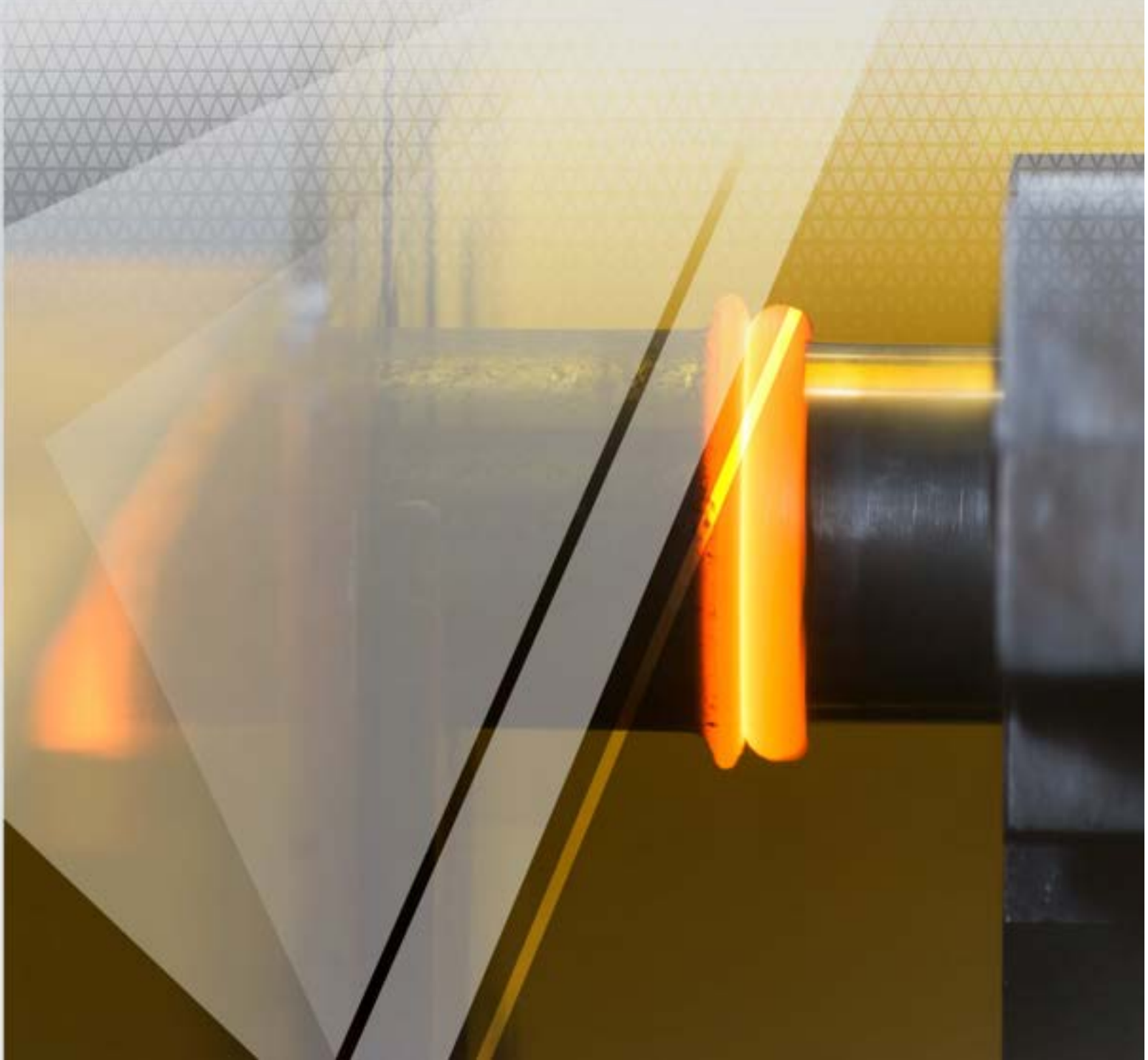
KUKA

Advanced welding solutions

_The friction welding advantage



Introduction

The question that engineers and manufacturers ask when considering their production joining and manufacturing processes is can we do this better, cheaper and more efficiently?

