

## Critical Assessment of Welding Techniques for Dissimilar Joining of Aluminium to Steel

P. B. Prangnell, J. D. Robson  
LATEST2, School of Materials  
The University of Manchester

New design concepts for light weight vehicles will increasingly involve multi-material structures, as they provide the best compromise solution between mass reduction, performance, and cost. Such designs allow materials to be used more efficiently and will involve combining light alloys with high strength steels and composites. Dissimilar joining is thus a key technology area for enabling increased fuel efficiency in transport.

Within LATEST2 we have taken an objective fundamental look at a range of welding technologies that could potentially be used for joining steel to aluminium. This work has focused on solid state processes, or processes with rapid thermal cycles to try to reduce the tendency for intermetallic (IMC) reaction at the joint interface, which is the main limiting factor in producing joints with acceptable failure energies. Examples of the processes

studied to date include; ultrasonic spot welding (USW), variants of friction stir spot welding (FSSW), and laser conduction spot welding. Ongoing work in the team is also directed at gaining a better understanding of IMC reactions in rapid dissimilar metal welding so that modelling tools and solutions can be evaluated for reducing the reaction rate in parallel with process developments.

A full range of techniques has been used to better understand the reaction behaviour, defects formed and, in the case of solid state welding, the material flow and bonding process; including 3D tomography, modelling and high resolution microscopy of the weld interfaces. With laser spot welding it has been shown that is very difficult to control the IMC layer to a thin enough level. There are also distinct problems when welding coated steels due to evaporation of the zinc. Friction based solid state processes appear more promising, but forming a reliable bond between a hard steel surface and a soft flowing aluminium alloy has been found to greatly increase the weld cycle time, which also allows significant IMC reaction to take place. This occurs because flow studies have shown that the aluminium sheet tends to develop a sticking condition on the steel

surface at an early stage in welding and as result there is little relative motion of the two materials across the interface. There is thus little benefit in terms of cleaning oxide off the steel surface and the joining mechanism is principally one of diffusion bonding, facilitated by frictional heating. There is also an issue with galvanised steels due to the low melting point eutectic reaction between aluminium and zinc, which creates a liquid film at the join line, leading to weld defects. As a result of the fundamental studies performed within LATEST2, one possible solution has emerged that has been termed 'abrasive circle welding'. This technique involves adapting the friction stir spot welding technique to use a slight orbital path, so that the tool probe lightly abrades the steel surface over a circular area to produce an oxide free surface during the welding cycle. This process has allowed successful welds to be produced between steel and aluminium with a very rapid weld cycle of less than one second, which greatly reduces IMC growth and, as a result, weld failure energies equivalent to that of aluminium-aluminium joints have been achieved. With the same approach, successful dissimilar welds have also been demonstrated on galvanized zinc coated steel sheets.

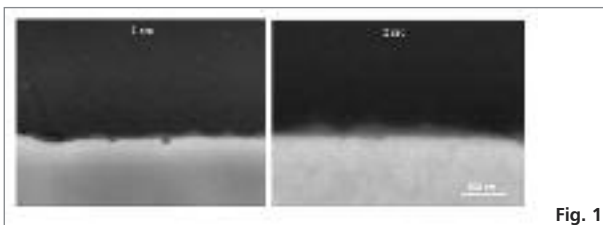


Fig. 1

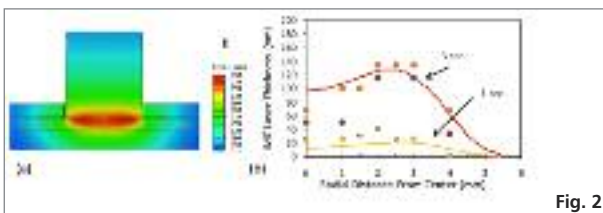


Fig. 2

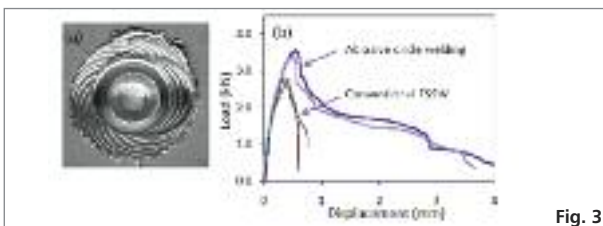


Fig. 3

**Fig. 1** Development of a thin IMC reaction layer in a conventional FSSW between steel and aluminium with increasing welding time.

**Fig. 2** (a) Predicted weld temperature distribution (courtesy of H. Shercliff Cambridge Engineering) and (b) corresponding IMC reaction layer thickness across the weld interface in an Al-steel FSSW.

**Fig. 3** (a) Surface appearance of an abrasive circle friction spot weld between Al and steel and a comparison of the lap shear test load displacement curves with that from a conventional FSSW.

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**Publications:** Y. C. Chen, A. Gholinia, P. B. Prangnell, Interface structure and bonding in abrasion circle friction stir spot welding: A novel approach for rapid welding aluminium alloy to steel automotive sheet, *Materials Chemistry and Physics*, 134 (2012), pp. 459-463

F. Haddadi, D. Strong and P. B. Prangnell, Effect of Zinc Coatings on Joint Properties and Interface Reaction in Aluminium to Steel Ultrasonic Spot Welding, TMS, San Diego (2011) *J Minerals, Metals and Materials Soc (JOM)* 64.02 (2012), pp. 407-413

Y. C. Chen and P. B. Prangnell, Interface Structure and Bonding In Rapid Dissimilar FSSW of Al to Steel Automotive Sheet, In *Symposium 13th International Conference on Aluminium Alloys (ICAA13)* Edited by: Hasso Weiland, Anthony D. Rollett, William A. Cassada, TMS, Pittsburgh, PA, (2012), pp 777-782.

P. Jedrasiak, A Reilly, H.R. Shercliff, G.J. McShane, Y. C. Chen and P. B. Prangnell, Thermal Modelling of Al-Al and Al-Steel friction Stir Spot Welding, In *Mathematical Modelling of Weld Phenomena 10*, Verlag der Technischen Universität Graz, Austria, 2012 - in press.

A Reilly, H.R. Shercliff, G.J. McShane, Y. C. Chen and P. B. Prangnell, Novel Approaches to Modelling Metal flow in Friction Stir Spot Welding, In *Mathematical Modelling of Weld Phenomena 10*, Verlag der Technischen Universität Graz, Austria, 2012 - in press.