Experimental report

16/09/2019

Proposal: **1-02-245** **Council:** 4/2018

Title: Characterization of a dissimilar Al/steel joint with the influence ofhot-tears.

Research area: Engineering

This proposal is a continuation of 1-02-212

Main proposer: **Thaneshan SAPANATHAN**

Experimental team: Thaneshan SAPANATHAN
Aude SIMAR
Jean-Marie DREZET

Local contacts: Thilo PIRLING

Samples: Steel
Aluminum

Instrument	Requested days	Allocated days	From	To
SALSA	4	3	22/10/2018	27/10/2018

Abstract:

Recently, multi-material assemblies for automobiles become attractive to lighten the vehicles and thus reduce the greenhouse gas emission while maintaining their crashworthiness. The combination of Al and steels is of a particular interest due to the lightweight of Al alloys and the high strength of steels. Although dissimilar welding of Al/steel brings some metallurgical challenges, the new Friction Melt Bonding technique developed at UCL enable to achieve good quality joints.
Our previous study at ILL (Proposal 1-02-212) helped to understand the residual stresses (RS) near the Al-steel interface. Another recent finding in such weld bring the question of whether the formation of hot-tears is a RS relaxing mechanism in such welds or not. Experimental results indicated that many welds with minor hot-tears are stronger than welds without them. Thus, identifying the correlation between hot-tear and RS in a weld could provide a solution to make stronger and tougher welds. Thus, neutron diffraction measurements are required to understand the role of RS on the samples with and without hot tears, and that can shed a light in the understanding of hot tear formation in welded joints.

Project Proposal No: 1-02-245

Title: Characterization of a dissimilar Al/steel joint with the influence of hot-tears.

Investigators: 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), to join dissimilar materials with different melting temperature (e.g. aluminium to steel) [1, 2]. When considering an FMB of Al/steel joint, it is performed in a lap welding configuration while the upper steel plate is heated locally by friction stirring using a simple rotating cylindrical (flat faced) tool powered by a FSW 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 at the interface, and thus it induces residual stresses (RS) due to the large difference in the coefficient of thermal expansion (CTE) of both aluminum and steel. Our previous study at ILL (Proposal 1-02-212) helped to understand the origin of RS near the Al-steel interface, and the work has been recently published in "Journal of Material Processing Technology" (IF: 4.18) [3].

Another challenging in FMB welds is Hot-tear; it brings the question of whether the formation of hot-tears is a RS relaxing mechanism in the welds or not. Experimental results indicated that many welds with minor hot-tears are stronger than welds without them. Thus, identifying the correlation between hot-tear and RS in a weld could provide a solution to make stronger and tougher welds. Thus, neutron diffraction measurements was performed at Institut Laue-Langevin (ILL) using the SALSA diffractometer (see [4] for more detail of the instrument) to evaluate the RS of an FMB joints with various amount hot-tears. The obtained raw data of measurements are accessible in the data depository of ILL [5]. This short report provides the experimental procedure and the results after a detailed data analysis.

2. Experimental procedure

Welded samples were fabricated using FMB process with a transverse speed of 200 *mm/min* and 400 *mm/min* with both brass and stainless steel backing plates, and the rotational speed of 2000 RPM. The naming convention of the samples are given below in Table 1. The samples have 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 AA6061 (3.1 *mm* thickness).

Table 1: measured samples and welding parameters.

Sample	B200	B400	SS200	SS400
Backing plate	brass	brass	stainless steel	stainless steel
Welding speed	200	400	200	400

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 ω of –49.0° or 41.0° for Al and -136.51° or -46.51° for steel. In this measurement, each scan was performed with 800 counts, to obtain a reliable diffraction peak with minimum error. 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 the maximum possible resolution. It should be noted, that using a small gauge can increase the acquisition time.