Joining similar, dissimilar or exotic materials directly to each other with a high integrity bond is the holy grail of industrial manufacturing. The benefits of achieving this is to reduce cost, increase quality, efficiency and reliability. All are major considerations for OEM's competing in the global market place and who need to establish their positions with innovative, quality and cost effective products.

Friction welding processes provide an efficient and sustainable method of achieving high integrity similar and dissimilar material bonds.

In this White Paper we will consider the role of friction welding processes in manufacturing today and how it can be used to improve performance, reduce waste and increase product effectiveness.

We will also explain how KUKA Thompson Advanced Welding Solutions (AWS) can help to access friction welding technology through KUKA Thompson sub-contract services.

What is Friction Welding?

There are several types of friction welding processes, however for the purposes of this white paper, we will focus on Rotary Friction Welding.

This process requires specialist technology to control them which offers the advantage of enhanced quality assurance, efficiency and repeatability. The friction welding equipment 100% controls and monitors all the key characteristics of the friction welding process, including rotational speeds, times, pressures and length loss to provide repeatable and reliable high integrity bonds every-time. Coded and skilled personnel are not required, nor are any consumables.

The process can be automated for high volume applications utilising robots to load and unload or specialist subcontract departments can be used for small batch production where demand is more limited. OEM's of safety critical components specify friction welding as the only approved method of joining for their components, these include for instance, light vehicle, beam and banjo axle manufacturers, hydraulic cylinder manufacturers with piston rods and mining and oil and gas manufacturers with drill pipes.

Friction "Welding" is a misnomer in relation to the rotary friction welding process which is essentially a forging process. There can be confusion surrounding friction welding processes, often they are incorrectly described as fusion welding processes, which they are not. The bonds created by rotary friction welding consist of 100% parent material across the whole cross section of mating interface, and crucially, neither material reaches its' melting point at any point during the friction welding process. Therefore, the process is described as a solid-state joining process and not a fusion weld process.

Other than repeatability and time cost saving, the large advantage of these processes is the ability to weld dissimilar materials with different thermal expansion coefficients and those bonds generally retain their intrinsic parent material characteristics with the bond between them maintaining a minimum integrity equal to the weakest of the two parent materials. This is very appealing to manufacturers seeking a high integrity joint who also need to reduce cost and weight by joining dissimilar materials. For instance, electrical connector manufacturers.

Friction welding occurs when the two components to be joined are brought into contact with each other and frictional heat is generated using rotational motion for a pre-determined amount of time until the parent materials soften and plasticise and by the application of a forge force which displaces/extrudes the softened parent material (weld flash) and results in a permanent molecular bond across the entire interface of the parent materials.

The cycle times for such joints can be as short as a few seconds depending on material combination and the cross-sectional area.

Advantages & Features

Provides a fully homogenous bond across the entire joint interface

Unlike conventional welding where the materials only have a surface weld or peripheral weld with limited penetration. During the friction welding process, the materials are bonded together through the entire contact surface area whether the component is solid or tubular.

Produces dissimilar material direct bonds

The ability to join dissimilar materials together that are considered un-weldable through conventional welding or some combinations that are otherwise considered incompatible or un-suitable due to differences in thermal expansion coefficients or the growth of inter-metallic phases reducing bond performance or integrity.

Materials do not melt during the friction welding process

The materials do not reach their melting points. The materials plasticize rather than melt created by the heat generated from one material rubbing against another. This means there are no solidification defects (for example gas porosity, segregation, or slag inclusions), in the finished product. The weld remains in the solid-state, avoiding many of the defects associated with melting and solidification during conventional welding, such as porosity and solidification cracks. The amount of distortion in the welded component is also significantly reduced.

High speed-high integrity bonds

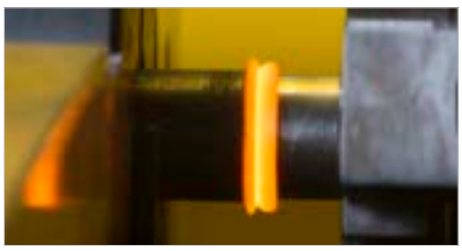
In most cases friction welding is quicker than traditional convention or fusion welding techniques with cycle times as little as a few seconds (subject to material combinations, geometries & section sizes).

