heaters.

Good brazing practice is to bring the whole joint area up to the melting temperature of the brazing alloy as quickly as possible. If both components are similar in size and metal, e.g. copper to copper, this can be achieved by playing the flame all around the joint area. If one of the components is larger, or of a material with poorer heat conductivity properties, such as steel, heat must be concentrated on this part of the assembly. The smaller or more heat conductive part of the assembly will get its heat from the other part.

A good guide to the temperature is the appearance of the flux paste. Once the paste has turned from a white 'milky' liquid to clear (like water) it is starting to work and so the joint area is around 550 °C. A little more heat and then the brazing alloy can be applied to the joint. Do not heat the joint, but now concentrate the heat where you want the alloy to flow, since molten brazing alloy will always flow to the hottest point. If you are joining two tubes, when the joint is hot enough apply the rod at '3 pm' and the flame at '9 pm'.

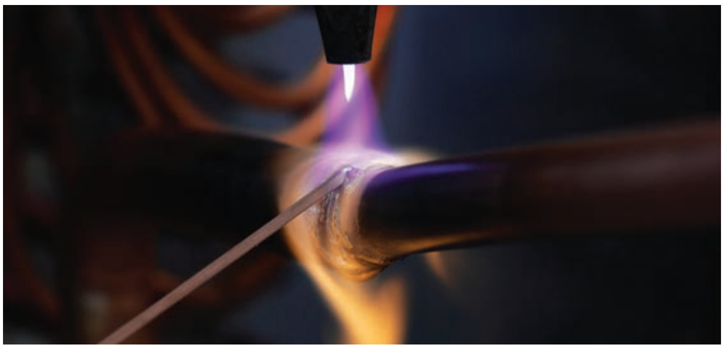


Figure 5: Brazing copper to copper using a copper-phosphorus alloy

With the correct heating technique the allow will flow into the gap by capillary attraction producing a sound leak free joint. Do not heat the rod, heat the joint. In the case of brazing copper to copper with a copper-phosphorus alloy, where no flux is used, the copper is at brazing temperature when it turns cherry red. (Figure 5).

As a precaution when heated both flux and metal will produce fumes. Ensure there is adequate ventilation around the brazing station and never work from above looking down on the workpiece.

Once the joint has been brazed, allow the component to cool and then clean with warm water and a wire brush. Ensure the flux residues are removed as these can be corrosive, particularly the more aggressive fluxes used on, for example, stainless steel. For stubborn residues an acid solution may be required such as citric acid, or with specialised equipment sulphuric or hydrochloric may be the correct choice.

Closing remarks – the current market

Aluminium is now widely used in heating and heat exchangers requiring new developments in brazing alloys. Aluminium traditionally was a very difficult material to join, whether brazed or welded, but now new alloys are emerging allowing it to be brazed much more readily.

Traditional markets for brazing remain strong and with emerging new economies comes new markets, notably in refrigeration and air-conditioning products. The demand for brazed joints is predicted to experience continued growth in the future.

Shaun Meakin

Shaun Meakin is joint managing director of 'CuP Alloys (Metal Joining) Limited.' CuP alloys was formed in 1982 initially to supply copper phosphorus alloys (the chemical symbols are Cu and P) to the heating, ventilating, refrigeration and air-conditioning industries. Today they also serve other markets such as shipbuilding, aerospace and automotive industries, including hobbyists.

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ADVANCED BRAZING PRODUCT FORMS REDUCE FLUX HANDLING AND INCREASE PRODUCTIVITY

Phil Webb, Commercial and Technical Director at VBC Group, discusses the Meta-Braze Advanced™ forms of brazing products that contain both a filler metal and a flux.

Background

VBC Group are a provider of consumables for brazing, welding and additive manufacturing. The Company is based in Loughborough, UK where it undertakes welding wire processing and manufactures furnace brazing pastes. In 2016 VBC Group expanded its range of technical brazing products under the Meta-Braze™ brand.

What is a Brazing Flux?

In most cases brazing in air requires the use of a product called a flux. Brazing flux is a chemical compound, which acts to reduce oxides on the surface of the components being brazed. During the process of heating to brazing temperature the flux becomes 'active' and begins to perform three primary functions:

- Removing oxides on the base metal surface and filler metal.
- Excluding oxygen during the heating process to prevent oxidation of the metals.
- Assisting the flow of the brazing filler metal by creating oxide-free faying surfaces.

The Health and Safety Considerations

Fluxes for silver or aluminium brazing generally consist of a complex mixture of borates of alkali metal halides. These chemicals have always required careful handling, observing the guidance on safety data sheets (SDSs) and wearing correct PPE to ensure the safety of operators. In recent years the chemicals in fluxes have come under more scrutiny as the scope of the EU REACH directive broadens. Boric acid, one ingredient in flux manufacture, is included in the REACH Candidate List of Substances of Very High Concern (SVHC). All fluxes carry a hazard designation which needs to be taken seriously. Some manufacturers have sought to reformulate fluxes with chemicals that have attracted an apparently less harmful designation. Others have taken the view that any flux that contains borate chemicals is likely to carry the same risks, whether it has been designated as such at present or not.

There is a growing realisation that reducing the amount of flux used may be the way to go. Controlling how much flux is used and where it is positioned during brazing can help with this goal. In any event, understanding the risks and following the suppliers' guidelines will protect brazing operatives.

Flux Containing Products

Flux containing or integrated brazing products have been around for a few years now and can offer some interesting advantages, particularly to companies brazing pipe and tube fittings. They are being looked at afresh not only because of their potential productivity benefits but also because of the health and safety and REACH classification issues.

Flux containing brazing products have the flux, which is normally applied separately, contained within the brazing alloy. There are several ways in which this is done, and suppliers of these products can advise on the best for a particular application.

Flux Containing Brazing Alloy

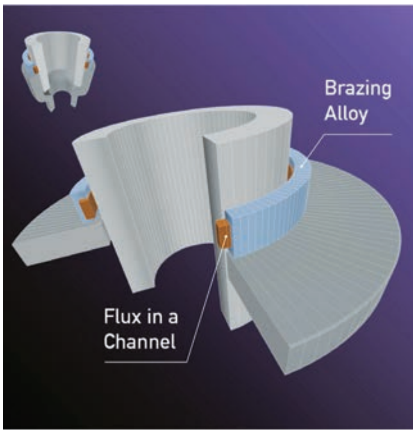


Figure 1:
Flux in channel in brazing alloy

This highly effective form of flux-cored product allows the flux to melt from the channel in a grooved section. A benefit arises from the flux in the braze filler metal ring being directly in contact with the tube or pipe close to the joint opening. This means that it is the heat from the components which melts the flux and not the heat source. If a braze ring is placed correctly the flux will penetrate the joint and the brazing alloy will follow it shortly afterwards. This gives rise to high quality and repeatable joints being made.

It is sometimes necessary to use a spiral with 1 ½ or 2 turns to get sufficient alloy into the ring when replacing a solid ring. Different types of flux are available for use in combination with silver and aluminium brazing filler metals.

Flux Cored Brazing Alloy Wire

Figure 2:
Flux cored brazing alloy wire

This form of flux cored product has proven to be reliable in a number of brazing applications. The flux melts from the central core of the product coming out through the seam and the ends of the ring before the filler metal melts. The amount of flux in the ring can be reduced further by incorporating a wire inside the flux cored part of the ring. This product is available in both silver and aluminium brazing filler metal alloys.

Flux Impregnated Brazing Alloy

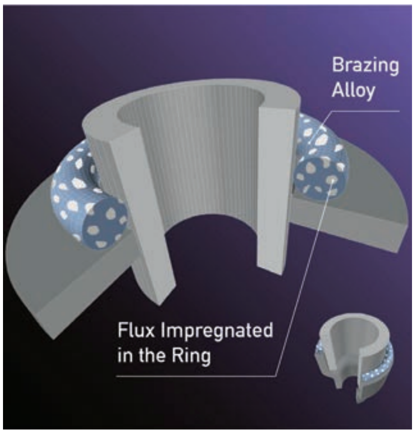


Figure 3: Flux impregnated filler metal

This form of flux-cored product is only available as an aluminium brazing filler metal and flux combination. The flux is impregnated in the brazing filler metal and melts out of it as the brazing temperature is reached.

This type of product is best suited for induction heating as opposed to flame brazing where there is a potential of flux exhaustion.

Preformed shapes, such as oval washers, can be pressed using special tooling making this a potentially interesting solution for mass production of components which have geometries that don't suit a ring.

