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Dissimilar joining of AA7475 Aluminium alloy and AISI 304 Stainless by friction stir welding

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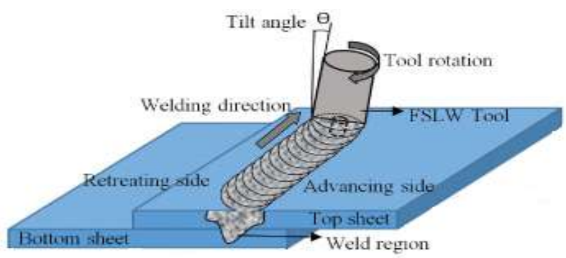
ABSTRACT

Recent days, the prime requirement of industrial sector is to produce the engineering components with lighter weight and increased strength. In order to facilitate this, Friction stir welding (FSW) is emerging as a numerous technique to join difficult to weld similar and dissimilar materials. In the present study, FSW process is performed to join dissimilar materials AA7475-T761 aluminum alloy and AISI 304 stainless steel. These materials are widely used in aerospace, space shuttles and transportation industries. Friction stir welded lap joints for varying ratio of dissimilar materials are analyzed for tensile strength and microstructure. Large variation in thermal and mechanical properties of base materials causes non-homogeneous mixing in the stir zone which resulted in the formation of defects. The optimum thickness ratio 1.3 of AA7475-T761 aluminum alloy to AISI 304 stainless steel was found as suitable joint.

Keywords: Friction stir welding; AA7475; AISI 304 stainless steel; Microstructure; Tensile strength

I. INTRODUCTION

In modern time, various industries are replacing heavy density material with lower one in order to reduce the inertia force of moving bodies. Apart from this, the other objective of manufacturers is to obtain the good combination of mechanical properties of different materials to enhance the engineering requirements. Keeping this in view, industries such as aerospace, nautical, automobile, etc. have started joining of dissimilar materials [1]. In this regard, ferrous materials such as steel, stainless steel (SS) are replaced to a certain extent with non ferrous materials such as aluminium, copper and magnesium. Ferrous material stainless steel finds wide applications in fuel tanks, exhaust parts, engine parts and outer panels of various industries [2]. Aluminum is a light weight material inherited with attributes like high strength to weight ratio, good formability, and involves low production cost [3]. Non ferrous material aluminium is extensively used in shipbuilding, railway cars and aircrafts, etc. [4]. The numerous features and wide applications of aluminium and SS put emphasis to join the both materials using a suitable joining technique to meet out the demand of different industries. Earlier, the fasteners and adhesive binders were used for joining purpose up to the end of nineteenth century. In 1991, Friction stir welding (FSW) was first introduced and patented by "The Welding Institute" (TWI) in UK [5]. TWI employed FSW at initial stage on aluminium but now it is successfully used to join different materials including high temperature materials also. FSW being a solid state welding process avoids the several quality issues associated with fusion welding such as distortion, oxidation, porosity, solidification cracks and distortion, etc. [6]. In FSW process, the materials required to be join are firmly held in a robust fixture and a non consumable rotating tool containing suitable probe and shoulder is first plunged into the abutting surfaces of the plates. Continuous rubbing action of tool shoulder generates sufficient amount of heat causes softening of materials which are further stirred by probe causes severe plastic deformation throughout the joint length between the abutting surfaces. Subsequently tool traverses along the joint line and produces the sound quality of weld as shown in Fig. 1. [7].