Machine controlled process eliminates human error

100% in-process monitoring of quality and 100% production repeatability. By having a fully machine-controlled process with pre-validated process parameters and an in-process weld control software monitoring all key process characteristics, the resulting weld quality of the finished components are the same every time. No matter what the skill or experience level of the operator, the equipment can provide playback data to support the quality assurance of the product.

No consumables required

Fluxes, filler materials, and shielding gases are not required during the rotary friction welding process.



Suitable for high or low volume production

Automation and robotics can easily be integrated to RFW systems for loading/unloading and or the provide any pre or post weld treatments that may be necessary subject to material combinations/applications. Also allowing a manufacturer to use additional automated shift patterns with minimal human supervision or downtime for high volume production requirements. For low volume production, use of a sub-contract service would be recommended.

High bond quality

RFW maintains the parent material fine grain structure and produces a very narrow heat affected zone with hardening more limited than with fusion bonding methods like Arc, Tig or Mig or EB. Retaining fine grain structure, no porosity and minimal distortion of the components due to uniform heat input.

Pre-weld preparations can be less critical for this process

For Friction Welding, machined, forged, saw cut, and sheared surfaces are weldable subject to the alignment and quality requirements of the customer and also subject to the component type and the materials themselves.

Friction welding is a friend to the environment

No toxic smoke, fumes, or gases are emitted, and no exhaust systems are required.

Standard RFW geometries:

Bar to Bar, Bar to Plate, Tube to Tube, Tube to Bar, Tube to Plate and Plate to Plate.

Case Study - Kugel Motion

Joining different grades of steel in precision components

Headquartered in Derbyshire, England, **Kugel Motion** specialises in the repair and overhaul of linear and rotary motion products. With extensive capability for refurbishing and manufacturing high quality, affordable ball screw assembly, it is the only company in the UK that can manufacture precision ball screws. Its specialities include ball screw repair, ball screw servicing and rapid ball screw manufacture.

Kugel Motion's customers come from a range of manufacturing sectors, including machine tools; automotive; aerospace; and oil & gas industries. Its end products are for as wide a range of solutions as its client list. Something all the applications have in common is that they require high precision, which requires precise grinding and means that the screws themselves have to be highly resistant, hardened steel.

Kugel Motion's screws have, traditionally, been made of a single piece of hardened steel, machined from a billet to the appropriate specifications and dimensions.

Each screw went through a number of machining passes. The company considered that the established process was wasteful, both of material and of time, and looked around for a better way of doing things.

One suggestion was that the mounting shaft and the screw itself could be made of different quality steels. The shaft has to be strong but it doesn't have to be as strong as the screw itself, so there was the possibility of savings, if a suitable joining method could be found.

A colleague of **Director Alex O'Neill's** had encountered friction welding before and suggested it as an alternative. Kugel Motion visited KUKA Thompson AWS, undertook an analysis and testing project and concluded that KUKA's rotary friction welding (RFW) was the appropriate solution.

"We found the weld quality to be very, very good," Alex O'Neill said. "We undertook testing with a selection of our customers and there were no issues at all." Having satisfied the quality requirements, attention could turn to other needs.

"Time, manufacturability and material usage were all important considerations," he continued. "RFW scored well on all three. RFW saves at least 25 per cent of manufacturing time over conventional machining. It saves material costs, as we can use different steel grades for the screw thread and the shaft; and there is less wastage, as well."

Kugel Motion is also very happy with **KUKA Thompson AWS' subcontracting services**, as they save it the capital expenditure on investing in its own friction welding equipment and have delivered on time, in full, every time.

Rotary Friction Welding

Cost-efficient, superior bonding, suitable for mission critical applications

RFW is suitable for an immeasurable amount of applications where it is possible to rotate two components axially.

In the case of bi-metallic, copper-aluminium connectors, there is simply no other viable method of joining these two materials directly to each other due to the difficulty presented by them having very different thermal expansion coefficients. Low-cost aluminium is joined directly to high cost copper. Other than the obvious benefit of cost reduction by limiting the use of expensive oxygen free, high conductivity copper material, reducing direct costs, waste and the increased threat of theft are also reduced. Aluminium is the optimum mating material which does not impede conductivity and is useful for ease of crimping to electrical cabling. The electrical connector market for power distribution and rail is a significant market to benefit from this solid-state bonding process.