The diffraction scans were performed across the weld indicated by the broken line in Fig. 1a (135 mm in x direction). A fine spacing was used for the measurements near the welded zone defined by $-12 \le y \le 12$ (Fig. 1b) while a course spacing was used outside the weld zone (Fig. 2b). In order to avoid the pseudo strain effect [6, 7], that resulting from the partial immersion of the gauge volume in the measured material and to obtain an accurate RS, the steel was measured with the stage oscillation having the oscillation speed of 0.6mm/min to cover the whole thickness for an amplitude of ~1.5 mm. In the Al side, measurements were performed at z_{IGV} = -1 mm (i.e. 1 mm from the interface into the Al, Fig. 1b). The longitudinal and transverse components were measured in the transmission mode while the normal component was obtained using the reflection configuration. Residual stain and residual stress calculations, and error analysis were performed using the post treated data obtained from LAMP software [8].

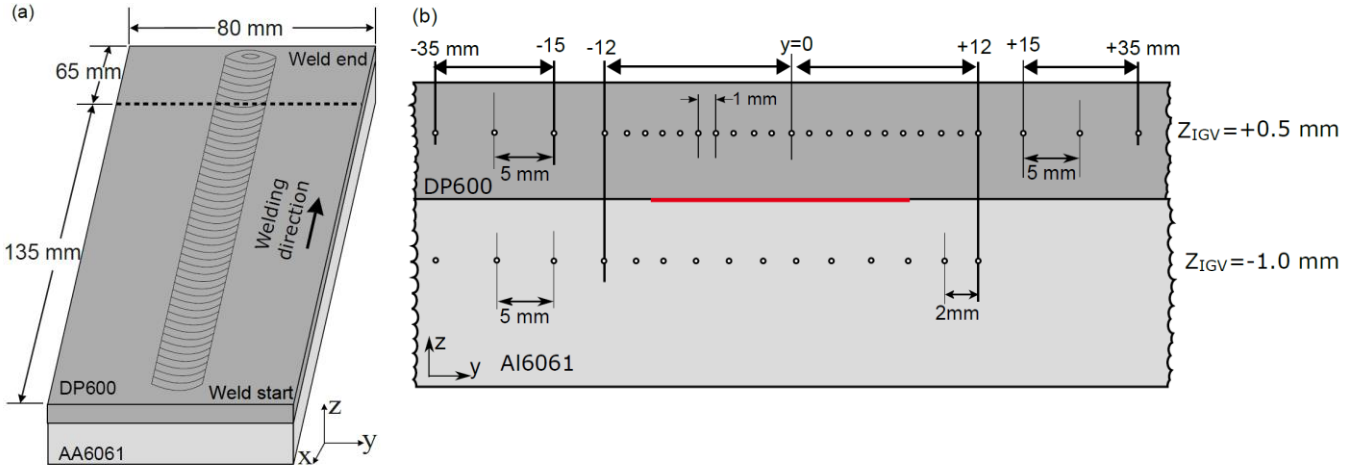

Fig. 1. Schematic illustrations showing (a) location of the neutron diffraction scan indicated by the dashed line (at 135 mm along the x direction from the beginning side of the weld) and (b) the transverse plane indicated with the measured centroids points of instrument gauge volume (Z_{IGV}) for the scans parallel to the interface in both steel and aluminum. The red line in (b) represents the welded region at the transverse cross section.

3. Results and discussion

Fig. 2 shows the average longitudinal RS (σ_{xx}) in the steel obtained for the four welds (Table 1). σ_{xx} increases with the increase of heat input; i.e. residual stresses increase for a given transverse speed when replacing the brass backing plate by stainless streel backing plate. Moreover, for a given backing plate, similar to friction stir welding (FSW), σ_{xx} increases with the increase of transverse speed due to the reduced heat input for short duration.

