Experimental report

14/02/2018

Proposal:	**1-02-212**	**Council:**	10/2016
Title:	Characterisation of a dissimilar Al-to-steel joint. From process parameters to residual stresses and mechanical properties		
Research area:	Materials		

This proposal is a new proposal

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Samples: Fe
Al

Instrument	Requested days	Allocated days	From	To
SALSA	4	4	24/02/2017	28/02/2017

Abstract:

In the automotive industry, developing multimaterial car bodies is seen as a way to lighten vehicles to reduce greenhouse gas emissions while keeping crashworthiness. The combination of aluminium and steel is of particular interest due to the lightness of aluminium and the strength of steel.

In this context, a novel method to weld aluminium to steel has been developed at UCL, the Friction Melt Bonding (FMB) process. The weld is achieved by the formation of a bonding intermetallic layer (IML) at the interface between the base materials. Due to the temperature reached during the process, of the order of 700 °C, and the large difference of the coefficients of thermal expansion, residual stresses are induced. These ones have an impact in the measurement of the weld strength in general and the IML toughness in particular.

Two welds performed at different welding speeds are studied in order to understand the building up of residual stresses. In particular, the transfer of stresses between the steel and the aluminium, the level of residual stresses with different heat affected and fusion zones and its impact on the mechanical properties on the IML interface will be considered.

Project Proposal No: 1-02-212

Title: Characterisation of a dissimilar Al/steel joint: From process parameters and heat affected zones to residual stresses and mechanical properties

Investigators: N. Jimenez-Mena, T. Sapanathan, J.-M. Drezet, P.J. Jacques, T. Pirling, T. Simar

1. Introduction

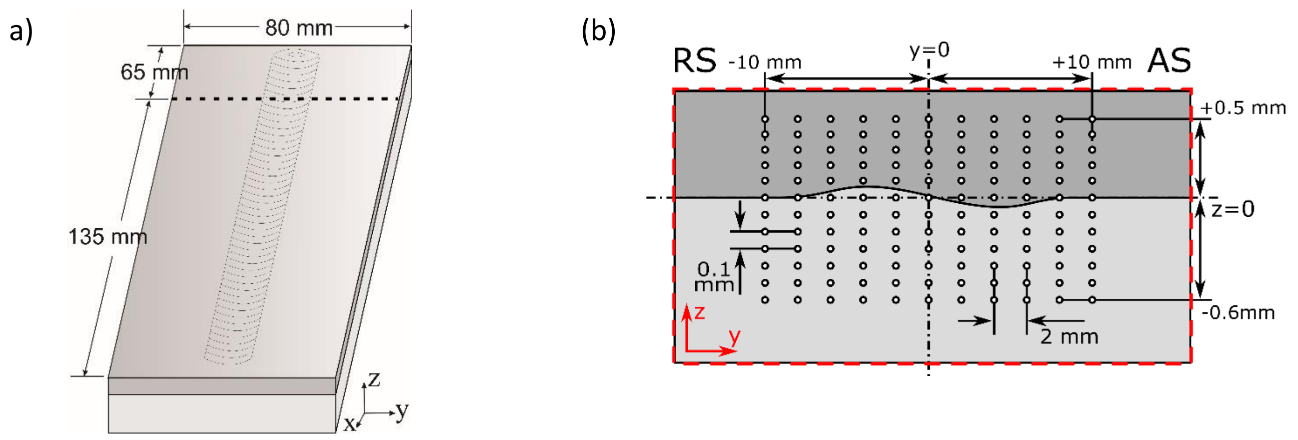
Friction Melt Bonding (FMB), a recently developed welding method at Catholic University of Louvain (UCL), has been used to join aluminium to steel [1, 2]. FMB employs a lap welding configuration and the upper steel plate is heated locally by friction stirring using a simple rotating (flat faced) cylindrical tool powered by a generic milling machine. The generated heat during the process locally melts the aluminium and facilitates the bond formation. It also enables to form one or more intermetallic compounds (IMCs) at the interface. Moreover, experimental observations and numerical simulations of FMB indicate that the temperature during the welding process reaches ~700 °C, and thus it induces residual stresses (RS) due to the large difference in the coefficient of thermal expansion (CTE) of both aluminum and steel. RS are crucial as they affect the joint strength and the load carrying capacity of the joints produced by FMB process.

