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Research Paper

Development and testing of fixtures for friction stir welding of thin aluminium sheets

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ABSTRACT

A simple mechanical fixture is proposed to overcome the fixturing issues present in joining of thin sheets. The fixture is similar to a lever type clamp and unlike some common FSW fixtures can hold the thin sheets close to the weld line with precision and uniform pressure. To reduce heat loss, asbestos were used as cover plate. The feasibility of the fixture was confirmed by successfully welding 0.5 mm thin aluminium alloy 6061-T6 sheets at five different tool travel speeds. A joint efficiency ($UTS_{FSW}/UTS_{Basemetal}$) of 74% and ductility of 8% in terms of percentage elongation were obtained corresponding to 150 mm/min of tool travel speed in which case the weld also withstood 180° bending test. The welds had a distorted shape similar to that of a saddle. The macrostructure indicated that TMAZ area decreased with tool travel speed.

1. Introduction

In Friction Stir Welding (FSW), the heat, produced from friction between the tool and workpiece, softens the workpiece material (Mishra and Ma, 2005). The rotating tool while plunging, plastically deforms the two workpieces under it and with its advancement along the weld line, a consolidated joint is formed. During welding, ideally zero movement of workpieces in any direction is desired (Parida et al., 2015). Imposing this movement restriction on thin sheets becomes more challenging because it demands higher precision in fixturing (Teh et al., 2012). A constant tool-workpiece contact, which depends on uniform clamping, is essential during welding so as to distribute equal heat flux throughout the weld line (Schmidt et al., 2003 and Fehrenbacher et al., 2011). Ensuring uniform clamping is more challenging in case of thin sheets because they are comparatively less stiff. Moreover, application of clamping pressure on such sheets can lead to its undulations which result in unwanted weld zone thinning and noticeable micro defects (Scialpi et al., 2008). Again, such sheets are more prone to rise, ahead of the tool, under the thermal load. Therefore, clamping as close as possible to the weld line is necessary in case of thin sheets unlike thicker ones (Sattari et al., 2012). Furthermore, due to reduction in thickness, the heat loss is relatively high in thin sheets. The fixture needs to reduce this heat loss because increasing some process variables (and hence the heat input) have critical limitations. For instance, excessive plunge force and rotational speed have risk of tearing in thin sheets (Teh et al., 2012).

Although there are fixturing issues with FSW of thin sheets as mentioned above, one cannot overlook the advantages this welding technique can offer over other conventional fusion welding techniques such as GTAW, GMAW in joining of thin sheets. Low distortion and residual stress, improved joint quality due to mechanized nature of the process and environment friendly method are some of them (Mishra and Ma, 2005). Joining of thin sheets can have applications in hermetic sealing of electronic packages, joining of thin mechanical structures, etc. (Teh et al., 2012). Nishihara and Nagasaka, (2004) were amongst the first to join sheets less than 1000 μm. They joined sheets of AZ31 magnesium alloys to affirm the feasibility of joining thin sheets by friction stir welding.

Out of the few works available on FSW of very thin sheets, a full description of the fixture used is missing in literature. In welding of 0.7 mm titan zinc sheets, Papaefthymiou et al. (2015) used special hold-downs for clamping and marble as a heat resistant backing material. The special hold downs used was however, not described and although marble does resist heat but it is prone to brittle fracture during welding of high strength alloys. Sattari et al. (2012) proposed a special fixture for FSW of thin sheets. A roll was used in front of the tool to avoid sheet separation during welding of 0.8 mm thick aluminium alloy 5083. Use of roll, would however, increase heat loss from the workpiece surface in contact with the roll. In joining of 0.8 mm thick workpieces of 6082 and 2024 aluminium alloys, Scialpi et al. (2008) recognized that certain

Abbreviations: FSW, friction stir welding; BM, base material; HAZ, heat affected zone; TMAZ, thermo-mechanically affected zone; NZ, nugget zone; AS, advancing side; RS, retreating side

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challenges are indeed present in thin sheets' FSW. In addition to careful selection of process parameters, positional accuracy during welding which depends upon the fixture used was pointed as challenging. However, no detail on the fixture used was given.

Important joint properties from application point of view and to test the fixture's feasibility include weld's strength, ductility, surface appearance and distortion, if any. Scialpi et al. (2008) studied the mechanical properties of similar and dissimilar μFSW of 0.8 mm thick AA2024-T3 and AA6082-T6 by conducting transverse tensile test. An ultimate tensile strength of about 69% of base metal and an elongation of 6.7% were observed in case of similar joints of 6082-T6 workpiece. Although FSW involves low heat input as compared to fusion welding however, the less stiff thin workpieces are more susceptible to distortion and hence quantifying distortion is important from the application point of view but this is missing in available work on FSW of very thin sheets. Measurement of out of plane distortion was performed by Shi et al. (2008) on 3.0 mm thick aluminium alloy 6013 welds. Anti-saddle shape of the welded plate was reported. Increasing tool rotation speed increased the distortion, however no clear effect of welding speed was observed. Analysis of weld microstructure and measurement of microhardness across the weld zone cross-section are useful for a better understanding of the weld mechanical properties. Typically for 6061-T6 alloy, a W-shape of hardness curve has been obtained (He et al., 2016).