Other industries that specify RFW as their standard bonding method include the automotive sector producing axles, cv joints, turbo chargers, airbag canisters and other such safety critical components. The aerospace industry utilises the process for manufacture of landing gear shafts, steering shafts, ejector seat components and other high integrity components. The construction and yellow goods industry use friction welding for manufacture of piston rods and hydraulic cylinders where large diameter high quality steel chromed rods are joined to eyes, yolks and pinions for heavy duty industrial service.

Mining, oil and gas industries, manufacture drill pipes and rods for deep hole water boring, directional drilling, rock drilling and oil & gas (sour) service applications whereby the integrity of the joint is paramount as it can be performing under the harshest of conditions and under extreme compressive and torsional loads or percussive forces. The cost of failure in these components can literally cost the operators millions of pounds in lost revenues.

The integrity of the friction welded bond is so superior to other joining processes by offering in many cases parent material properties, that most world renowned, OEM's across these industries own and operate their own rotary friction welding equipment to produce their safety critical components in-house.

Cryogenic applications also benefit from the processes' ability to join dissimilar materials. For instance, stainless steel to copper and interlayered transition joints consisting of stainless steel welded to titanium by use of an aluminium alloy interlayer to facilitate bond between the stainless steel and titanium which it is not suitable for direct bonding. Joints manufactured for this industry sector perform in very low temperature environments. Again, this is a unique benefit of the process, that these very dissimilar materials can successfully be directly bonded and operate in very demanding environments.

Relevant Standard: BS EN ISO 15620: 2019 The Friction Welding of Metallic Materials.

Case Study - Phase 3 Connectors

Connecting aluminium and copper in high current electrical components

Phase 3 Connectors Ltd. is a privately-owned British manufacturer of industrial power cables, connectors, plugs and devices for industries including power generation; events; military; cable assembly and others. It is headquartered in Merseyside, England and has a manufacturing site in Fife, Scotland.

It has supplied connectors and cables to sports events across the world, including football stadiums; the Confederation Cup; and the XXIII Winter Olympics in South Korea. It is the confirmed supplier for the 2020 Olympic Games in Tokyo. It is probably the world's most experienced supplier of cabling and power connection equipment to music festivals, such as Glastonbury in the UK.

Its connectors handle currents up to 800 amps, the highest rated connector available on the market.

The cabling used in global sports/entertainment requires the best solution to ensure the best performance possible. Phase 3 has also developed a bi metal connector, used specifically with aluminium cable. There are huge benefits in using aluminium cable, it's lighter, cheaper and the cable is clearly identified as aluminium, reducing the risk of theft but at the point of connection, copper is still the preferred material. The challenge is to connect aluminium to copper in such a way that the joins are not affected by different coefficients of expansion, they aren't vulnerable to ingress from water and are as safe and secure as possible.

Phase 3's preferred solution is rotary friction welding (RFW), which is carried out by KUKA Thompson AWS on a subcontract basis.
"The connection made by RFW is so solid that it 'fools' the connector into thinking that it is made entirely of copper," said Andy Glachan, Director of Phase 3 Connectors Ltd.

"RFW is a relatively low-cost process but it provides an excellent result," he continued. "Doing the manufacturing ourselves would not be appropriate. We subcontract to KUKA Thompson AWS, who do a good job – and their turnaround time is good."

Safety at high levels of electrical current is always going to be paramount. Reliable performance is mission critical in conditions ranging from very cold (Winter Olympics) and wet (offshore wind farms) to muddy (Glastonbury music festival, many years!), and where spectacle is the show. Phase 3 Connectors chooses to rely on KUKA Thompson AWS, for its Powersafe, Showsafe and other connectors.

"Sixty-five per cent of our sales are overseas. We cannot afford to take any risks, with safety or with our reputation. We rely on KUKA Thompson AWS, and our connectors are the highest-rated on Earth," Andy Glachan concluded.

Less Time, Materials & Machining

For improved bonding in hydraulic pistons

Friction welding has proven to be the most cost-effective method available to hydraulic cylinder OEM's.

