Effect of Process Parameters on Tensile Properties of Friction Stir Weld of Dissimilar Pure Copper to 6061-T6 Aluminium Alloy

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Abstract— Friction stir welding is a solid state welding process where material gets plastically deformed due to generation of frictional heat between the surfaces of the plates to be joined and the FSW tool. Various Aluminium alloys have been successfully welded using FSW. So presently FSW of dissimilar materials is now challenging research work to produce sound defect free welds with less intermetallic compounds, Such as Aluminium to copper, which differ in their mechanical properties but have a wide application in aerospace industries. So the present work is based on feasibility and effect of different process parameters upon tensile strength of dissimilar weld of 6061-T6 aluminium alloy with pure copper. In this study the maximum tensile strength of the weld was achieved using threaded tool with 1000 RPM tool rotational speed and 25mm/min weld speed.

Key words: Friction Stir Welding, Dissimilar Butt Joint, Aluminium Alloy, Pure Copper, Tool Rotational Speed, Tool Geometry, Tensile Strength

I. INTRODUCTION

In FSW, materials to be welded are plastically deformed by the application of frictional heat generated between the tool and surfaces of the plates [1]. FSW process doesn't get affected due to solidification and liquation cracking related with the conventional welding processes. The capability of joining materials with high specific strength has successfully made this process applicable in an increasing number of joining applications all over the world. Plastic deformation is induced due to rotation of tool at an elevated temperature. Fig.1 shows the schematic diagram of the process.

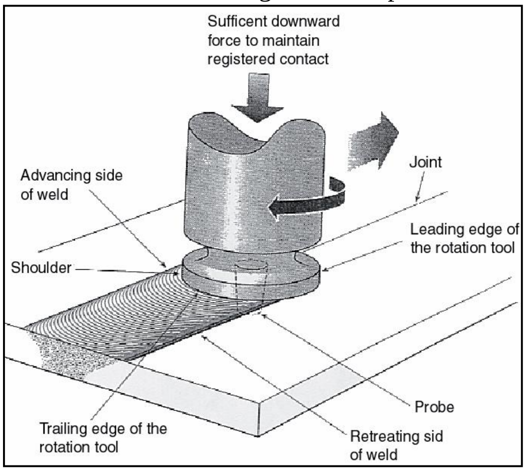

Fig. 1: Schematic of FSW [2]

The highest temperature attained is lower than the melting temperature of parent metal. The combined action of frictional heating and mechanical deformation forms the weld. It is also known as a thermo-mechanical process, in which heterogeneous microstructure is transformed to a more homogeneous microstructure of parent metal [3]. This process is suitable in joining of structural components made of aluminium and its alloys and in various critical applications.

In FSW, various welding parameters and tool geometries affect the material flow pattern and temperature distribution which in turn affects the microstructural evolution of material [4-5]. The geometry of tool plays an important role in material flow which also influences the traverse rate at which FSW can be conducted. The generation of heat, plastic flow, power required, uniformity of microstructure and mechanical properties are regulated by the design of tool. The heat is generated from the friction between pin and work-piece in initial stage of tool plunge [6]. The purpose of tool is to 'stir' and 'move' the material at the same time and the shoulder provides confinement for the heated volume of material [7]. The microstructural evolution within and around the three zones viz. nugget zone (NZ), thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) is due to the heat associated with the FSW process which leads to considerable changes in post weld mechanical properties like strength, ductility, fatigue and fracture toughness.

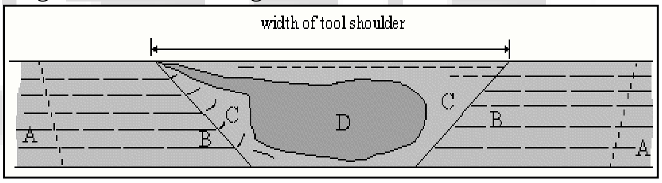

Fig. 2: Four distinct zones in FSW [2]

A Unaffected material,
B Heat-affected zone (HAZ),
C Thermo-mechanically affected zone (TMAZ),
D Weld nugget (Part of TMAZ)

The parent material, known as the unaffected material is not deformed and is isolated from the weld. In HAZ region, the material experiences a thermal cycle which modifies the microstructure and mechanical properties, also the grains are elongated here. IN TMAZ region, the tool plastically deforms the material and the heat generated from the process affects the material. The grains are in deformed state. The recrystallized area is called the 'nugget'. More refined grains are present in this region, than in the TMAZ.