Brazing Paste

Brazing paste is a well-established product which incorporates a flux and brazing filler metal in a form in which it can be applied to components prior to heating.

This is a versatile solution for components where there is a suitable horizontal surface, groove or ledge on which the paste can be positioned. The brazing alloy to flux ratio and flux type can be configured to provide a bespoke solution. Handling of the paste can be reduced using automated dispensing equipment.

Paste can be applied in dots, stripes or around complex profiles which would otherwise require tooling to produce a shaped brazing preform. Paste can also replace numerous brazing preforms with one product formulation giving potential inventory savings.

Which Solution is Right?

Choosing the correct product for a particular application will depend on several factors. These include the parent metals, the brazing alloy, the amount of flux needed, the heating method and the size and geometry of the components being made and how they relate to the joint itself.

Careful assessment of the amount of filler metal needs to be made during initial testing. This can also be calculated taking into consideration the materials involved, thermal expansion rates, dimensions and tolerances.

For some manufacturing processes the benefits of flux containing brazing products aren't sufficiently great to outweigh the increased cost of a bespoke solution. In some cases, manufacturers find that the flux they use is also protecting the surface of the parts away from the joint area and this makes post braze clean up easier. This benefit should be balanced against the increased use of flux chemicals. Once the preferred brazing filler metal form is decided upon it is normal to undertake a period of testing in which the entire cost of making the brazed joint is calculated.

Summary

Advanced flux containing brazing product forms can reduce handling of flux chemicals during brazing and this safety advantage is adding to the existing productivity benefits from these product forms.

QUIZ ON PREHEAT - ANSWERS

a) Preheat is not a mandatory requirement in most application standards – it is only a recommendation. It becomes mandatory when the WPS is qualified with it – and is then ignored at your risk!

b) Austenitic steels do not normally require preheating due to having an extremely high tolerance to the presence of hydrogen, because of their crystal structure (face-centred cubic). They are therefore highly resistant to cold cracking.

c) Advice on preheat temperatures for creep resistant alloys can be found in many application standards, particularly the ASME codes, with detailed tables in ASME B31.3 and BS 2633.

d) Ferritic steels undergo changes in crystal structure on heating and cooling which means that brittle, crack sensitive microstructures can be formed on rapid cooling. Preheat slows the rate of cooling and reduces the risk of cracking.

e) The four factors are steel composition, welding heat input, component thickness(es) and weld metal hydrogen content.

f) Composition of the steel is the most important factor with carbon being the major element. In any application consider the composition first to assess the level of risk of heat affected zone hardening and cracking and the potential strategy for its avoidance taking into account the other factors and assessing the necessary level and complexity of mitigation measures.

g) Oxy-gas heating either with a direct flame or by radiation, electrical resistance elements and HF induction.

h) A temporary attachment will probably be fillet welded thus there are three directions for the diffusion of heat resulting in a faster cooling rate than the adjacent butt weld.

i) Matching the tensile strength of a very high strength steel may require the use of a highly alloyed filler metal – an S/P960 for example may be welded with a MnNiCrMo filler metal with a CEv around 0.75.

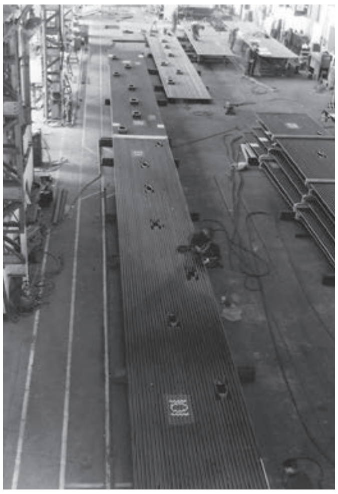
j) Both ISO 15614-1 and ASME IX permit the preheat to be reduced by 50 °C from that recorded in the relevant PQR but only if this reduction can be justified by additional testing or by calculation in accordance with BS EN 1011-2 Annex C.

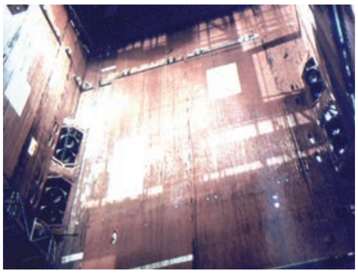
FLASH BUTT WELDING OF BOILER TUBES

EUR ING Gene Mathers CEng MSc DipIIM FWeldI.

Water-wall boilers

During an almost 40-year period from the mid-1950s there was a rapid expansion in the number and size of coal fired power stations with the early boilers generating around 200 MW and later, super-critical designs, generating some 660 MW. The majority of these boilers are described as “water wall” boilers comprising what is essentially a large, vertical rectangular box – the water walls forming the combustion chamber some 50 m in height and with heat exchanger elements suspended from the roof. Typical boiler panels are illustrated in Figure 1a and Figure 1b.





Left: Figure 1a: Typical water wall boiler panels

Above: Figure 1b. A water wall combustion chamber during erection

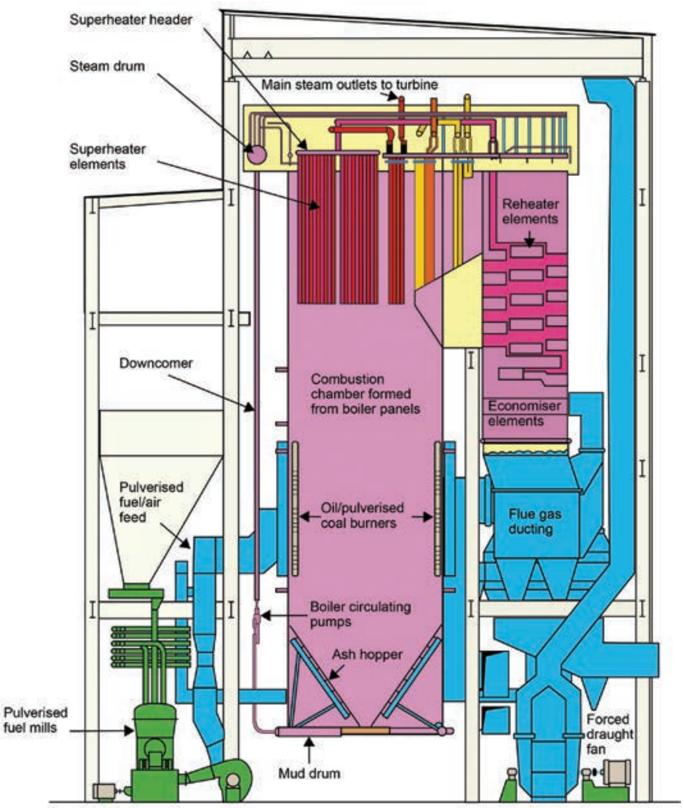


Figure 2: A 660 MW Pulverised Coal (PF) Fired Boiler

Each boiler therefore contains hundreds of miles of small diameter tubes between 25 mm to 90 mm diameter, containing thousands of welds. Most of the butt welds joining the panel ends were manual metallic arc welded on site during boiler erection. The tubes of the superheater, reheater and economiser heat exchanger elements were flash butt or manually welded, necessary due to the maximum length at which tubes could be purchased and transported, to form serpentine or “wrip-wrap” elements. Typical of a later design of boiler is that illustrated in Figure 2.

Flash-butt welding

During a 40-year period NEI-International Combustion Ltd supplied some 3.5 million flash butt welds from the Derby works for a range of utility boilers including High Marnham, West Burton and Kingsnorth for the CEGB, Tsing-Yi for China Light and Power, Rihand 1 for NTPC in India and Jacui for Eletrosul, Brazil.

On a more historical note, flash butt welding in the 1950s was carried out in the Derby works with two AI machines that had been used to fabricate “PLUTO” (Pipe Line Under The Ocean), the undersea pipeline used to supply fuel to the liberation forces following the Normandy landings in 1944.

The flash butt welding facility on which many of welds were made was upgraded in 1983 with the purchase of an ESAB-ASEA SVU 7883-H FBW machine, which is the subject of this article and is illustrated in Figure 3 which shows the operation during the preheat phase of welding a 50mm diameter carbon steel test piece. Argon purge tubes can be seen inserted in the tube ends.

Figure 3: Flash butt welding of a boiler tube test piece – preheating phase

The ESAB-ASEA machine is rated at 150 kVA and is capable of welding tubes ranging in outside diameter from 25 mm to 90 mm with the maximum weldable wall thickness varying with the steel composition, the maximum weld area for a carbon steel being 2360 mm^2 but only 1060 mm^2 for an austenitic stainless steel.