The eyes can be forged or machined from bar stock with a simple hole bored and flat milled prior to welding. They are then bonded to the chromed rod using the rotary friction welding process. RFW machines can grip the chromed rod and resist the torque forces throughout the welding sequence without damaging them or leaving any external marking on the chrome surface. Internal and/or external threads can be completely machined prior to welding. The extruded material or weld flash can be removed in a simple next turning operation on the friction welding machine leaving a smooth clean surface required for seal fitting.

Friction welding of induction-hardened chrome plated rods to forged eyes or clevises creates a joint with tensile and yield properties equivalent to the weakest of the parent material properties across the entire weld area.

Cost savings along with increases in overall piston rod strength and service life can be achieved over other fusion methods of bonding. Machining time can be reduced significantly by pre-machining both the chromed rod and forged eye prior to welding.

OEM yellow goods manufacturers, whilst running their own Thompson friction welding machines in-house, utilise KUKA Thompson
AWS sub-contract friction welding services for R&D, process knowledge and expertise, and during periods of peak demand for overspill production needs.

Advanced Forming Research Centre

The University of Strathclyde's Advanced Forming Research Centre (AFRC), near Glasgow Airport in Scotland, is one of seven High Value Manufacturing Catapult centres acting as a catalyst for the future growth and success of UK manufacturing.

The AFRC works with businesses of all sizes, across the UK and beyond, by bridging academia and industry, helping apply metallurgical and engineering research to the production shop floor. It aims to help companies turn innovative technologies and ideas into a commercial reality that will allow them to increase their competitiveness, boost their business and enhance their sustainability. Projects can encompass the entire product development cycle – from material testing and metallurgical characterisation through to industry standard manufacturing trials and product validation.

One of the many offerings at the centre is solid state joining in the form of two aerospace grade rotary friction welding (RFW) machines with a forging capacity ranging from 30,000lbs to 300Tons. The two machines offer the capability of performing welds via either continuous/direct drive friction welding (C/DDFW), inertia friction welding (IFW), or a hybrid of the two techniques. Solid cylinders or tubular welds can be achieved with outer diameters ranging from 35 mm to 250 mm. The RFW capability at the AFRC is the largest industrial scale welding equipment in any UK research centre, and we look forward to working with KUKA to develop our capability further.

Rotary friction welding can now be used to not only join metals but also thermoplastics and metal matrix composites in a wide variety of industrial applications [1]. The advantages of rotary friction welding as opposed to other fusion joining processes are as follows [2];

(i) the processes do not form a molten pool and therefore solidification defects (e.g. hot cracking, porosity, segregation, etc.) are reduced significantly

(ii) the processes are especially suitable to weld dissimilar metal joints, where other joining technologies have been unsuccessful, thus allowing the combination of different materials which can provide uniquely tailored solutions to engineering problems

(iii) in the majority of joints, localised intense deformation and high temperatures result in recrystallized microstructures resulting in good mechanical properties in the joint

(iv) there is no requirement for shielding gas or filler metals

(v) IFW provides a narrow heat affected zone

(vi) the processes possess a self-cleaning ability due to the wearing action of the relative movement of parts. The wear debris is continuously removed during
the initial phases of the process by the relative movement of itself into the flash

(vii) the inherent reliability and repeatability of the processes are very good, which translates to minimal non-destructive testing time and expenses

[1] M. Maalekian:'Friction welding - critical assessment of literature',Sci. Technol. Weld. Joi.,2007,12, (8), 738–759
[2] Linear and rotary friction welding review. Available from: https://www.researchgate.net/publication/293328438_Linear_and_rotary_friction_welding_review [accessed Feb 15 2018]

(viii) as all the process parameters are set before welding, operator errors are minimal

(ix) furthermore, the process cycle is very fast, of the order of a few seconds, reducing a bottleneck from the production line

(x) most rotary friction welded joints possess high integrity characteristics with the area of bonding being approximately 100% of the cross-sectional area of the joined parts

(xi) friction welders are versatile enough to join a wide range of part shapes, materials and sizes

(xii) the process is ecologically clean—no objectionable smoke, fumes, or gases are generated that need to be exhausted

The key advantage indicated above is that dissimilar materials, even metal combinations normally considered incompatible, can be joined by friction welding. Examples include, aluminium to steel, copper to aluminium, titanium to copper and nickel alloys to steel.

