Effect of Process Parameters on Defect Features and Mechanical Performance of Friction Stir Lap Welded AA6063 and ETP Copper Joints

Nitin Panaskar, Ravi Terkar

Abstract—The effect of process parameters such as tool rotational speed and tool traverse speed on mechanical properties of AA-6063 and ETP Cu lap joint is investigated. At present, Friction Stir Welding is being employed to join dissimilar metals. However, the difference in the physical properties of the base metals makes it difficult to join these metals. The present study investigates the effect of using a compatible intermediate layer on weld strength. Different joint defects and their effect on joint strength has been discussed. The experiments were conducted with tool rotational speed of 800, 1000 and 1200 rpm each and with tool traverse speeds of 10, 15 and 20 mm/min. The dissimilar metals are successfully lap welded with fair tensile strength. The effect of process parameters on weld strength and defect formation is discussed.

Index Terms—Al-Cu joint, AA-6063, ETP copper, inter filler, dissimilar friction stir welding, lap weld.

I. INTRODUCTION

Aluminium and copper joining have several applications in electrical, automotive and heat, ventilation and air conditioning, refrigeration industries [1, 2]. These industries stress on complete or partial replacement of the copper parts with aluminium to trim down the cost [3, 4]. Friction Stir Welding (FSW), invented by W.M. Thomas et al, is a newer technique which has been employed to feasibly weld aluminium and copper [5]. This process was mainly employed for joining aluminium and its alloys [6]. FSW is employed to produce various types of lap and butt joints. Aluminium and copper are hard to be lap welded because of difference in their physical properties. However, few studies have demonstrated the use of an intermediate layer of zinc which is compatible with both aluminium and copper [7, 8].

II. BACKGROUND

Joining of 6000 series aluminium alloys to copper find application in manufacturing of heat sinks. Al 6063 is usually used in heat sink applications because of its high thermal conductivity, tensile strength and hardness. It is preferred for complex cross sections and easy to anodize, making it a favorable choice for heat sink applications [9]. Al 6063 has excellent corrosion resistance and good weld ability. The thermal conductivity can be further improved by adding Boron and Titanium. An improvement of 13% and 6% in thermal conductivity was obtained with the addition of 0.05% of Boron and 0.3% of Titanium respectively [10].

Copper is another preferred material for heat sinks, and has approximately twice the conductivity of aluminium, but is three times denser and expensive than aluminium. For an economical heat exchanger, it is essential to weld aluminium and copper, where the copper part will reduce the temperature in high load areas whereas for the moderate and low load areas, the aluminium will suffice the heat transfer requirement. However, the differences in chemical, thermal, and mechanical properties in case of dissimilar metal joining pose serious problems. Ouyang et al. [11] observed that FSW of 6000 series aluminium alloy such as Al-6061 to copper resulted in a weak joint owing to excessive formation of brittle Inter-metallic compounds (IMCs) in the nugget of the weld. Abdollah-Zadeh et al. [12] reported presence of IMCs such as AlCu, Al_2Cu, and Al_4Cu_9 close to the weld interface, where the possibility of crack initiation and propagation is high during the tensile test.

Arbegast and Hartley [13] have reported the relation between maximum temperature achieved during FSW and the process parameters, namely tool rotational speed (v, rpm) and tool traverse speed (n, rpm)..

$$\frac{T}{Tm} = K\left(\frac{w^2}{v\ X\ 10^4}\right)^{\alpha}$$

where K (constant) = 0.65 to 0.75, T_m = metal melting point, K = 65 to 0.75, α = 0.04 to 0.06

Akbari et al. [14] produced joints between AA7070 and copper and observed that when aluminium sheet is positioned atop copper sheet, a better weld is observed compared to that obtained when copper is placed on top of aluminium. This can be attributed to the comparatively lower thermal conductivity of aluminium which results in less frictional heat loss. Further, from other previous studies in FSW lap welding, it is generally observed that better weld properties are attained by placing the softer and thinner metal sheet at the top during welding [15, 16]. Tran et al. [17] observed that greater weld region is attained for weld produced with a thinner and softer top sheet material. Hence, the comparatively softer aluminium sheet was positioned atop the copper sheet. Further, the comparatively lower melting point of aluminium enables it to plasticize easily as compared to copper during the FSW process. Kuang et al. produced Al-Cu joints of fair tensile strength using a pinless tool and a zinc inter-filler material [8].