The equipment comprises a robust frame carrying one fixed and one movable clamp, both water-cooled, which carry the welding current and which grip and force together the workpieces. The clamps are adjustable horizontally and vertically by ±10 mm for work piece alignment and were fitted with removable phosphor bronze inserts of varying diameter to accommodate various tube sizes. (Figure 4).

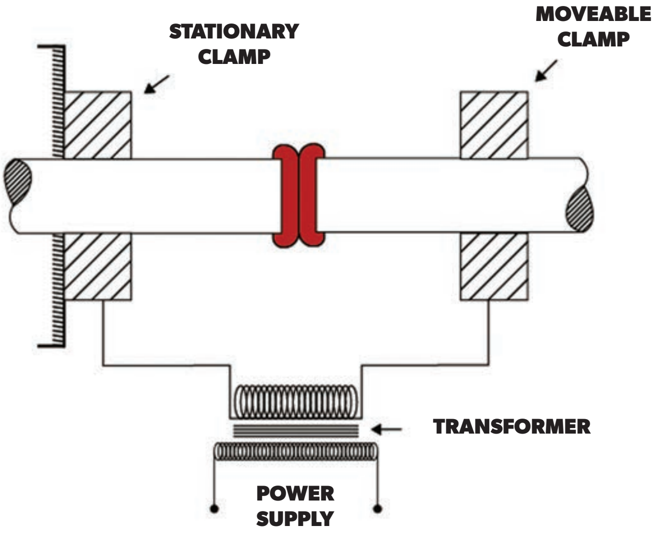


Figure 4: Schematic of the flash butt welding process

The essential features of flash butt welding of tubes are as follows. The tube ends are machined square and are initially brought into light contact and the current applied. Short lived arcs are established as the local points of contact melt and rupture. The movable clamp is moving forward during this period and fresh points of contact are made repeating the melting/rupture cycle – this is known as the flashing period and can be quite spectacular! Flashing continues until the surfaces are uniformly heated at which point the clamp speed is rapidly increased and the tube ends are forged together, forming a characteristic fin or flash that contains the contaminated metal expelled from the weld, both internally and externally as shown in Figure 5. The result is a sound, flaw free solid phase joint. In general, the fin is removed as the next operation in the production line. Figure 5 illustrates the upset with the natural profile of the internal flash and the external flash dressed.

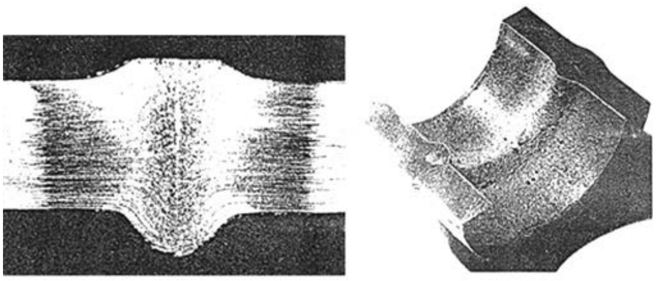


Figure 5: Sections of an FBW in 51 mm x 7 mm carbon steel tube. (Only the external flash has been dressed)

The process variables are a) the speed at which the clamps approach each other, b) the applied voltage, c) the welding current and d) the upset distance. These affect the heat build-up and distribution in the joint. Too high a clamp speed or too low a current result in a "cold" joint with poor mechanical properties and perhaps lack of fusion. Too low a clamp speed or too high a welding current result in a joint which is too plastic, which may have excessive flash, excessive belling of the tubes and an overheated structure. Sufficient voltage must be applied to ensure that arcs initiate when the contact points rupture. The upset distance must be sufficient to expel all of the contaminants from the joint.

To shorten the welding cycle the workpiece may be preheated – this is achieved by bringing the tube ends into contact for some 1 or 2 seconds and withdrawing them so resistance heating can occur, the flashing cycle being delayed until sufficient heat has built up in the joint, which is shown in Figure 3.

Production, quality requirements and monitoring

Production rates vary little with tube diameter or thickness, the welding rate being determined more by the weight of the tube as the tubes were manhandled into and out of the machine. The time to weld averaged 40 seconds per weld which includes 20 seconds for the argon pre-purge. A production rate of between 100 and 120 welds in an 8-hour shift was relatively easy to maintain.

Welding procedures were developed and qualified for the welding of carbon-manganese, 1CrMo, 2CrMo alloy steels and type 304 and type 316 stainless steels. As the hot strength of the steel increases the cross-sectional area that can be reliably welded decreases. For example, the equipment was capable of welding a 90 mm diameter x 9.5 mm wall carbon-manganese tube, the tube size decreasing to 90 mm diameter x 4 mm wall for a type 304 tube.

Bore protrusion is an important variable, limited to 7 % of the bore diameter or 2.5 mm whichever is the lesser. Bore protrusion had, in the past, been removed by broaching but this occasionally resulted in corrosion in service due to the fin being smeared along the tube bore and acting as site for preferential corrosion. To eliminate this problem, it was decided that the tubes should be purged from both ends with argon at a pressure of 2 kg/cm^2 - the argon purge tubes can be seen in Figure 3. This bore purge reduced spatter and oxidation and gave a smooth rounded root bead as can be seen in Figure 5. The quality of the bore protrusion was such that it did not require removal.

The cornerstone of any automatic welding process is consistency, both of welding parameters and the quality and consistency of the weld preparation. To demonstrate that the required consistency was being achieved the 1981 revision of BS 4204 "Flash Butt Welding of Tubes for Pressure Purposes" required all production welds to be monitored for current, force, displacement and time. A monitor and a typical chart is shown in Figure 6. In addition, production test welds were required to be tested at regular intervals, two test welds being made at the start, middle and end of each shift and sectioned to provide 20 bend coupons that were bent to 90° around a 3t former (t=pipe thickness), 10 with the root and 10 with the face in tension. The length of any fissures was measured and the length of the fissures summed and expressed as a percentage of the total weld length. Anything over 5% was cause for rejection of all the welds made since the previous successful batch of test welds.

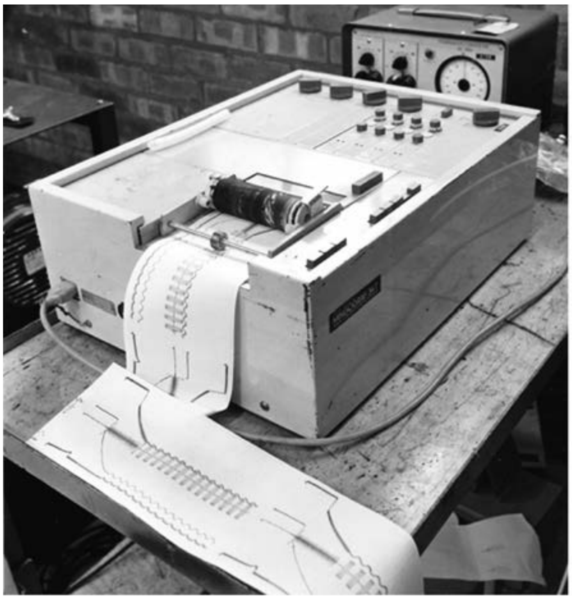


Figure 6 Siemens Oscillomink 4 channel chart monitor and chart

The operator and welding foreman were supplied with transparent overlays of the procedure qualification trace for comparison with the production weld trace. Any deviation was cause for quarantining of the batch for additional testing. This quality control regime resulted in the rejection of 36 welds out of a total of 24,356 welds made over a 2-year period, a reject rate of 0.15%.

Conclusions

The flash butt welding process was shown to be capable of providing high quality tube welds at a consistently high production rate provided that a stringent quality control regime is adopted. In-service experience has been excellent. No systematic problems with the more than 20,000 flash butt welds supplied from the Derby works using the new equipment and quality control regime have been reported by users.

QUALIFICATION, TESTING AND LEGISLATION REQUIREMENTS FOR BRAZED JOINTS

Tony Davies IEng MinstNDT AWeldI C-IWT/EWT Lead Welding Engineer and Welding Examiner at WQ Inspection & Certification Ltd.