Out of several studies on joining of dissimilar materials, there are limited literatures observed on the joining of aluminum to steel using FSW. Lee et al. [8] welded Al 6056-T4 to 304 SS at rotational speed of 800 rpm, welding speed of 80 mm/min and found intermetallic compound (IMC) layer as Al_4Fe of thickness 250 nm. Habibina et al. [9] reported the effects of welding parameters, together with annealing process on tensile behavior and microhardness of FSW of dissimilar 5050 Al alloy to 304 SS. They found better joint qualities by decreasing the tool rotational speed from 710 to 500 rpm simultaneously with raising the traverse speed from 40 to 80 mm/min. Subsequently, higher tensile strength was obtained by increasing the tool offset up to 1.5mm resulted in decreasing voids and defects in the weld nugget region. Yazdipour et al. [10] conducted FSW between Al 5083-H321 and 316L SS at fixed tool rotational speed of 280 rpm and scrutinized the effects of FSW parameters on tensile strength, microhardness, macrostructure and microstructure at different regions. Dehghani et al. [11] performed FSW on dissimilar materials Al-5186 and mild steel and evaluated the role of FSW parameters such as tool pin geometry, tilt angle, traverse speed and plunge depth on the tunnel formation, tensile strength and formation of IMCs. The FSW parameters were optimized by Chen [12] for AA6061 aluminum alloy and SS400 low-carbon steel. He attained best quality of impact values with acceptable quality of tensile strength at transverse speed of 0.9 mm/s and rotational speed of 550 rpm. From literature review, very limited research work is observed on joining of dissimilar materials aluminum alloy and SS. Most of the researchers have analyzed joint quality for conventional FSW parameters. The growing demand of industries to replace riveted lap joints and heavy density material by friction stir welded lap joints [13] put emphasis for joining of AA 7475 to AISI 304 SS. In this study, three set of experiments were

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conducted to join Al 7475 to AISI 304 SS for half lap joint configuration. The metallurgical characteristics and tensile strength of joint cross section were analyzed to obtain the optimum ratio of aluminum to SS.

II.EXPERIMENTAL METHOD

The AA 7475 and AISI 304 SS rectangular plates of 150 mm length, 45 mm width and 2.5 mm thickness were used for welding. The chemical composition of AA 7475and AISI 304 SS materials are presented in Table 1 and 2 respectively. Subsequently, the mechanical and thermal properties of these materials are shown in Table 3. In FSW, since the high temperature is generated on advancing side as compared to retreating side, high strength material AISI 304 SS was kept on the advancing side and low strength material AA 7475 was kept on retreating side of the joint line. The advancing side is one where the direction of tool's rotary motion and linear motion lie same along the progress of welding and the side where the direction of tool's rotary motion and linear motion are opposite is referred as retreating side.

TABLE I. CHEMICAL COMPOSITION OF AA7475 (WT. %)

Material	Chemical composition of AA7475 (wt. %)								
	Al	*Zn*	*Mg*	*Cu*	*Cr*	*Si*	*Ti*	*Fe*	*Mn*
AA7475	Base	5.26	2.22	1.64	0.203	.05	.023	0.101	0.0063

TABLE II. CHEMICAL COMPOSITION OF AISI 304 (WT. %)

Material	Chemical composition of AISI 304 (wt. %)											
	Fe	*Cr*	*Mn*	*Mg*	*Cu*	*Si*	*Ni*	*N*	*C*	*P*	*V*	*Mo*
AISI 304	Base	12.87	9.43	2.22	1.34	.335	.314	.145	.077	.042	.033	.027

TABLE III. PROPERTIES OF AA7475 AND AISI 304

Material	Mechanical and Thermal properties of AA7475 and AISI 304				
	UTS (MPa)	*Yield Strength (MPa)*	*Elongation (%)*	*Melting Point (°C)*	*Thermal Conductivity (W/mK)*
AA7475	468	430	13	477-635	163
AISI 304	515	215	70	1400-1450	16.2

FSW on dissimilar materials AA 7475 and AISI 304 SS was conducted using tungsten carbide tool with specifications; shoulder diameter of 25mm, cylindrical tapered probe of length 1.7mm, root diameter 6.5mm with semi cone of angle 20°. The plates were used for half lap joint configuration with varying thickness ratio of aluminum to SS as shown in Table 4. However, other parameters were kept fixed in all experiments such as tool rotational speed of 560 rpm, traversing speed of 50 mm/min., tool to work piece tilt angle of 1.5° and plunge depth of 2.2 mm. In addition, tool offset was also kept fixed at 1.5mm towards the weaker material i.e., AA 7475 to avoid defects such as tunneling and kissing bond [14]. To conduct FSW, the plates were thoroughly cleaned by using acetone, washed and dried. A special work fixture was indigenously devised to perform FSW. The dissimilar plates were kept on the backing plate and firmly clamped in the fixture as shown in Fig.2. Subsequently, plates were longitudinally butt welded using a retrofitted robust Vertical Milling Machine (Make: Bharat Fritz Werner, India) as shown in Fig.3. For metallographic investigation, the specimens were polished using different emery papers of grit size viz. 100, 200,320, 600, 800, 100, 1200, 1500 and 2000. Further, specimens were obtained with fine mirror polished surface using diamond paste and velvet cloth. The microstructural analysis was performed using computer interfaced microscope fitted with a closed circuit digital camera. Tensile test coupons with front view and side view are shown in Fig. 4. Three coupons were taken out from friction stir welded zone as per ASTM: E8M using wire cut electric discharge machine. The tensile strength of the specimens was measured using a computer interfaced tensometer at a testing speed of 2 mm/min.