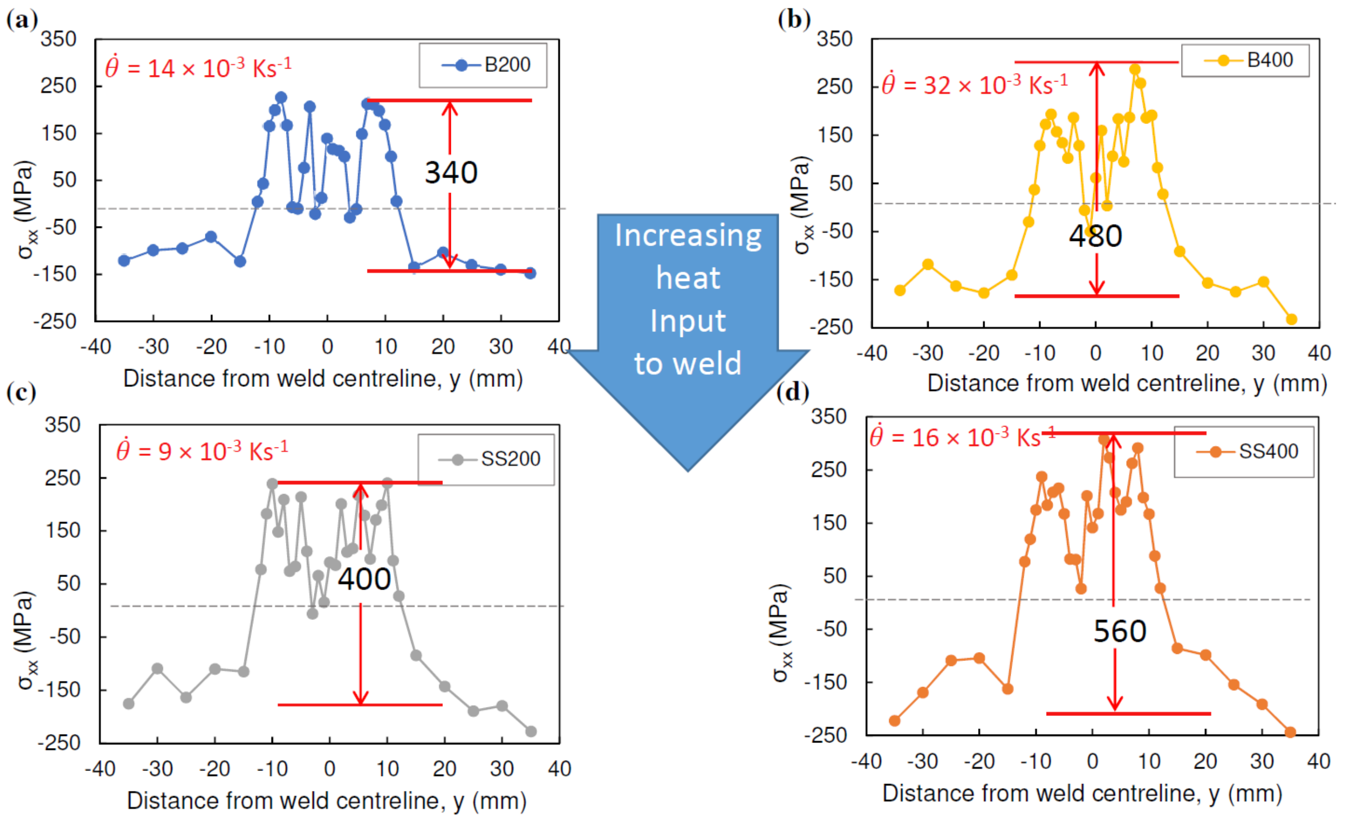

Fig. 2. Average Longitudinal RS on the steel side for the 4 welding cases of (a) B200, (b) B400, (c) SS200 and (c) SS400.

The transverse RS (σ_{yy}) slightly increases to tensile in the middle of the weld, when changing a brass backing plate (Fig. 3a) by a stainless steel backing plate (Fig. 3b). Similar trend also observed for the welds preformed with 400 mm/min transverse welding speed.