Introduction

Brazing is a commonly-used method of joining materials, including those which are considered difficult or impracticable to join using standard arc welding techniques. In brazing the parent material does not melt, instead a bond is typically formed through interdiffusion of the base material and filler metal during the joining process. The filler material has a lower melting point than the parent metal and in its liquid state it is drawn into gap between the abutting surfaces of the materials by capillary attraction.

The strength of the joint is reliant on the selection of a suitable filler material and dependent upon the bond or 'wetting' achieved between the filler material and the parent material. Typical joints are strong and malleable and, when correct methods and selection of filler material is achieved, can match the strength of the parent material.

Brazing is typically used for joining the materials and combinations of dissimilar metals and alloys listed below:

Metals and alloys	Dissimilar metal combinations
•Copper and copper alloys •Medium and high-carbon steels •Aluminium and aluminium alloys •Nickel-based alloys	•Copper to brass •Copper to steel •Brass to steel •Titanium to copper

Relationship between the application and applicable legislation for brazed joints

The most common applications of brazed joints in the UK market are in the aerospace, refrigeration and the heating, ventilation and air-conditioning (HVAC) industries.

Brazing is used to join a wide variety of assemblies, due to its ability to produce leak-proof, strong and temperature resistant joints. These range from a simple electrical contact on a conductor through to joining pipework and fittings to form a refrigerant or water circuit. These industries also utilise the ability to produce multiple joints at once in assemblies such as manifolds and heat exchangers.

In terms of legislation, the requirements of Pressure Equipment (Safety) Regulation (PE(S)R) may be applicable for components being sold within the UK market dependant on the pressure and service conditions of the component.

Brazed joints which contribute to the pressure resistance of equipment must be carried out by suitably qualified personnel according to suitable operating Brazing Procedure Specifications (BPS).

For higher category pressure equipment such as equipment in categories II, III and IV, the operating procedures and personnel must be approved by a competent third party which, at the manufacturer's discretion, may be:

- A Notified Body.
- A Recognised Third-party Organisation.

A list of UK Conformity Assessment Bodies for pressure equipment can be found on the GOV.UK website. **https://find-a-conformity-assessment-body.service.gov.uk/?Keywords=&LegislativeAreas=Pressure+equipment**.

WQ Inspection & Certification Ltd is approved to work as a Recognised Third-party organisation.

For pressure equipment brazing qualifications are required which involves qualification tests and the production of Brazing Procedure Approval Records (BPARs) and Brazing Personnel Qualifications (BPQ). These are performed in accordance with the appropriate designated standards.

In the UK, notices of publication and consolidation of designated standards for pressure equipment are available through the government website.

https://www.gov.uk/government/publications/designated-standards-pressure-equipment

Applicable Brazing Procedure & Personnel Qualification Standards

Brazing procedure qualification is essential in developing suitable joining methods for components and demonstrating the ability to produce joints of appropriate quality and suitable mechanical properties for the intended application.

Brazing personnel qualifications, either in the form of brazer or brazing operator qualifications are essential to demonstrate that the personnel have the necessary skills. Brazers must have suitable manual dexterity to manipulate the equipment to heat the brazed area adequately. Brazing operators must demonstrate understanding of preparing the joint and skill in operating the automated joining equipment such that they produce a joint of adequate quality.

Typical standards used for Brazing Procedure and Personnel Qualifications are:

- **BS EN 13134:2000.** Brazing. Procedure approval.
- **BS EN ISO 13585:2021.** Brazing - Qualification test of brazers and brazing operators.
- **BS ISO 11745:2022.** Brazing for aerospace applications. Qualification test for brazers and brazing operators. Brazing of metallic components.
- **ASME BPVC Section IX-2023.** Qualification Standard for Welding, Brazing, and Fusing Procedures; Welders; Brazers; and Welding, Brazing, and Fusing Operators.

There are also various product / application standards, particularly for pressure equipment, which define the qualification route for brazed joints for that product. Some examples of these are as below:

- **BS EN 14276-1:2020.** Pressure equipment for refrigerating systems and heat pumps – Vessels. General requirements.
- **BS EN 14276-2:2020.** Pressure equipment for refrigerating systems and heat pumps – Piping. General requirements.
- **BS EN 378-2:2016.** Refrigerating systems and heat pumps. Safety and environmental requirements - Design, construction, testing, marking and documentation.

Samples and Testing used for Qualification

There are many factors that determine the type of joint used for either procedure or personnel qualification. Typically most qualification tests are performed as a basic lap joint (Figure 1) either in sheet or as a sleeve joint in tube (Figure 4). Other joint types are possible such as straight butt joints (Figure 2) and T-butt joints (Figure 3) where it is required to simulate the production assembly or where it is necessary to produce test specimens for non-destructive and destructive testing.

The choice of joint type and test sample size is different from welding where a range of joint types and sizes is qualified by a test on a single specific joint configuration. For brazed joints there are additional considerations including coefficients of thermal expansion, (particularly for dissimilar joints), and the heat sink of the joining materials, notably where low thermal conductivity can limit the joinability of larger / thicker samples. Consequently in brazing qualification it is sometimes necessary to perform qualifications on representative size samples to avoid unforeseen issues in manufacture.

Figure 1: Lap joint

Figure 2: Square butt joint

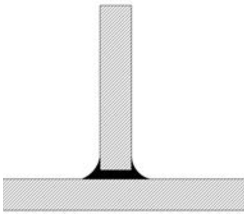


Figure 3: T-butt joint

For brazing, brazer or brazing operator qualifications, the type and extent of mechanical testing is specified by the qualification standard but non-destructive testing methods and requirements may be determined by both the qualification standard and the product/application standard.

Non-destructive testing, used to establish joint quality, may include any or a number of the following inspection methods:

- Visual examination
- Ultrasonic examination
- Radiographic examination
- Penetrant examination
- Leak testing
- Proof testing
- Thermography

Both qualitative (i.e. assessment of joint quality) and quantitative (where a specific property value has to be attained in the test) destructive tests are used to assess the filler metal performance and ascertain joint properties. These may be required for qualification purposes, to optimise joint design, to assess and monitor quality in manufacture and performance in service. Typically, destructive tests may include any or a number of the following tests:

- Metallographic examination
- Shear test
- Peel test
- Tensile test
- Bend test
- Hardness test

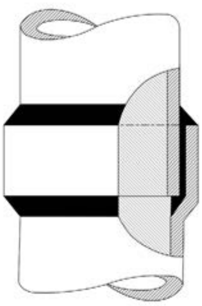


Figure 4A: A sleeve lap joint

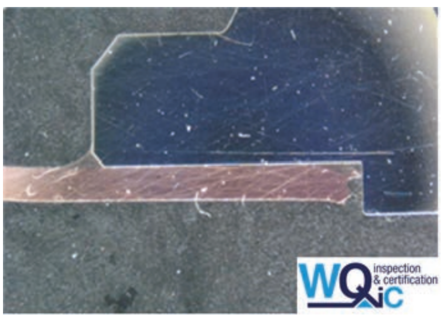


Figure 4B: Metallographic cross-section of a sleeve lap joint revealing bonding imperfection exceeding the specified quality requirements of BS EN ISO 18279 Quality Level B i.e. 10% Max.

Imperfections

It's not uncommon for brazed joints to contain imperfections of various types. What is acceptable in manufacturing a component depends upon the service requirements of the joint and the component, and generally the acceptance criteria are defined in the product or manufacturing standard or specification.

The types of imperfection are defined according to a quality standard such as BS EN ISO 18279:2023. This standard also provides guidance on quality levels for general applications which may be applicable in the absence of specific quality levels defined by the product or application standard or specification. Imperfections in brazed joints are defined in terms of whether they are external imperfections or internal imperfections.

External imperfections	
• Underfill • Crack(s) • Surface-breaking porosity • Incomplete fillet • Overlap • Localised melting	• Rough surface of seam • Flux seepage • Discolouration • Spatter • Residual flux • Surface erosion of parent material

Internal imperfections	
• Crack(s) • Filling imperfection • Solid inclusion • Gas entrapment	• Flux inclusion • Lack of fusion • Excessive alloying of filler material and parent material (sometimes called erosion)

Closing remarks

Brazing remains a key technique for joining materials, in a wide variety of industries due to its flexibility in producing fast, reliable and high integrity joints in both critical and non-critical components. It can be used in situations where welding is not possible or viable.

Brazing technology continues to evolve and improve and new developments which have become available include resistance, induction, electron beam and laser brazing methods. As these faster, consistently repeatable processes are adopted it is increasingly important that manufacturers develop qualified brazing procedures to ensure consistent quality in production to ensure components remain fit for service. It is no longer sufficient to rely upon previous practice, choice of filler metals and tried and tested methods.