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III. METHODOLOGY

Plates of AA6063 and ETP copper were employed, as given in Table I. both 3 mm thick, 130 mm in length and 90 mm in width were chosen for producing lap joints. A 0.2 mm thick zinc foil was used as an intermediate layer. A heat treated H13 steel tool was used as shown in Figure 1. The tool pin was inverse conical with top and bottom diameters 4.7 mm and 5.2 mm respectively. The tool pin length was 4.6 mm. The tool with a flat shoulder of 20 mm diameter was used and the shoulder penetration of 0.1 mm was used for generating sufficient frictional heat for welding. The work pieces were placed on a mild steel base plate and clamped firmly as shown in the Figure 2. 9 experiments were conducted with different tool rotational and traverse speeds. The tool rotational speed used were 800, 1000, 1200 rpm; and the tool traverse speed used was 10, 15 and 20 mm/min. The chemical constituents of the base metals are shown in Table II. The mechanical properties of the base metals are shown in Table III.

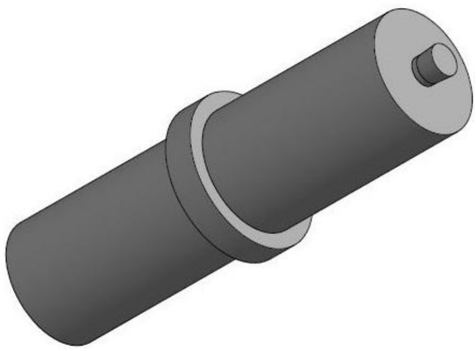

Figure 1. Tool for FSW process

I.Dimensions of experimental sample

Metal	Thickness (mm)	Width (mm)	Length (mm)
Al 6063 ETP Cu	3	20	130

II. Main chemical constituents of the base metals

Sheet Metal	Al	Cu	Mg	Mn	Zn
Al 6063	Base	0.08	4.8	0.8	0.1
ETP Cu	0.02	Base	–	–	4.7

III. Mechanical properties of the base metals

Sheet Metal	Ultimate tensile strength (MPa)	Microhardness (HV)
Al6063	160	80-85
ETP Cu	263	85–90

For testing the mechanical properties, tensile shear tests were conducted. The tensile shear test samples were taken from the weld portion, as shown in Figure 3. Three samples were taken from each welding experiment.

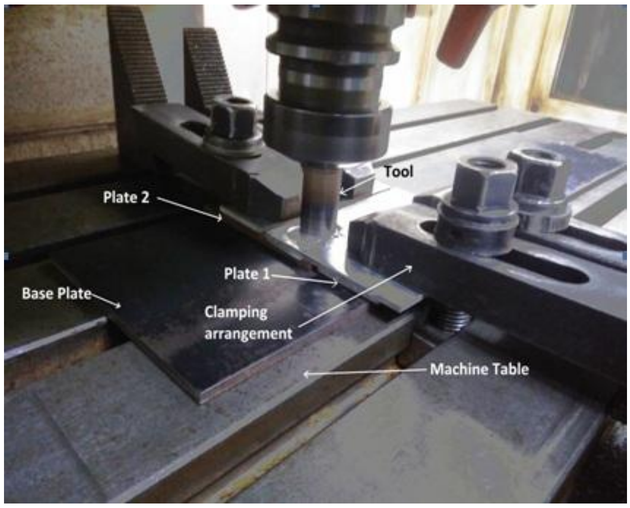

Figure 2. Set-up for FSW process

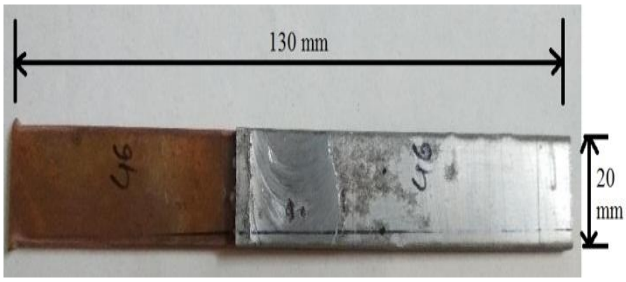

Figure 3. Specimen for tensile shear strength test

IV. RESULTS AND DISCUSSION

It was observed that the spatter was less to moderate at low rotational speed. No spatter or less spatter was observed at moderate rotational speed. Low to high spatter was observed at high rotational speed. The weld macrostructure is shown in Table IV.