Thus, neutron diffraction measurement was performed at Institut Laue-Langevin (ILL) using the SALSA diffractometer (more detail of the instrument can be found in [3]) to evaluate the RS of an FMB joint. The obtained measurements are accessible in the data depository of ILL [4]. This report provides the experimental procedure and the results after a detailed data analysis.

2. Experimental procedure

Weld sample was fabricated using FMB process with a transverse speed of 300 *mm/min* and the rotational speed of 2000 RPM. The sample has a dimension of 200 x 80 x 4.0 *mm* with a weld length of ~165 *mm*. The base materials are dual phase steel (0.9 *mm* thickness) and an aluminium alloy AA1050 (3.1 *mm* thickness). To avoid the texture owing to the directional solidification of the molten pool that could influence the scattering, TiB2 is added to the Al alloy to obtain an equiaxed microstructure.

The chosen diffraction peaks for aluminium and steel were {311} and {211}, respectively. The wavelength of the neutron beam was set to 0.166 *nm*, and the detector was set with the angle 2ω of 136.84° and 139° for aluminium and steel, respectively. In this measurement, each scan was performed with 500 counts, since it was sufficient to obtain the corresponding diffraction peak. Nominal gauge volume (NGV) of 0.6×0.6×2 *mm* (the smallest NGV achievable with the SALSA) was used in this experiment to obtain local measurements near the interface. It should be noted, that using a small gauge increased in the acquisition time.



(c)

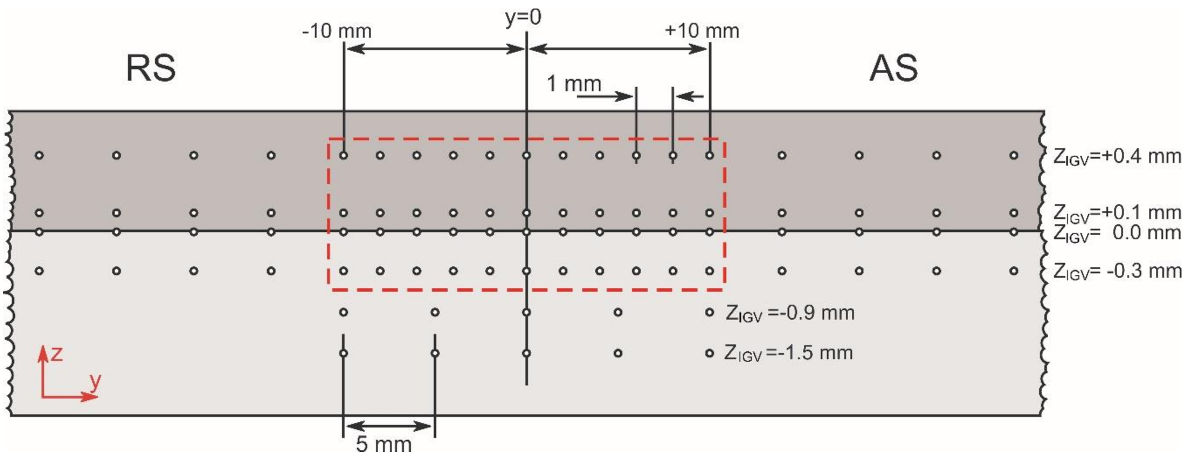


Fig. 1. (a) Schematic illustration showing the location of the neutron diffraction scan indicated by the dashed line. Schematic representation of the analysed centroids of instrument gauge volume (Z_{IGV}) for diffraction points for (b) the steel plate close to the interface used to track the interface and (c) line scans parallel to the interface in both steel and aluminum plates.