At present the industry is seeing a declining resource of skilled and knowledgeable brazing personnel. Consequently it is necessary that brazers and brazing operators are qualified by test to ensure they can produce joints of required quality, prior to making production joints on costly components.

It is the responsibility of the manufacturer to ensure compliance with any contract specification, product standard and legislative requirement and this includes where it mandates that brazing is to be performed by qualified personnel in accordance with qualified operating procedures to a defined set of criteria.

Tony Davies is employed by WQ Inspection & Certification Ltd as Lead Welding Engineer and Certification of Persons Scheme Manager. He supports the business with their Inspection, Certification of Persons and Laboratory accreditations specialising in permanent joining testing and certification.

Tony's career spans over 20 years specialising in compliance with manufacturing welding requirements in a variety of sectors including Defence, Nuclear, Gas & Oil and Aerospace Industries.

Tony supports the standard development of qualification of welding personnel and welding procedures for BSI technical committee WEE/36,and provides representation at SAFed TC4 Welding & Materials.

A NOVEL DIFFUSION BONDING TECHNIQUE FOR AL-ALLOYS - DEVELOPMENT

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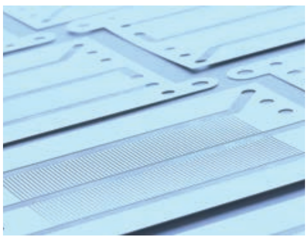
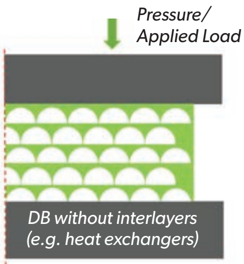
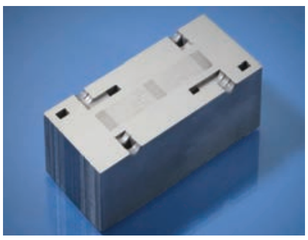
Introduction

TWI has developed a novel surface preparation technique that allows diffusion bonding of materials that were previously challenging to diffusion bond, such as aluminium alloys.

A key potential application relevant to this technology that TWI has been investigating is the use of aluminium in diffusion bonded PCHEs, also known as compact micro-channel heat exchangers (MCHXs), where a combination of efficient design and lightweight material make it an attractive proposition for not only reducing the weight of the heat exchanger, but also increasing the efficiency. The process involves stacking a series of photochemically etched shims which are diffusion bonded to create a complex internal 3D structure. Due to the channels being smaller and closer than conventional heat exchangers, they are more efficient, and the high integrity of the diffusion bonded joints allows them to the run at higher pressures. Recent publications have used the terminology Laminate Object Manufacture (LOM), Figure 1.







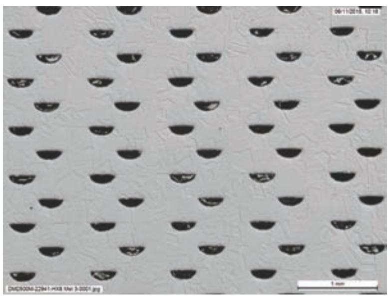


Figure 1: The principles of PCHEs/MCHXs. The example shown is 316L stainless steel. Copyright TWI Ltd

The challenges

The diffusion bonding of Aluminium is challenging due to several reasons:

Challenge 1: Aluminium and its alloys have a tenacious oxide layer, which does not reduce in a vacuum atmosphere below the melting point of the alloy. This thin ceramic layer acts as a diffusion barrier.

Challenge 2: Aluminium alloys have a low melting point, therefore lower processing temperatures are required, thereby reducing the driving energy for diffusion; a temperature-dependent process.

Challenge 3: Aluminium alloys are relatively low strength, and are prone to high deformation at elevated temperatures, meaning that internal features become deformed. As we need to process close to the melting point, to drive diffusion, there are limits to the pressures that can be applied.

Despite the challenges, there are 3 main approaches that can be employed:

Approach 1: Induce a large deformation to disrupt the oxide layer. However, this could damage and collapse internal structures.

Approach 2: Use interlayers to form low melting point phases that become molten during diffusion bonding, and disrupt the oxide layer. Common interlayers include Cu, Zn and Ag, however Cu can form brittle intermetallic phases, Zn is not vacuum compatible and Ag is costly.

Approach 3: Remove the surface oxide in an oxygen-free environment, however, the challenge is in how the assembly is loaded into the diffusion bonding furnace without exposing the free-surfaces to oxygen.

All these techniques have issues, especially when trying to apply them to etched shims, and interlayers may also cause issues in service related to galvanic corrosion.

TWI's development

In response TWI has developed a technique to diffusion bond aluminium without the use of any interlayers, thereby producing a completely autogenous joint. This process has been demonstrated to be scalable, as TWI has manufactured full-scale heat exchanger prototypes made from grade 6061 aluminium alloy (Al-6061). The work was sponsored by Meggitt plc through an Aerospace Technology Institute (ATI) funded project. TWI diffusion-bonded several prototypes of approximately 100 separate layers, and even when using a manual process to prepare the surfaces, they showed significant promise, Figure 2.

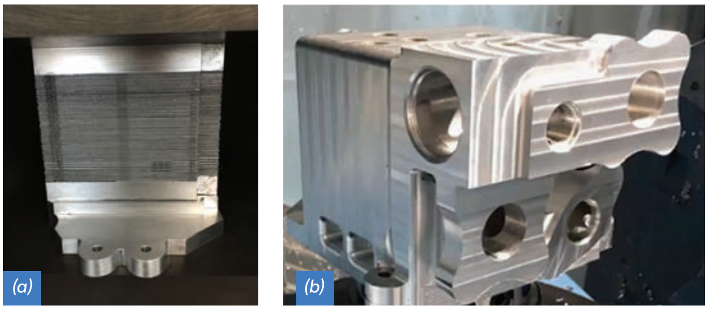


Figure 2: A diffusion bonded Al-6061 heat exchanger. (a) post-diffusion bonding, Copyright TWI Ltd (b) post-machining. Courtesy of Meggitt plc

Other applications

Other components that require internal features can be designed and manufactured using this methodology. Examples include, but are not limited to:

- Heat sinks
- Process intensification reactors
- Conformal cooling dies for injection moulding
- Semi-conductor manufacturing and atomic layer deposition equipment
- Electronics cooling devices

In addition, the process can be used to manufacture a wide range of different items, such as:

- Cryogenic components
- Parts for superplastic forming
- Fine channel filters for powder categorisation

Cryogenic applications, such as those involved in the transfer of liquid gases (H_2, He, N_2, O_2 etc.), are of interest because aluminium alloys are well suited to such conditions due to having a face-centre cubic (FCC) micro-structure, meaning that there is no ductile-to-brittle transition temperature.

Further Investigation

To build on TWI's success with Al-6061, internal funding was used to explore if TWI's proprietary method can be transferred to other Al-alloys, with Al-6082 and Al-2024 selected for trials. All trials were carried out using TWI's graphite-lined vacuum diffusion bonding furnace, Figure 3.

Figure 3: TWI's uniaxial diffusion bonding furnace. Copyright TWI Ltd

Al-6082 Results

An example of a diffusion bonded stack manufactured using Al-6082 is shown in Figure 4.

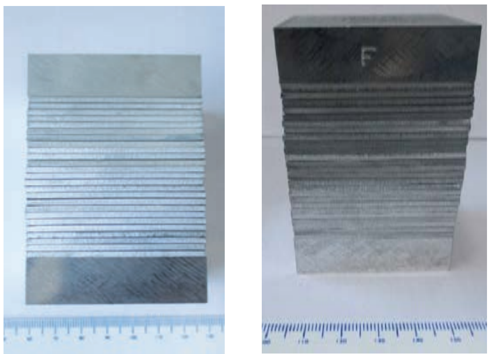


Figure 4: Example of a diffusion bonded stack, Al-6082. Copyright TWI Ltd

The bonding is not externally evident due to the visually-evident cut edges. From these stacks, metallographic sections were taken, with coupons also machined for mechanical testing. Micrographs showing representative bondlines are shown in Figure 5.

The following relationships were determined:

- Diffusion time, temperature and pressure have marked effects on joint microstructure and strength.
- These parameters control the deformation in the bond region, which in turn controls the ability to make a high integrity diffusion bond.
- The relationships developed can be used to select processing parameters that balance joint performance with process speed.

