Evaluation of the intermetallic fracture toughness in Al-to-steel welds performed by Friction Stir Welding and Friction Melt Bonding

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Abstract

The toughness of the intermetallic bonding of Al-to-steel welds is assessed from lap-shear and dedicated mechanical testing. The welds have been performed in lap-joint configuration using two techniques; Friction Stir Welding (FSW), a solid-state process and Friction Melt Bonding (FMB), a novel fusion-based process developed at the UCL [1].

Introduction

One of the suggested paths to reduce the weight of the automobile structures while keeping the crashworthiness is to efficiently combine aluminium alloys and advanced high strength steel alloys. Despite the potential role of these welds in the upcoming generations of transports, not much is known on the fracture toughness of the joints and their brittle behaviour.

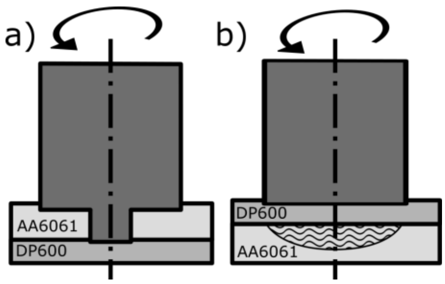

Figure 1: Schematic view of a) FSW and b) FMB showing the molten pool in the AA6061

The bonding mechanism of Al-to-steel welds relies in the formation of Fe/Al intermetallic compounds (IM) at the interface as a results of the reaction of both base materials. In FSW, the required heat to carry out the reaction is provided by the friction and deformation caused by a rotating cylindrical pinned tool which is plunged in the aluminium. The heat generated close to the pin, either in contact or not the steel, is enough to activate the formation of the Fe/Al IM without melting the aluminium (Figure 1a). On the other hand, the generation of heat in FMB relies on the friction and deformation of the steel plate in contact with a rotating cylindrical tool showing no pin. The heat is subsequently transmitted through the thickness of the steel plate. The aluminium in contact with the steel locally melts and reacts forming the IM (Figure 1b) [2]. In both cases the tool was made on cemented tungsten carbide (WC-Co) with no additional features.

Results and discussion

The base materials are AA6061-T6 aluminium alloy and Dual-Phase 600 steel with respective thicknesses of 3.1 and 0.8 mm.

Intermetallic Observations

Cross section observations at SEM reveal that the intermetallic in FSW is thinner than in FMB due to the lower temperatures attained. In the case of FSW no signs of local melting are observed, however, the contact of the tool with the steel plate leaves a wavy interface with a steel hook into the aluminium plate product of the deformation. (Figure 2a)

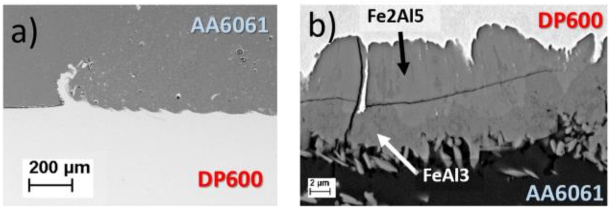

Figure 2: a) Wavy interface in FSW showing a steel hook into the AA6061 and b) observation of a thick IM in FMB showing a crack and both intermetallic compounds (Fe_2Al_5 and $FeAl_3$)

In the case of FMB, the interface is smoother, but the much higher heat input can lead to the formation of an IM so thick that shows cracks prior to testing (Figure 2b). An EDX analysis reveals that the IM is formed of two phases, Fe_2Al_5 and $FeAl_3$ (Figure 2b).

Lap shear testing and simulations

Lap-shear testing revealed that the fracture initiated and propagated through the IM in a brittle fashion for both methods. Tanaka et al. [3] observed that a thinner IM resulted in a stronger IM. Conversely, little to no difference is observed in fracture loads of FSW and FMB.

To explain this observation finite element analyses are carried out in order to assess the fracture toughness of the IM, the effect of the observed hook in the case of FSW welds and the variations in mode mixture coming from variations of the IM length and the thermal history of the welds. In parallel, more suitable testing methods are carried out to asses any dependence on the thickness and the welding method.

References

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