The diffraction scans were performed across the weld indicated by the broken line in Fig. 1a (135 mm in x direction). Two distinct approaches were taken to scan both material and their interface. Firstly, the surroundings of the welded interface were probed for the steel to track the position of the interface and to obtain the RS in the steel plate near the interface (Fig. 1b). It was performed in a fine grid array including the processed zone defined by $-10 \leq y \leq 10$ (Fig. 1b). The second series of measurements were performed along the lines parallel to the interface for both aluminum and steel to obtain the profile of RS on the transverse cross section of the entire plate (Fig. 1c). The lines correspond to positive Z_{IGV} were used to take the residual stress measurements in the steel plate while the lines with $Z_{IGV} \leq 0$ were used for the aluminum. The longitudinal and transverse components were measured in the transmission mode while the normal component was obtained using the reflection configuration. The measurements were post processed using LAMP software and treated with appropriate pseudo correction, based on the method prescribed by Bruno *et al*. [5].

3. Results and discussion

Fig. 2 shows the RS in the steel obtained for the small step scan (Fig. 1b) near the interface. The intensity peaks also helped to identify the interface position accurately.

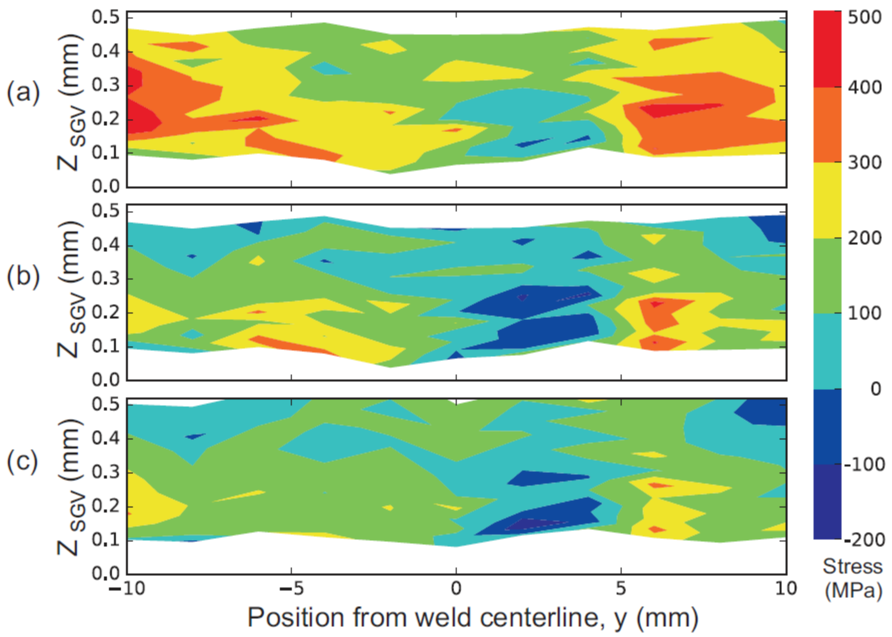


Fig. 2. Residual stress maps obtained for the steel from the small step scans provided in Fig. 1b. 3D components of the RS correspond to the steel {211} peak in the (a) longitudinal, (b) transverse, and (c) normal directions. [Z_{SGV} – centroid z position of sampled gauge volume]

Fig. 3 shows the RS in the steel and aluminum obtained for the large step scan (Fig. 1c), and after the post processing treatment of pseudo stress correction for the near interface scans.