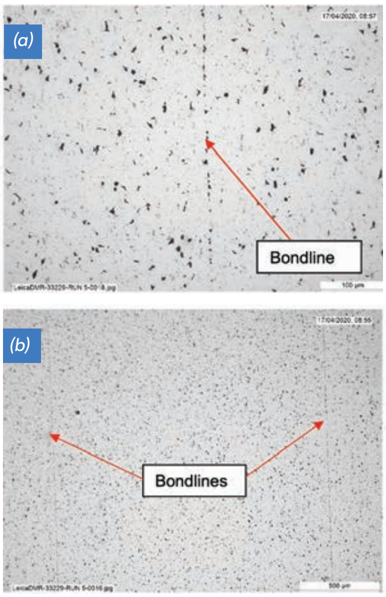


Figure 5: Micrographs showing a diffusion bonded tile-to-tile joint (running vertical in the images) for Al-6082: (a) high magnification, (b) low magnification. Copyright TWI Ltd

The bondlines were visible as a linear arrangement of voids and/or inclusions. The size of these were of a similar scale to particulates present in the bulk of the aluminium alloy. The voids/inclusions were not continuous in nature, which is evidence of material diffusion across the joint.

In order to determine the effectiveness of TWI's proprietary method, samples were compared which were diffusion bonded under the same conditions, but with one sample having simple preparation (mechanical abrasion), and one using TWI's proprietary method. TWI's proprietary method showed some strength improvement over mechanical-abrasion with significantly higher elongation values.

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Al-2024 Results

Two key observations were made from the tensile testing results for the diffusion bonded Al-2024 stacks, as follows:

- Diffusion bonding was highly sensitive to temperature.
- The alloy was resistant to deformation, therefore, a wider range of trial conditions had to be explored to select hold times and pressures, in comparison with the 6xxx series alluminium alloys.

Micrographs showing representative bondlines are shown in Figure 6.

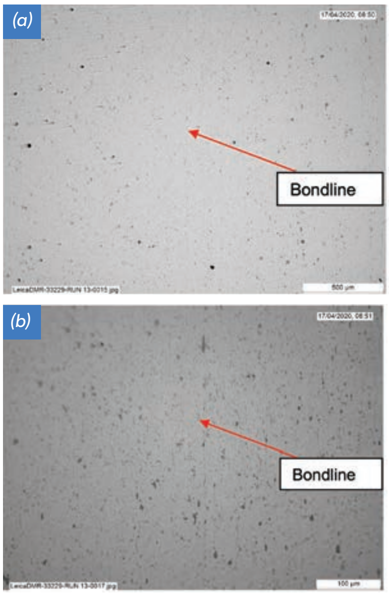

Figure 6: Micrographs showing a diffusion bonded tile-to-tile joint (running vertical in the images) for Al-2024: a) Low magnification; b) Higher magnification. Copyright TWI Ltd.

The bondlines were visible as a linear arrangement of voids and/or inclusions. The size of these were smaller than particulates present in the aluminium alloy and the bondlines were difficult to resolve. The voids/inclusions were not continuous in nature, which is evidence of material diffusion across the joint.

As with the Al-6082 study, a control study was carried out with Al-2024, using samples prepared using mechanical abrasion. That sample had a significantly reduced 0.2% proof strength and UTS in comparison with samples used TWI's proprietary surface preparation method.

In summary, TWI's surface preparation method had a large impact on the joint strength of Al-2024. For Al-6082 there was a smaller enhancement of joint strength but a larger enhancement of joint elongation.

Heat Exchanger Demonstrator

Following the promising results, a PCHE demonstrator was produced as a simplified, scaled-down representative unit, comprising a stack of photo-chemically etched shims, Figure 7. These contained channel geometries sandwiched between end plates, and diffusion bonded using TWI's proprietary technique. Each layer incorporates zig-zag channels (semi-circular in shape, with a diameter of 500μm) and built-in headers. The design is a cross-flow concept, with each individual layer alternating between the hot and the cold working fluids and the microchannels stacked directly in line with each other, the overall stack consisting of 30 hot and 30 cold shims.

The diffusion bonded PCHE demonstrator was successfully achieved, with little-to-no deformation observed.

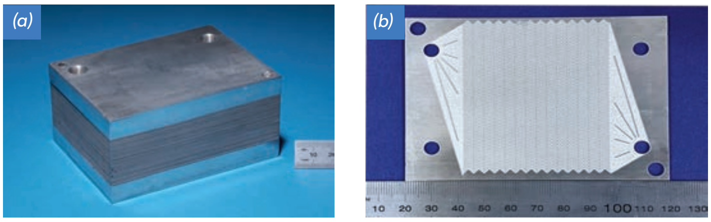

Figure 7: Images showing the diffusion bonded PCHE demonstrator: (a) post-diffusion bonding (b) one of the photochemically etched shims with the channel geometry evident. Copyright TWI Ltd

Conclusions

- TWI's proprietary surface preparation method for the diffusion bonding of aluminium alloys can be successfully transferred to Al-6082 and Al-2024.
- Sets of parameters that balance joint strength against deformation have been successfully developed for Al-6082 and Al-2024.
- For the best set of parameters, the diffusion bonded joints were free of continuous (unbonded) features with small, discrete pores/voids visible. For Al-6082 these were a similar size to inclusions in the parent material. For Al-2024, these were smaller and difficult to resolve.
- TWI's proprietary surface preparation technique was shown to improve joint tensile properties. There was a significant improvement for Al-2024 and a marginal improvement for Al-6082.
- TWI successfully manufactured a representative Al-alloy PCHE by diffusion bonding photochemically etched shims.

Future Work

Following diffusion bonding the alloys are in a softened state due to the thermal cycle. This is greater for the 6xxx series alloys in comparison with Al-2024. Therefore suitable post-DB heat treatments to recover the mechanical properties could be investigated.

Suitable heat treatments would require "solid-solutionising + quenching" to recover the strength. These are known to impart large thermal stresses on the parts, which present a risk of delamination. Once suitable heat treatment profiles have been explored and developed, avoiding delamination and demonstrating adequate strength then diffusion bonded PCHEs/MCHXs could become a reality, with all the benefits that they bring.

To find out more, or if you wish to collaborate, please contact James Redman (james.redman@twi.co.uk), Team Manager of the Thermal Processing Technologies team.

Acknowledgement

The support of colleagues at TWI, in particular the technicians, is greatly appreciated, along with Meggitt plc for allowing the use of the images shown in Figure 2.

References

[1] Crawford, D.G. (1987) *'The Joining of Aluminium and its Alloys to Similar and Dissimilar Materials by Diffusion Bonding – A Review'*. The Welding Institute Research Report 216/1983. May 1983.

[2] https://www.meggitt.com/insights/step-changing-technology-for-the-next-generation-of-aero-engines/ - last accessed 18th January 2024

A CLOSER LOOK AT BRAZING OF ADVANCED MATERIALS

Prof. Russell Goodall and Dr Frances Livera, University of Sheffield.

Introduction

Brazing is a very old technology; humans have been using brazing for longer than they have been writing. As a result, brazing suffers from a similar issue to other technologies of great antiquity; the perception that it is a solved problem and that we know everything there is to know about the science and technology of the process.

However there is much ongoing development in brazing. As a process, brazing depends on a number of fundamental metallurgical phenomena that change over short distances. These include phase changes, both in response to temperature and compositional change, diffusion, and the development of mechanical properties across complex multiphase microstructures. Many brazing filler metals and materials used for joining are multi-component alloys. The understanding of these continues to be under active development, and in this article we will discuss some of the current features of our research.

Joining of advanced materials

New materials are continuously being developed to meet new application requirements and these can present difficulties for joining. These are not developed with joining in mind, and often have highly optimised microstructures, which mean that changes introduced during a joining process may be unacceptable.

An example is metals processed by additive manufacture (AM). AM offers advantages in the production of very complex shapes and a significant reduction in material wastage during processing, but introduces its own characteristic microstructures and defects to the materials. Of particular relevance to joining, it usually also produces a very rough surface finish, which can be controlled to some extent through the manufacturing parameters.

AM offers manufacturing advantages for relatively small and complex shapes, but these may not comprise the whole of a component. It is likely that AM parts would need to be joined together or to larger, simpler shaped pieces manufactured by conventional processes. To create the joints, ideally we would want to avoid machining smooth surfaces onto the AM parts, as this adds manufacturing steps and results in material wastage. Therefore we have investigated how the AM process can influence joining by brazing.