In this work, a simple mechanical fixture was developed so as to overcome the peculiar fixturing issues present in FSW of thin aluminium sheets as mentioned above. The topical issues addressed include (i) precise fixturing, (ii) uniform clamping along and across the weld line, (iii) clamping close to the weld line and, (iv) minimizing heat loss from the thin workpieces. To test the feasibility of the developed fixture, 0.5 mm thin sheets of aluminium alloy 6061-T6 were joined at five different tool travel speeds. The obtained welds were then investigated for the effect of tool travel speed on joint properties.

2. Proposed fixture and experimental details

2.1. Details of the proposed fixture

A simple mechanical fixture similar to a lever type clamp was developed. The model of the developed fixture is shown in Fig. 1(a). The fixture had compressive force over the top clamp plate which was in contact on one end with the workpiece and on the other end with the support. The distance 'a' was kept less than the distance 'b' so that more part of the compressive force got shared by the workpiece. Stainless steel (thermal conductivity = 14.2 W/m-K, melting point = 1454 °C and tensile strength = 515 M Pa) was used as fixture material and as backing plate. The main parts of the developed fixture were (a) backing plate, (b) top clamp, (c) clamp support, (d) cover plate, (e) lateral clamps, and (f) front clamp.

Table 1
Chemical composition of the workpiece material (weight %).

Element	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Al
AA6061-T6	1.0	0.58	0.42	0.22	0.05	0.02	0.02	0.16	Bal

2.2. FSW of thin aluminium sheets

To test the developed fixture's feasibility, very thin (0.5 mm) sheets of aluminium alloy 6061-T6 were FS-welded. Table 1 list the chemical composition of the work material and Table 2 gives some of its important mechanical and thermal properties. The sheets were cut on wire-EDM (model: SPRINTCUT; make: ELECTRONICA) into a dimension of 50 mm × 120 mm. Tool steel H13 was used as the tool material. The welding tool was of 6.4 mm shoulder diameter and tapered pin was used. The detailed tool geometry and its image are shown in Fig. 2. The welding tool was prepared by micro-turning of H13 rod on micro-machining set-up (model: DT-110; make: MIKROTOOLS). Welding was performed parallel to the rolling direction of sheets on CNC milling machine (model: FLEXMILL; make: MTAB). The welding set-up used is shown in Fig. 1(b). Five different tool travel speeds (150, 200, 250, 300 and 350 mm/min) were used and a fixed value of tool rotation speed (2000 rpm) and shoulder plunge depth (0.1 mm) was used. A dwell time of 1 s and a tool inclination angle of 1° were used.

2.3. Weld characterization

Out of plane distortion in welded workpieces was measured using an optical microscope (model: STM6; make: OLYMPUS) at the marked positions as shown in Fig. 3 taking reference of a flat plate over which the workpiece was placed. Tensile test samples were cut on wire-cut EDM to test the joint strength transverse to the welding direction and the test was performed on UTM machine (make: ZWICK/ROELL; model: Z050). ASTM-E8 standard dimension of subsize specimen was followed. For microstructural characterization, the samples were wire cut perpendicular to the weld line and then epoxy mounted. Standard metallographic technique was followed and for etching modified Keller's reagent (195 ml distilled water, 5 ml HNO_3, 2 ml HCl and 3 ml HF) was

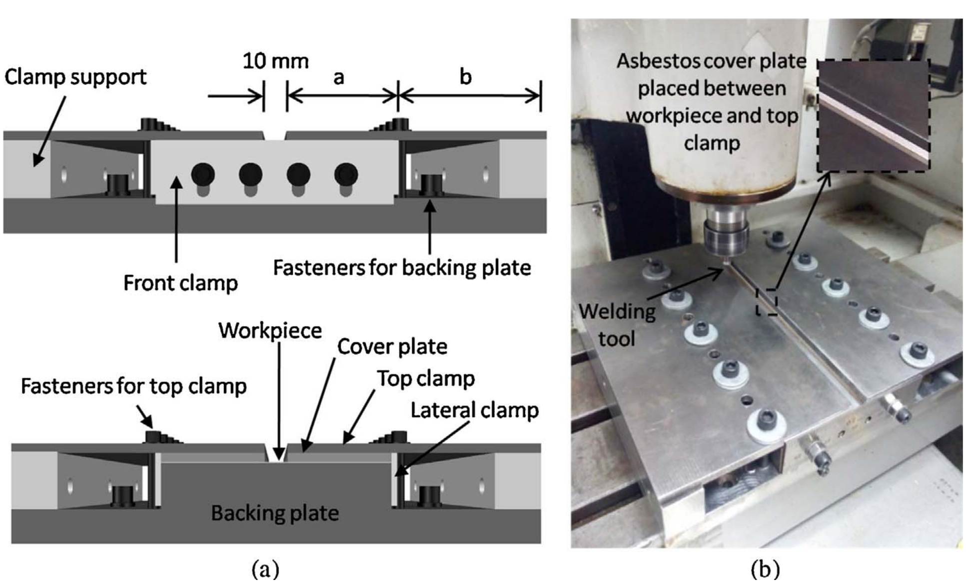

Fig. 1. (a) Fixture model showing detailed parts of the proposed fixture, and (b) Experimental set-up showing the developed fixture used for welding.