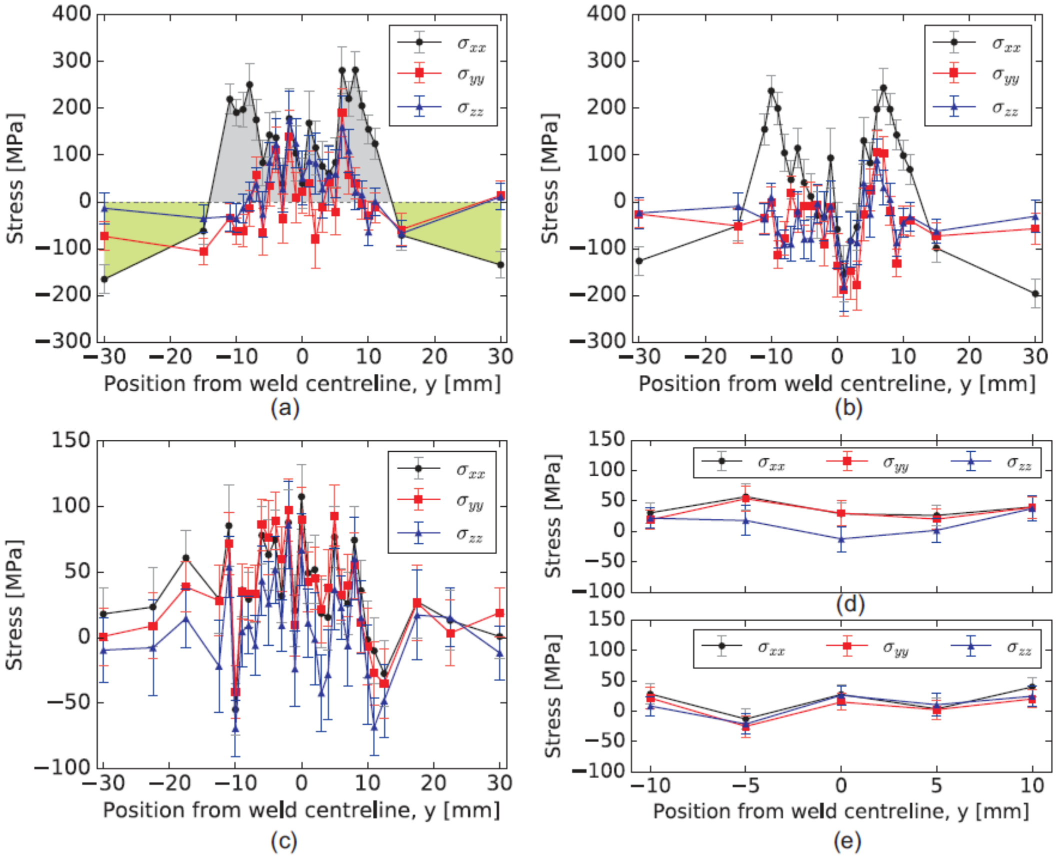


Fig. 3. Residual stress components in the steel and aluminum plates obtained according to the line scans in Fig. 1c. RS in the steel plate corresponds to the lines at (a) Z_{IGV} = +0.4 mm and (b) Z_{IGV}= +0.1 mm. Residual stress components in the aluminum correspond to the lines at (c) Z_{IGV} = -0.3 mm, (d) Z_{IGV} = -0.9 mm and (e) Z_{IGV} = -1.5 mm. Longitudinal RS at Z_{IGV} = +0.4 is shaded by grey and green for tensile and compressive stresses, respectively.

The results indicate longitudinal RS in the upper steel plate has an overall "M" shape distribution (Fig. 3b), while the Al alloy shows a "W" shape near the interface (Fig.3c). This mirror effect is obvious at the vicinity of the interface and is mainly caused by the mismatch in CTE. Another source of RS in the steel mainly comes from a similar effect of friction stir welding (FSW) like processing condition while the RS in Al partly comes from the melting-solidification. The experiments provided a better understanding of RS in a dissimilar joint and various origins of RS particularly near the interface. An in-house coding of pseudo stress correction also developed based on a theoretical models in a literature that helped to estimate the near interface and surface RS. **A paper will be submitted soon on these highly original findings of RS in a dissimilar joint [6].**

Acknowledgements

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