TABLE IV. FSW PROCESS PARAMETERS AND THEIR LEVELS

Experi-ment No.	FSW Process parameters and their levels		
	Plate thickness AA 7475 (mm)	*Plate thickness AISI 304 (mm)*	*Ratio (AA:AISI)*
1	1.3	1.2	1.1
2	1.4	1.1	1.3
3	1.5	1.0	1.5

Fig. 2. Fixture holding plates for welding.

Fig. 3. Experimental setup of FSW.

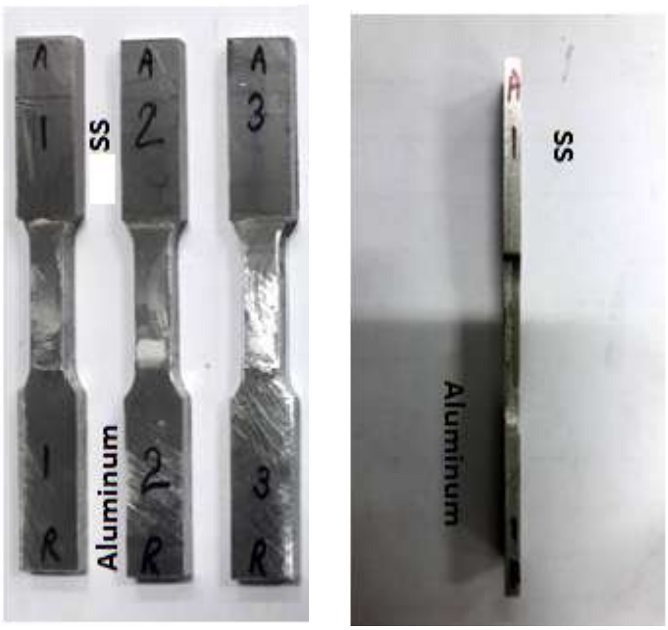

Fig. 4. Tensile test coupons.

III. RESULTS AND DISCUSSION

Present study is aimed to investigate the effects of base material thickness ratio on the tensile strength and microstructure of friction stir welded dissimilar aluminum to SS joints. The surface morphologies of welded joints at different thickness ratios are shown in Fig. 5 (a-c).

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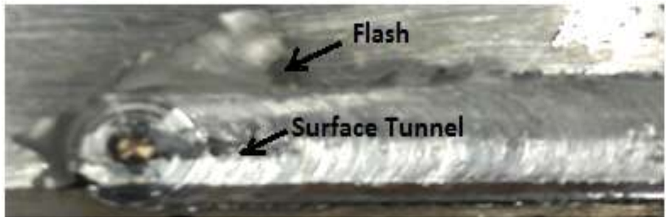
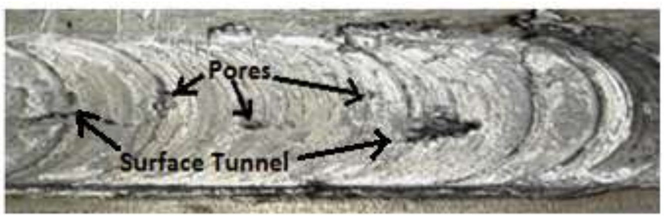


(a) AA:SS ratio 1.1

(b) AA:SS ratio 1.3:1



(c) AA:SS ratio 1.5:1

Fig. 5.Surface morphology of welded joints with different thickness ratios.