Although a low surface roughness, such as an Ra of 0.6-1.6 µm, is usually the recommendation for brazed joints, we have found that it is possible to join materials with the native AM surface (with an Ra of 5-35 µm). The rougher surface of AM components arises due to the effect of layer thickness and the remaining structure from the melt pools, as well as residual powder particles partially attached to the surface.

We found that joints manufactured with a native AM surface can have acceptable joint quality, provided there is sufficient filler metal to fill the joint, with strengths that are only slightly less than achieved with a machined surface and a thinner joint gap. The rough surface affects the flow and spread of a filler as found in wetting trials on a single surface. There is much more spread of the filler metal on the AM surface due to the additional capillary forces that are introduced. Building on this effect, it would be possible to engineer a surface to enhance brazeability by creating a textured arrangement to control filler flow, or to introduce interlocking features to create stronger joints.

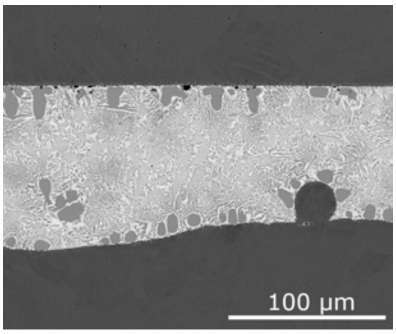

Figure 1: A cross section of a joint between a machined 316L stainless steel surface (top) and an AM 316L stainless steel surface (bottom)

Figure 1 shows a brazed joint between a machined surface (top) and an AM surface (bottom). It is made using Ag155 filler metal and produced by air furnace brazing and has been imaged in the Scanning Electron Microscope. The AM side shows a powder particle attached to the surface.

Joining with advanced materials

In addition to developments in the materials being joined, there are also developments in the materials doing the joining. Currently many of the filler metals that we use are have quite complex compositions. Multi-Principal Element Alloys (MPEAs) are an important strand of current research. (These are also designated as High Entropy Alloys (HEAs) or Complex Concentrated Alloys (CCAs)). Over recent years, the understanding of how to engineer these alloys and their performance has increased enormously with increasing ability to predict their properties. Consequently new alloys can be designed to meet specific capability requirements.

One example of this relates to the traditional boundary line of 450 °C set between soldering and brazing. This division has led to few established filler metal grades with processing temperatures near the boundary as evident in Figure 2 which shows the melting temperature (circles) and range (lines) of standard solders and brazing filler metals. (Brazing filler metals are from ISO: 17672 and solders are from BS EN ISO 9453). Nevertheless, many materials require joining at temperatures high enough to withstand operating conditions, but not so high that they cause changes in the materials themselves. Some of these applications mean that filler metals with operational temperatures around the boundary are desirable.

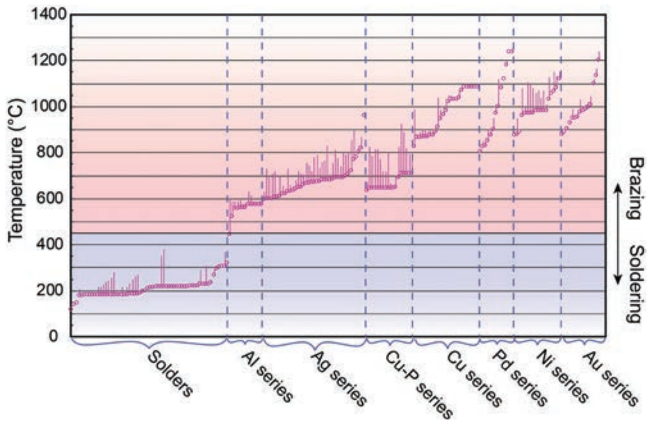

Figure 2: Melting temperatures of standard solders and brazing filler metals, arranged by series

Other requirements are sometimes encountered. The ability of brazing to join complex components, advanced materials, and mixed materials, means that it is applied in some very high specification applications, such as in aerospace or in nuclear fusion applications. These bring new, additional constraints which require the exploration of new filler metals. For example, for nuclear fusion there is a requirement that materials do not become highly radioactive themselves after exposure to high energy neutrons and this reduces the choice of elements in the filler considerably.

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In our work, we have developed new multi-component fillers using the acceptable elements, which have different processing and operational temperatures from current candidate materials. This widens the situations in which brazing can be used in nuclear fusion, and means that the operational temperature of the joint does not become the limiting factor in its application.

Any alloy is composed of elements within the periodic table but many are expensive, toxic, unstable, or otherwise unsuitable for practical processing, which greatly reduces the usable number. In addition we can exclude some based on the required service situation; in the case of fusion reactors this would be the response of those particular elements to neutron irradiation. From the elements left, we may be able to make an initial assessment of the likelihood of forming an alloy based on simple parameters, such as the atomic size, valency, or thermodynamic behaviour. Once a set of potential elements has been chosen further investigation can be carried out by a computational method known as CALculation of PHase Diagrams (CALPHAD). This technique, which is implemented in various commercial software packages, allows the phase diagram of an arbitrary alloy to be calculated. The accuracy of the prediction can vary depending on the quality of the databases available for the elements concerned. Usually this provides a good initial estimate of the kinds of microstructures that might form in the alloy as well as important parameters for its use as a brazing filler metal, such as the melting temperature and range.

Using this methodology we developed an MPEA filler which contains Cu, In, Au, Ge, and Al. The filler shows a high degree of interaction with the copper substrates. Figure 3 shows maps produced by Scanning Electron Microscope and Electron Probe Microanalysis (EPMA) which indicate the extensive interaction and transport of all the filler metal elements. Around the original joint, gaps are observable since the interaction has exhausted the amount of filler available in this particular joint.

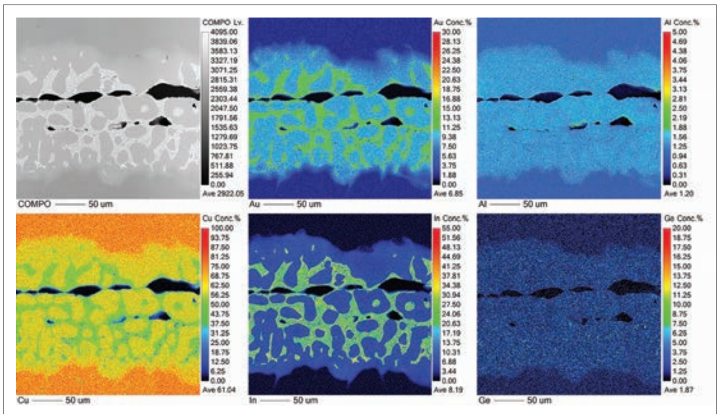

Figure 3: A cross section of a joint between two copper alloys, using the new filler metal in the CuInAuGeAl system

Potentially this could be addressed by the development of specific brazing practice and filler forms for this alloy. In some joints, such as those between difficult to bond alloys, the promotion of interactions that result from the use of MPEA fillers could be advantageous.

New discoveries about brazing established materials

Recent discoveries in brazing are not limited to new materials. We can use the improving characterization capabilities available to learn things about the brazing of well-established materials. For example, we used Electron Backscatter Diffraction (EBSD), to examine joints produced by brazing 316L stainless steel, both wrought and produced by AM.

With the wrought 316L we found a thin transformed layer at the interface between the filler and the steel. Under normal conditions 316L has a Face Centred Cubic (FCC) crystal structure, but we found a layer, approximately 10 µm thick, with a Body Centred Cubic (BCC) structure which forms after brazing. Our investigations have found that the layer develops due to the competing diffusion in and out of the metal surface by elements that stabilise either the BCC or FCC structure in the steel. We have found that the effect does not occur when the 316L has been processed by AM. The diffusion of elements still occurs but the complex structure of AM steels, including the presence of small-scale dislocation cells and residual stresses, have been shown to affect a number of other phase transformations which may be preventing the formation of a transformed layer at the joint interface.

This difference is shown in Figure 4 which shows a cross-section of a joint between wrought 316L stainless steel (top) and the same steel grade produced by AM (bottom) joined using Gemco filler metal. The images result from EBSD. The left image shows the different phase structures with the transformed BCC layer shown in blue. The right image shows the grain structure revealing the very different microstructures between the wrought 316L and the AM 316L.