It is generally considered that all forgeable metallic engineering materials can be friction welded. This is well aligned with the AFRC's other research areas of interest and provides the opportunity to combine RFW with the centre's other forging and incremental forming processes to create novel hybrid, near net shape manufacturing routes for new and existing products.

We believe the future focus of RFW research for industry will include using RFW in conjunction with other rotary forming processes to create high integrity near net shape components with lower material cost and minimal material waste. Additionally, significant benefits are anticipated by the development and application of modelling capability to predict weld zone microstructure, mechanical properties and integrity by linking the material characterisation to the RFW machine welding parameters such as speed, inertia and force. Measurement and modelling of residual stress generation in the weld zone and in part usage will add greater opportunity to predict and prevent failure in the final application of components.

Moreover, the development of real-time sensoring of RFW equipment for improved process monitoring and feedback control will aid companies in innovating for the future and Industry 4.0.

Research is also currently being undertaken to friction weld more exotic materials and combinations for specific applications, for example ceramics to metal, which could open up a wide range of potential new applications for RFW products.

RFW can be applied and utilised by many sectors, such as aerospace, automotive, construction, marine, oil and gas, nuclear, propulsion, renewables, space and security.

At the AFRC, we look forward to collaborating with innovative companies like KUKA, to help future focused firms across these sectors reap the many benefits that the technology brings.

Microscopy and Ananalysis

Aston Microscopy Engineering Ltd. was established in 2016 by Dr Kameel Sawalha, C.Eng, FIMMM, consultant metallurgist, and is based at KUKA's Advanced Welding Solutions Competence Centre in Halesowen.

The laboratory is fully equipped with stereo microscopy, digital microscopy, SEM & EDAX with a full suite of pre examination coupon preparation equipment for grinding, polishing and etching samples before analysis.

The laboratory is equipped to perform both Vickers & Rockwell hardness testing, tensile and bend testing and provides advanced metallurgical services.

With over 50 years of experience in advanced metallurgy, Dr Sawalha is an authority in forensic investigation and comprehensive failure analysis of any kind of engineering materials and components.

Invaluable: Perhaps the most valuable role is in providing assistance to customers to help them to avoid potentially expensive mistakes. This is a free service, available to customers of KUKA AWS at the quotation stage and through to production. This work begins at the concept or initial design stage with advice on the selection of appropriate materials and geometries suitable for the rotary friction welding processes.

"Having a metallurgist available to give advice can help customers to feel more confident," Dr Sawalha said. "We can discuss all the possibilities, compare the various properties and advantages or disadvantages of different materials and ensure that a development program is well-defined and the customer is informed from the outset of what is feasible or not feasible."

As well as material composition, component design and service life; environmental circumstances should also be taken in to account when considering where the component will be operating.

Avoiding cheap – but expensive - mistakes:

Customers under cost pressures – which is pretty much everyone – can be tempted to take advantage of what may look like very favourable prices for steel (for example) from a new supplier, perhaps from some distant shores. But cheaper material will not be a real bargain if it does not come up to standard.

"We can undertake electron microscope examination of material in order to confirm a material is the correct formulation, has the right carbon content and % element content for the grade/specification, and is what the customer thinks they are buying," Dr Sawalha said.

Overcoming Capital Costs & Conclusion

Overcoming capital costs

KUKA Thompson AWS sub-contract friction welding services

The capital equipment investment required to purchase a rotary friction welding machine could prove prohibitive to some potential customers' and applications if the return on investment is not justified by high volume production demand or high value production demand.

KUKA Thompson's UK AWS sub-contract facilities located in Halesowen, West Midlands provide a full range of friction welding and support services for those customers and applications that cannot justify the capital investment but who still want to benefit from the process to grow their businesses. Not only can KUKA Thompson AWS offer rotary friction welding on a subcontract basis, consultation, pre and post weld processing inclusive of specialist, induction heat treatment and metallurgical investigation and analysis via the fully kitted onsite laboratory is also available.

KUKA Thompson AWS is the only sub-contract friction welding company in the UK that can provide customers with a full suite of analytical and investigative metallurgical services onsite.

Conclusion

Rotary friction welding offers many benefits.

High integrity bonds, increased design and manufacturing flexibility with large potential cost savings and 100% repeatable and assured quality joints.

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