The effect of rotational speed, traverse speed and plunging depth or axial force on weld properties is a major topic for researchers whereas the parameters like RPM, WS and TG are rarely considered [8]. The study of tool geometries considered for purpose of comparison is complex in geometry and difficult to manufacture such as helical, spiral, trapezoidal, triangular etc. So, here the effects of different process parameters, viz. RPM, WS and comparatively simpler Tool Geometry on tensile properties like ultimate tensile strength and ductility have been considered.

II. EXPERIMENTAL DETAILS

3 mm thick plates of 6061-T6 Al alloy and pure Cu were used. The rolled plates were cut and machined into rectangular pieces, each 100mm long and 50mm wide for joining purpose. Butt joint configuration has been used. The chemical composition of the plates are given in the tables below:

Al	Si	Fe	Cu	Mn	Mg	Cr	Other
Weight%	0.4-0.8	0.7	0.2-0.4	0.2-0.8	0.8-0.12	0.15	0.5

Table 1: Chemical composition of Aluminium 6061-T6

Al	Si	Zn	Cu	Fe	Ni	Pb	Al
Weight%	.007	.025	Bal.	.009	.009	.017	.027

Table 2: Chemical composition of Pure Copper [9]

The material of the tool should be strong enough to withstand the vertical pressure and torque applied to it and should not wear out easily. Therefore, choosing the proper material of tool is important. The material used for tool here is high speed steel (H13) with excellent high temperature properties, good ductility and weldability, designed for high temperature range services. A vertical milling machine was used to carry out the experiment. The parameters used are given in the table below:

Parameters	Unit	Description
Tool Rotational Speed	Rev/min	Revolutions per minute of spindle.
Welding Speed	mm/min	Speed of tool advancing
Tool Geometry		Straight Cylindrical(SC) Threaded Cylindrical (TC) Threaded(THRD)

Table 3: Parameters description with units used

Two sets of experiments were carried out to study the effect of individual parameters. Each set containing three or four numbers of experiments in three or four varying parametric conditions, keeping all other parameters constant. Set 1 was for RPM, set 2 for TG (Tool Geometry). The tool used was mounted in the vertical milling machine using a suitable collate. The plates to be joined were fastened in place with a clamp in such a manner that the movement of plates under plunging and translation forces of the FSW tool was totally restricted. The tool rpm and translation speed of bed were already set in advance before each run of welding. The complete experimental setup is shown in Fig.3 below:

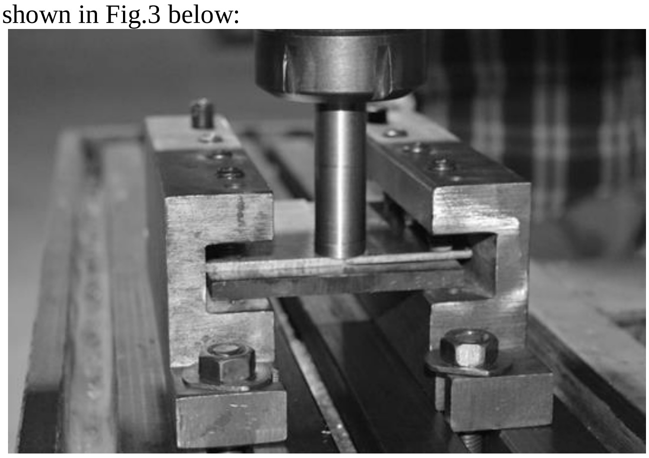

Fig. 3: Experimental setup

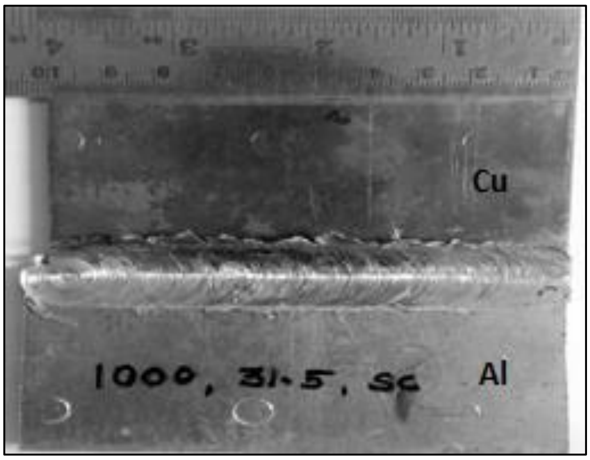

Fig. 4: Sample Weld

III. RESULTS AND DISCUSSION

The layout of the experimental details with test results is as given below in the Table 4.