Low tensile strength was obtained at lowest rotational speed of 800 rpm. At high rotational speed of 1200 rpm, the tensile strength was maximum for traverse rates of 10 mm/min and 20 mm/min, but slightly less than maximum for traverse rates of 15 mm/min. The tensile strength was maximum for traverse rates of 15 mm/min, followed by that for 10 mm/min, and for 20 mm/min, as shown in Figure 4. The Load vs. Strain curve is shown in Figure 5.

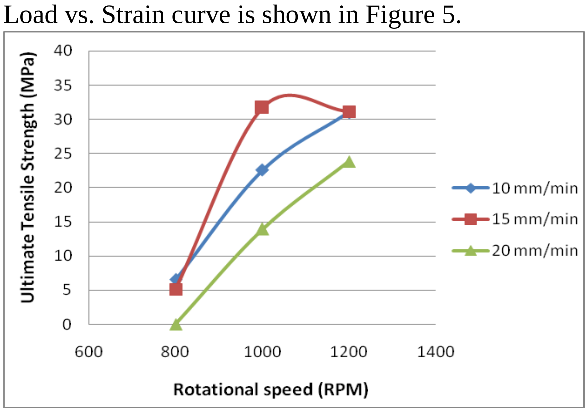

Figure 4. Graph of tensile strength vs. tool rotational speed at various tool traverse speeds

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The defects formed under various weld setting are shown in Figure 6. The defects observed are summarized in Table V. It was observed that samples with large hooking defect have low tensile strength. Further, samples with large tunnel defect have moderate tensile strength. Flash defect seems to affect the tensile strength marginally. Samples with large flash but less tunnel and hooking defect have best values of tensile strength.

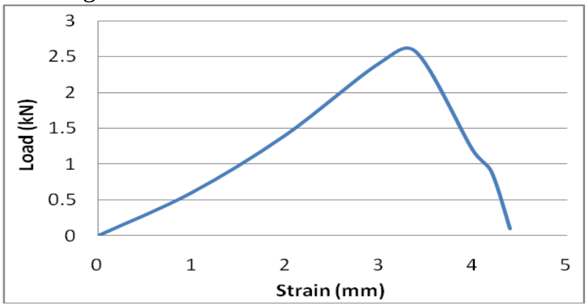

Figure 5. Load vs. Strain curve for tensile shear test at tool rotational speed of 1000 rpm and tool traverse speed of 15 mm/min

V. Summary of defects observed

Process parameters		Defects		
Traverse speed (mm/min)	**Rotational speed (rpm)**	**Hooking defect**	**Tunnel defect**	**Flash**
10	800	Large	NA	Large
15	800	Large	Large	Moderate
10	1000	NA	Large	NA
15	1000	Small	Small	Large
20	1000	Large	Large	Large
20	1200	Small	NA	Large