Figure 4: EBSD images of a cross-section of a joint between wrought 316L stainless steel (top) and the same steel grade produced by AM (bottom). Left image; phase structures. Right image; microstructures

Conclusions from this work

Our ongoing research is exploring the impact of these layers on joint properties. We have yet to confirm any definite effects due to the presence of phase transformations when concentrated in the region around a joint, but these could lead to alterations in the mechanical response of the material, or have potential consequences in application-based environments, such as on through-hydrogen ingress. These structures may be critical in certain applications and hence proper understanding of both the joint structures and their effect on the properties is very important. Despite brazing being well known, there is still much left to discover. The adaptability of the process and its ability to fill the gaps (!) left by other joining techniques makes it of continuing value as a method of joining. Further technical understanding of the processes will enable the deployment of many new materials.

Acknowledgements

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Russell Goodall is Professor of Metallurgy at the University of Sheffield, where he has been an academic member of staff since 2008. His research concerns the development of new alloys, particularly in multicomponent systems, and he has a particular focus on filler metals and their use in brazing, and a more general interest in how alloys can be designed to meet particular challenging applications. He is a member of BSI committee WEE/19 – Brazing and braze welding, a Fellow of the Institute of Materials, Minerals and Mining and a Chartered Engineer.

Frances Livera is a recent PhD graduate at the University of Sheffield, completing her thesis entitled 'Brazing of Additively Manufactured Metals' supervised by Prof. Russell Goodall and sponsored by the UK Atomic Energy Authority (UKAEA). Her research explored how intrinsic aspects of additively manufactured (AM) components impact brazed joint formation, microstructurally and mechanically, with an aim to unlock the full potential of AM components for nuclear fusion reactors.

INVESTIGATING DIGITAL TOOLS FOR BRAZING: A CASE STUDY IN THE 5G-ERA PROJECT

Meet the Authors…

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Alex Russell
BEng IEng. Senior Project Leader, TWI Ltd

Background

A significant proportion of manufacturing is still undertaken without automation. This is in part due to the high capital expenditure required to install new pieces of equipment but is more often because of the lack of flexibility in manufacturing automation equipment. The 5G-ERA project is investigating the development of intelligent manufacturing systems enhanced by 5G connectivity with a particular focus on the ability for highly flexible remote and autonomous robot operation.

The project

TWI is currently a partner in the 5G-ERA project **(https://5g-era.eu/)**, funded via the European Union Horizon 2020 scheme. This project showcases four experimentation demonstrators that leverage modular discrete software applications stored in a cloud-based application called '5G-ERA middleware'. TWI led a manufacturing-based demonstrator using brazing as the joining process.

The overall objective of this demonstrator was to develop a series of microservices (such as defect detection, toolpath generator and digital twin manager) to enable an autonomous robotic solution for a key part of the vacuum brazing process. These cloud-based microservices enabled the automation and digitalisation of the process for the set-up and manufacture of high-value components using a robot to replace certain manual operations, aiming to reduce waste and improve both the process quality and efficiency.

The project investigated replacing a highly-skilled, manual operator process of depositing braze paste, with the same operation performed by the use of a cobot with braze paste deposition from a syringe mounted on the cobot's arm. The applied paste bead was subsequently inspected, prior to brazing, using a laser scanner to ensure that the correct volume of paste had been deposited. The scanner was also used post-brazing to ensure that a good joint had been formed. (Figure 1).

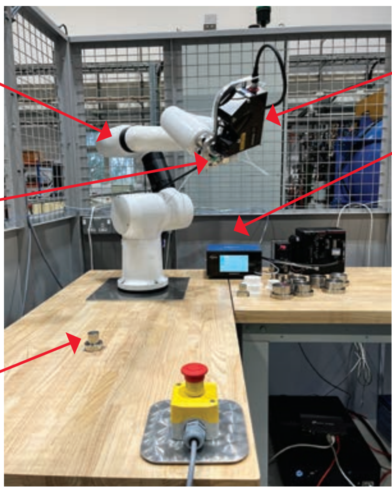

Figure 1: Manufacturing demonstrator at TWI showing use of a cobot for both braze paste deposition and pre- and post-vacuum brazing joint analysis using a laser scanner

The operator engages with the process through a mixed reality headset (Microsoft HoloLens) where they are prompted to select the appropriate manufacturing job card. Once selected, all relevant information required such as works instructions, engineering drawings, 3D model of assembly and manuals of all hardware are accessible on the operator headset removing the need for paper-based documentation.

Figure 2: Demonstration of the operator working within the cobot brazing cell with mixed reality headset

The anticipated benefits of combining an autonomous robotic system with remote support can be summarised as follows:

- Accessing processes on demand to enable troubleshooting and progress monitoring (e.g. paste deposition, collision detection scanning, laser scanning).
- Technical specialists (such as robotics and networking) are no longer physically required to configure the services if there is a change in part design, integration of new parts or adding a new manufacturing process.
- Flexible infrastructure which can be re-configured quickly for a different product or manufacturing process requirements.
- Rapid deployment and scalability as manufacturing cells can be set up and configured very quickly.
- Automation of labour-intensive processes and protection of complex manufacturing processes that are losing knowledge/ skilled workers.
- Digitalisation of the process makes it easier for relevant information to be accessed in one headset.

Acknowledgement

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No. 101016681.

The Welding Institute Branch Events

AUG - NOV 2024

The Welding Institute
ESTABLISHED 1923

Please check our website for current details of each event and to see which events are online, face to face or both. Our programme is constantly developing as our volunteers progress the arrangements. All events are subject to confirmation and details are correct at time of going to press.

RECENT AND UPCOMING EVENTS

August 2024

Date: 3rd August
Tea cruise to Hampton Court from Chiswick Pier
Advance booking only.
Details from Programme Secretary:
alkden57@hotmail.com
London Branch with Kent

September 2024

Date: 9th September
Talk: The importance of ISO 3834 and the role of the Conformity Assessment. Body Speaker: Jacob Bailey TŰV
Venue: TWI Sheffield and online
Sheffield Branch

Date: 11th September
Talk: Electron beam welding for nuclear applications. Speaker: Chris Punshon, Cambridge Vacuum Engineering
Venue: The Lancaster Hall Hotel, London W2 3EL and also online.
London Branch with Kent Branch and joint meeting with LMS

Date: 11th September
Talk: ISO 3834: The Joys and Sorrows of Managing Weld Quality. Speaker: Veronica Warner
Venue: Online
South-Western Branch with South Wales Branch

Date: 26th September
Talk: Joint event with ICORR
Speaker: TBC
Venue: Online
North Scottish Branch

October 2024

Date: 9th October
Talk: TBC. Speaker: TBC
Venue: The Lancaster Hall Hotel, London W2 3EL
London Branch with Kent Branch

Date: 24th October
Talk: Welding with Lasers
Speaker: Dave Hargest (Selmach Machinery Ltd)
Venue: Ultramag Inspection Services Ltd., Unit 1, Contech House, Rushington Business Park, Southampton SO40 9LT
Southern Counties Branch

Date: 28th October
Talk: Wire-Arc Additive manufacturing of high performance steel components.
Speaker: Ed Pickering (Reader in Metallurgy, Manchester University)
Venue: TWI Sheffield
Sheffield Branch

Date: 31st October
Talk: TBC. Speaker: TBC
Venue: Online
North Scottish Branch

November 2024

Date: 13th November
Talk: TBC
Speaker:TBC
Venue: The Lancaster Hall Hotel, London W2 3EL
London Branch with Kent Branch

Date: 15th November
North Western Branch Dinner in aid of the Gem appeal
Venue: The Cromdale Room at The Fence Gate, Wheatley Lane Road, Fence, Nr Burnley, Lancashire BB12 9EE
North Western Branch

Date: 28th November
Talk: TBC. Speaker: TBC
Venue: Online
North Scottish Branch

GET IN TOUCH WITH OUR TEAM

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Lotte Qvist Larkins BA AWeldI

Business Development Team Manager
Nadine Earp AWeldI

Membership and Volunteers Officer
Kate Day BSc (Hons) AWeldI

Education, Accreditation and Approvals Officer
under recruitment

Membership Officer
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Branch Email Accounts 2024

The Welding Institute now have email addresses for the following branches, and you can use these communicate directly with the appropriate branch committee.

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N. Ireland:
northenirelandbranch@theweldinginstitute.com
N. Scottish:
northscottishbranch@theweldinginstitute.com
Scottish:
scottishbranch@theweldinginstitute.com
Sheffield:
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S. Western:
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West Midlands:
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