Sl No.	RPM	TG	WS (mm/min)	UTS (MPa)
		SET 1		
Exp. 1	500	SC	25	98.80
Exp. 2	710	SC	25	110.43
Exp. 3	1000	SC	25	137.58
Exp. 4	1400	SC	25	122.53
		SET 2		
Exp. 5	1000	SC	25	137.58
Exp. 6	1000	TC	25	95.16
Exp. 7	1000	THRD	25	139

Table 4: Results

A. Effect of Tool Rotational speed

The Ultimate Tensile Strength values of the various welded joints at varying rotational speeds have been presented in Fig. 5. It is evident that with increasing rotational speed from 500 to 1000, improved tensile strength was achieved but afterwards further increase in RPM leaded to lower tensile strength.

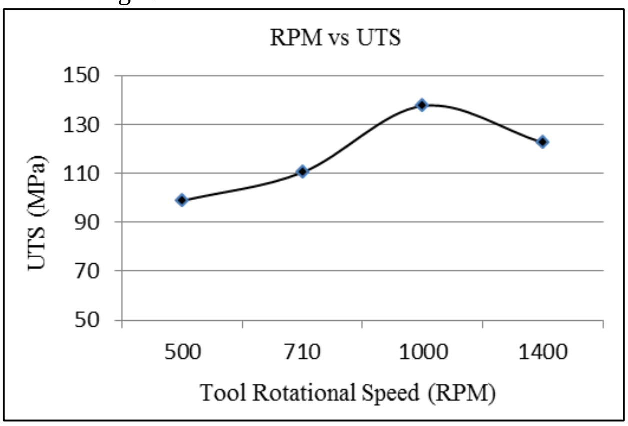

Fig. 5: Effect of Tool Rotational Speed

RPM plays a major role in mixing the materials on the top surface and in the depth along the thickness of the material. RPM controls the rotation of the tool which causes generation of frictional heat, so with increased RPM from 500 to1000, tensile strength also increased. But further increase in RPM caused excess heat generation which resulted defects in weld. Similar trend was also seen in case of ductility.

B. Effect of Tool Geometry

The Ultimate Tensile Strength values of the various welded joints produced using different tool geometries have been presented in Fig. 6. The results show similar trends in case of straight cylindrical and threaded tool geometry, but due to presence of threads, a better mixture of material along the thickness resulted higher tensile strength in case of Threaded TG. Using threaded cylindrical tool, resulted lowest tensile strength in weld because of non-uniform heat generation along the thickness of the plates, which also caused defects at the roots.

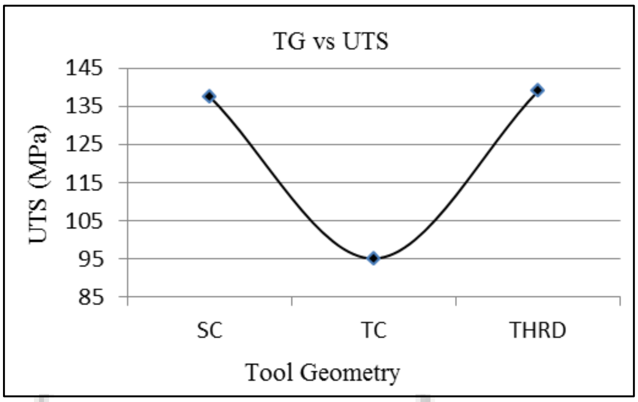

Fig. 6: Effect of Tool Geometry

IV. CONCLUSION

From the above study following points can be concluded:

- It is feasible to join dissimilar aluminium 6061-T6 alloy with pure copper using friction stir welding process without any defects along with good tensile strength (139 MPa).
- Among various rotational speeds tensile strength increased with increasing RPM from 500 to 1000. But afterwards further increase in RPM resulted to lower tensile strength.
- Straight cylindrical and threaded tool geometry showed likely similar trend in tensile strength. But among them threaded tool geometry resulted in maximum tensile strength.

In future, speed of the tool advancing through the workpiece can be varied to produce weld with more improved tensile properties.

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