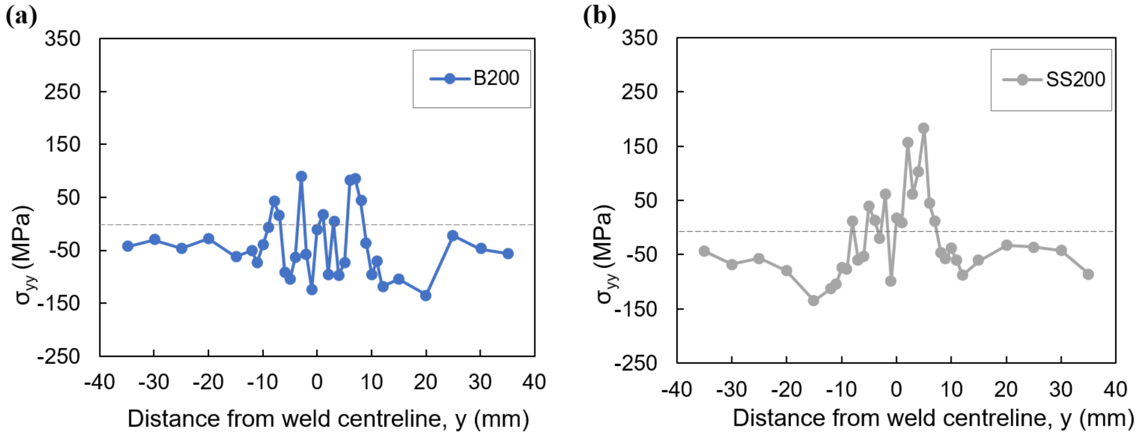

Fig. 3. Transverse RS on the steel side for the welding cases of (a) B200 and (b) SS200.

Moreover, after the measurement, when cutting the sample, the welds performed with stainless steel backing plate failed completely. This occurs as a result of large residual stresses, while the RS results confirms that the large residual stresses resulting from the processing conditions still remain present in the welds with hot tears. It was expected that the welds with large hot-tear (i.e. the welds with SS backing plate) will have the lower residual stress. However, it is identified that the opposite is true, where the hot tear does not affect the residual stresses along the mid thickness of the steel and in the aluminum at 1mm away from the interface. Hot tear may have slightly influenced the residual stresses at the interface, however, that requires fine grid measurement around the interface and hot-tear zone. Moreover, resolving fine grid measurements using neutron diffraction will have its own challenges due to the presence of pseudo strain. From this experiment and metallurgical characterization of joints, it was identified that; (1) amount of hot tear does not show a direct correlation with the residual stresses, and (2) process parameters correlates well with RS. **A conference presentation has been made on the original finding at the "6th International Conference on Scientific and Technical Advances on Friction Stir Welding & Processing (FSWP2019)" [9]. A paper will be submitted in the near future on these highly original findings of RS in Al6061/DP600 joints.**

Acknowledgements

TS acknowledges F.R.S.-FNRS, Belgium for his postdoctoral fellowship at UCLouvain. AS acknowledges the financial support of the European Research Council for a starting grant under grant agreement 716678, ALUFIX project. The authors the international Neutron Source at Institut Laue-Langevin (ILL) for the provision of beam time.

References

[1] C. van der Rest, P.J. Jacques, A. Simar, Scripta Materialia 77 (2014) 25-28.
[2] C. van der Rest, A. Simar, P.J. Jacques, Patent No. WO 2013164294 A1, 2013.
[3] N. Jimenez-Mena, T. Sapanathan, J.M. Drezet, T. Pirling, P.J. Jacques, A. Simar, Residual stresses of friction melt bonded aluminum/steel joints determined by neutron diffraction, Journal of Materials Processing Technology 266 (2019) 651-661.
[4] T. Pirling, G. Bruno, P.J. Withers, Materials Science and Engineering: A 437(1) (2006) 139-144.
[5] T. Sapanathan, J.-M. Drezet, P. Jacques, T. Pirling, A. Simar, Institut Laue-Langevin (ILL), doi: 10.5291/ILL-DATA.1-02-245, 2018.
[6] T. Pirling, Materials science forum, Trans Tech Publications Ltd., Zurich-Uetikon, Switzerland, 2000, pp. 107-112.
[7] G. Bruno, C. Fanara, D.J. Hughes, N. Ratel, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 246(2) (2006) 425-439.
[8] LAMP, The Large Array Manipulation Program, accessed 10/03/2017. http://www.ill.eu/data_treat/lamp/the-lamp-book/.
[9] T. Sapanathan, N. Jimenez Mena, J.-M. Drezet, S. Cabeza, T. Pirling, P. Jacques, A. Simar, Residual stresses in Al6061/DP600 welds produced by a process derived from Friction Stir Welding, 6th International Conference on Scientific and Technical Advances on Friction Stir Welding & Processing, Louvain-la-Neuve, 2019.