Surface morphology of the joint produced with thickness ratio of 1.1 shows the formation of heavy flash at lower melting point material (i.e., AA7475) side (Fig 5(a)). Generally flashes appear due to high heat generation during FSW [15]. Here heavy flash appeared at the end of experiment due to improper mixing of the base materials. Also, flash formation resulted in the deficiency of the material in the weld region which leads to the formation of tunneling defect at the end of the weld.

The micrographs of welded joints produced at different thickness ratios are shown in Fig. 6 (a-c). Void is observed at the interface as shown in micrograph Fig. 6(a) due to inadequate material movement in the stir zone. The joint was obtained with poor tensile strength of 102 N/mm^2.

Surface morphology of the joint produced with thickness ratio of 1.3 shows the defect free joint (Fig 5(b)) due to proper

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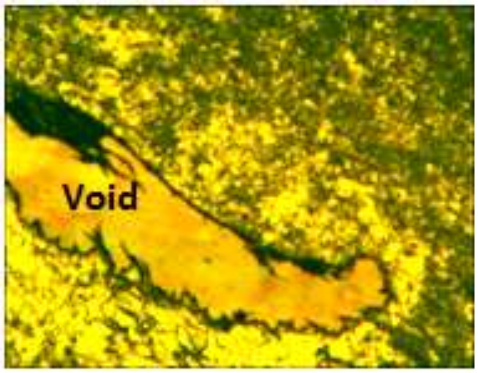
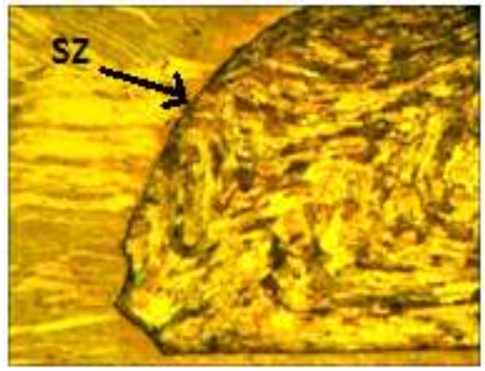
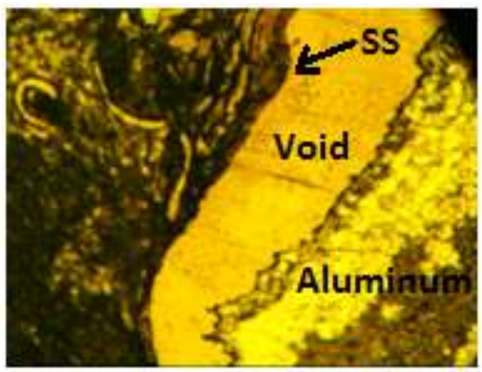




(a) AA:SS ratio 1.1 **(b) AA:SS ratio 1.3:1**



(c) AA:SS ratio 1.5:1

Fig. 6. Micrographs.

mixing of the base materials. The adequate proportion of aluminum and SS was extruded and forged well by tool and resulted in the formation of sound joint. Fig. 6(b) shows the micrograph of the mechanically mixed region in the stir zone. The joint was obtained with tensile strength of 148 N/mm^2 which is approximately 57% of the base material AA 7475.

Surface morphology of the joint produced with thickness ratio of 1.5 shows the formation of pores and surface grooves (Fig 5(c)) due to inadequate movement of the base materials around the tool pin. This might has resulted due to stirring of higher proportion of aluminum as compared to SS. Large variation in thermal and mechanical properties of dissimilar materials causes non-homogeneous mixing in the stir zone which resulted in the formation of defects. The micrograph Fig. 6(c) shows inadequate mixing of dissimilar materials. The tensile strength of joint was found 92 N/mm^2.

IV.CONCLUSION

The present paper investigated the influence of thickness ratios on tensile strength and microstructure in FSW AA7475 and AISI 304 SS. In this work 2.5 mm thick plates of dissimilar materials AA 7475 and AISI 304 SS were successfully welded using FSW employing tungsten carbide tool with conical probe. Based on the results following conclusions are drawn:

- Plates must be adequately clamped in the work fixture.
- Improper ratio of dissimilar materials cause improper mixing and leads to defects which in turn reduces the tensile strength of friction stir welded joints.
- Thickness ratio 1.3:1 of AA7475-T761 aluminum alloy to AISI 304 stainless steel has resulted in good quality joint.

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