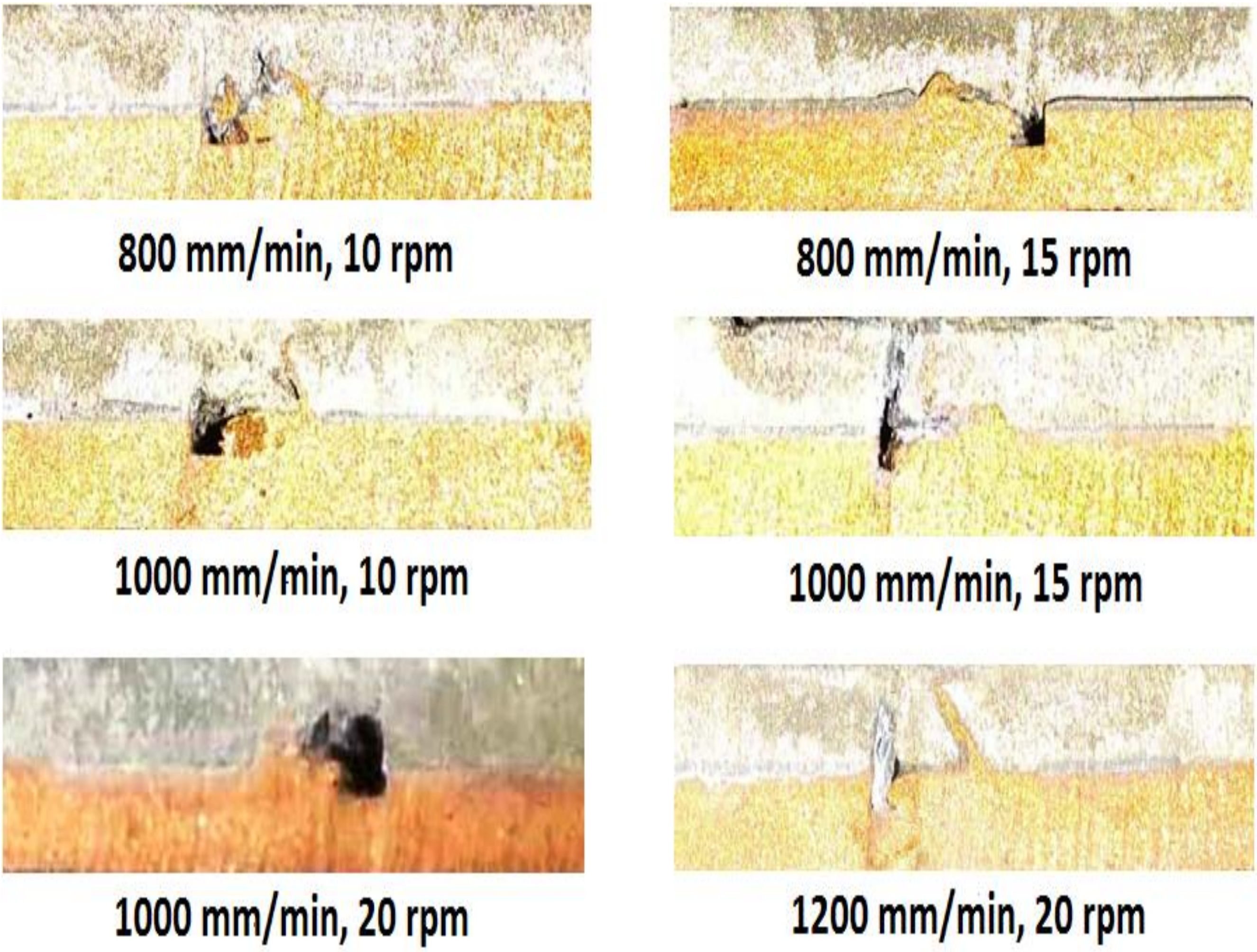

Figure 6. Defects in weld under different conditions

V. WELD MACROSTRUCTURE FOR DIFFERENT TOOL ROTATIONAL SPEEDS AND TOOL TRAVERSE SPEEDS

Sr. No.	Rotational speed (rpm)	Traverse speed (mm/min)	Macrostructure	Remarks
1	800	10		1)Defect found only at initial pin penetration and pin exit, 2)Rough surface with distinct tool marks, 3)Large Spatter, 4)No defect in weld
2	800	15		1)Defect found at pin exit, 2)Rough surface with distinct tool marks, 3)Moderate Spatter, 4)No defect in weld
3	800	20	Load Exceeded Machine capacity	
4	1000	10		1)Small voids at pin penetration, 2)Smooth surface with fine tool marks, 3)No spatter, 4)No defect in weld,
5	1000	15		1)Defect found only at pin exit, 2)Rough surface with distinct tool marks, 3)Large Spatter, 4)No defects in weld
6	1000	20		1)Defect found only at initial pin penetration and pin exit, 2)Smooth surface with fine tool marks, 3)Negligible Spatter, 4)Defects found in multiple locations in main weld
7	1200	10		1)Defect found only at initial pin penetration, 2)Rough surface with distinct tool marks, 3)Moderate Spatter, 4)Defects at multiple points in weld
8	1200	15		1) Defect at pin exit, 2)Rough surface with distinct tool marks, 3) Large spatter, 4)No defect in weld
9	1200	20		1) Defect at pin exit, 2) Rough surface with distinct tool marks, 3) Large spatter, 4)Large defect in the latter part of weld

VI. CONCLUSION

Aluminium 6063 and ETP copper are welded with sound tensile shear strength. The optimum tensile shear strength of 50.71 MPa was attained at tool rotational speed of 1200 rpm and moderate traverse speed of 15 mm/min. Hooking defect followed by tunnel defect had severe impact on tensile strength of the weld. Flash had less impact on the weld strength.

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