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Editorial

Dissimilar Metal Welding

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1. Introduction and Scope

The combination of distinct materials provides intriguing opportunities in modern industry applications, whereas the driving concept is to design parts with the right material in the right place. Consequently, a great deal of attention has been directed towards dissimilar welding and joining technologies. In the automotive sector, for instance, the concept of "tailored blanks", introduced in the last decade, has further highlighted the necessity to combine dissimilar materials. As far as the aeronautic field is concerned, most structures are built combining very different materials and alloys in order to match lightweight and structural performance requirements.

In this framework, the application of fusion welding techniques, namely tungsten inert gas or laser welding, is quite challenging due to the difference in physical properties, in particular the difference in melting points between adjoining materials. On the other hand, solid state welding methods, for example, friction stir welding and linear friction welding processes, have already proved to be capable of manufacturing sound Al-Cu [1], Al-Ti [2], Al-Mg [3,4] joints. Recently, promising results have also been obtained using hybrid methods. The main focus of this special issue is to discuss some recent advances in the field of dissimilar metal joining. Selected applications of major welding and joining processes have been highlighted. Special attention has been given to mechanisms behind the joining of dissimilar metals for special purpose applications, investigating the adoption of traditional experimental approaches in addition to computational modelling, for deeper information gathering. In the following section an overview of the selected articles is provided.

2. Contributions

This special issue of *Metals* covers sixteen articles [5–20] focused on dissimilar metal joining techniques. Some of the published reports have confirmed the increasing interest in solid state welding processes, in particular friction based welding [6–10] and electromagnetic pulse welding [11,12], due to benefits related to the properties and achievable microstructure, and to energy and environmental considerations. Other papers dealt with fusion welding techniques, mainly laser based [13–16], among others [5,17], and brazing processes [18,19]. Most of the applications are related to the automotive and aerospace sector, nevertheless dissimilar joints, characterized by improved fracture resistance, were indicated as an indispensable part of nuclear power plants for connecting the safe end (austenitic stainless steel 316L) to the pipe-nozzle (ferrite low-alloy steel A508) [20].

More specifically, a thorough review article proposed by Patel et al., has shed light on the potential of friction stir welding (FSW) in dissimilar welding of distinct aluminium alloys [6], commenting on microstructure, mechanical properties, corrosion and fatigue behaviour. The authors discussed in detail, aspects related to the processing parameters and setup, in terms of placement of the adjoining materials and tool offsets. Furthermore, pros and cons given by the application of bobbin and stationary shoulder tools were evidenced as well. Li et al. demonstrated the capabilities of FSW to mitigate some limiting factors associated with Al/steel fusion welding, attributable to the formation of brittle Al/Fe intermetallic compounds (i.e., AlFe3, AlFe, Al2Fe, Al3Fe, Al5Fe2, and Al6Fe), welding distortion, cavities, and cracks, providing some intriguing opportunities for the automotive industry [7]. In particular the effect of revolutionary pitch on interface microstructure and mechanical behaviour of friction stir lap welds of AA6082-T6 to galvanized DP800 dual-phase steel sheets was investigated. The experimental results were commented on, taking into account numerical calculations provided by an iso-strain-based linear mixture law of the stir zone [7]. The automotive sector has witnessed the emerging trend of incorporating Cu-based materials in electrical components. The solid state joining of dissimilar Cu alloys, and of Cu alloys with Al alloys, is the focus of articles [8,9], respectively. In the former, Sun et al. successfully welded dissimilar CuNiCrSi and CuCrZr in a butt joint configuration using FSW. The microstructure and mechanical properties were investigated, highlighting the absence of the typical heat affected zone [8]. The transformation of coarse grains in the base metal (BM) into fine equiaxed grains in the nugget zone (NZ) was observed. In the latter, Eslami et al. pointed out that an adjustment of the cross-section is required to realise electrical conductors free of resistive losses [9]. In [10], Zhou et al. carried out friction stir spot welding-brazing of aluminium alloy and a hot-dip aluminized titanium alloy, using a Zn interlayer to extend the extremely narrow joining area, generally addressed as the main drawback of FSSW process. The formation of the brazing zone between the Al alloy and Al coating on Ti6Al4V alloy was successfully introduced by the addition of a Zn interlayer. A dramatic enhancement of the fracture load was proved using this hybrid technique.

Magnetic pulse welding (MPW) is an eminent impact welding process which utilizes the high-speed collision between two metallic surfaces in order to promote the creation of metallurgical connections. Bellmann et al. [11] discussed the influence of temperature in dissimilar MPW, assuming aluminium alloy EN AW-6060 for the outer tube and C45 steel for the inner rod [11]. Their experiments showed that jetting in a strong material flow was not mandatory for a successful MPW process. A cloud of particles ejected during the impact, with lower velocities, can in turn enable welding. Faes et al. investigated electromagnetic pulse welding process to join copper to steel tubular elements, comprehensively discussing the role of stand-off distance and discharge energy [12].

As far as dissimilar fusion welding processes are concerned, relevant efforts have been directed toward laser based methods [13–16]. Dual-beam laser welding has been investigated for dissimilar welding of steel/Al [13]. Cui et al. studied the effect of the major process parameters, including the dual-beam power ratio and dual-beam distance on steel/Al joint features, in terms of weld shape, interface microstructure, tensile resistance and fracture behaviour. Intermetallic compound (IMC) layer formation (needle-like θ-Fe4Al13 phases) was also highlighted [13]. The article by Pereira et al. [14] deals with dissimilar metal laser welding between DP1000 Steel and AA1050, by employing a pulsed Nd: YAG laser. Welding parameters such as laser beam power, laser beam diameter, pulse duration and welding speed were optimized for the obtainment of a better set of weld joints, even for highly dissimilar materials. On the similar note, Xue et al. [15] investigated the interfacial features of a dissimilar Ti6Al4V/AA6060 lap joint produced by pulsed Nd:YAG laser beam welding. The potential phases, TiAl, TiAl2, and TiAl3, were observed near the Ti/Al interface. The phase change was situated mainly in the Al-rich melted zone. By using an orthogonal experimental design method, the sensitivity order of the selected key process parameters on peak shear strength were: overlap, duration, laser beam diameter and power. Jarwitz et al. also focused on laser beam welding of different set of materials, in order to clarify the influence of the oscillation parameters on the weld seam geometry, and the implications on the electrical resistance of the joints [16].

Xue et al. [18] inspected the microstructure and properties of a Cu/304 stainless steel dissimilar metal joint brazed with a low silver Ag16.5CuZnSn-*x*Ga-*y*Ce braze filler after aging treatment. The addition of Ce reduced the intergranular penetration depth of the filler metal into the stainless steel during the aging process by 48.8%. The Ag16.5CuZnSn-2Ga-0.15Ce brazed joint showed optimum performance compared to the other joints. Yu et al. proposed the method of welding/brazing to realise a high quality welding of dissimilar metals, using 5A06 aluminium and galvanized steel welding using laser beam as the main heat source, and a trailing arc in an assisting role [19]. Under suitable welding parameters, a sound welding seam was obtained. The highest tensile strength was observed to be 163 MPa, which was nearly 74% 5A06 aluminium alloy when the fracture occurred at the weld seam. Near the aluminium welding brazing seam, two different IMC formations appeared [19].

3. Conclusions and Outlook

A varying range of dissimilar welding processes and configurations have been discussed. Evidently, the major focus in these investigations was to overcome the challenges posed by dissimilar metal joining and to achieve sound joints with mechanical and metallurgical property changes. The usage of solid state and hybrid/mixed techniques have yielded interesting results in terms of joint performance. Nevertheless, there are still many challenges to address, related to both material and processing aspects.

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