TOOL OFFSET INFLUENCE ON MECHANICAL AND MICROSTRUCTURE PROPERTIES OF DISSIMILAR AL6082 AND COPPER FRICTION STIR WELDED JOINTS

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ABSTRACT

This work is to find the role of tool offset on mechanical and microstructural behaviour of Friction Stir welded of AA6082 and pure copperbutt joints. The major factors considered in this study are, tool rotation speed, tool travel speed and tool offset. The dissimilar butt welds are produced using cylindrical tapered pin by keeping the copper plates on advancing side of joint. Tensile and Bending tests are conducted to evaluate the strength of weld joints. Microhardness test is done in transverse direction of welds to evaluate the hardness distribution on weld nugget. Experimental investigation reveals that, at tool rotational speed of 1000 rpm, tool travel speed of 24 mm/min and offset of 1mm towards aluminium side yields the better Tensile Strength of 121 Mpa, Bending Strength of 24.3 Mpa and Hardness of 100 HV are obtained at the nugget zone. Microstructure reveals that if more quantity of copper particles are present in the aluminium section at the stir zone, that attributes to good mechanical properties.

KEYWORDS: Friction Stir Welding, Aluminium 6082 Alloy, Copper, Tool Offset

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INTRODUCTION

In Friction Stir Welding (FSW), a rotating tool with cylindrical shoulder and profile pin is plunged into the joint area. Due to heating and stirring at the joint line it softens the material around the pin which gives plastic deformation. The rotating tool travels along the joint line which leaves a welded zone behind, due to movement of the material from advancing side to the retrieving side[1]. The FSW technology is considered to be the most suitable metal joining process to weld dissimilar materials due to its less environmental impact, energy efficiency and economical advantages. It is currently used in industries such as aerospace, nuclear, chemical, electronics, electrical etc.[2][3].

LITERATURE REVIEW

The joining of Aluminium (Al) to Copper (Cu) is a challenging work because of wide differences in properties. These differences may cause many defects in the weld [4]. Moreover, the Al was easily oxidized at higher temperature, and some welding cracks were produced easily in a joint of brazed or fusion welding. Therefore, excellent weld joints of Al/Cu was difficult to get with other welding techniques [5].

Several studies were carried out on joining of Al and Cu and influence of process parameters on microstructural and mechanical properties. A good metallurgical bonding in between Al and Cu results higher tensile and bending strength [6]. Studies also show that impact of tool profile on microstructure and corrosion

behaviour of AA2219 Al - Cu friction stir weld nuggets. It was witnessed that the wide deformation experienced at the nugget and the developed microstructure strongly influence the hardness and corrosion behavior [7]. Positioning of base materials will have a solid influence on butt joints morphology and configuration. Irregular morphology was found for the joints produced with keeping aluminium towards advancing side, due to the eviction of the aluminium from weld zone. When the rotating speed is increased, it results in creation of mixing regions with increased dimension, homogeneousness and intermetallic mixture. Tool Shoulder diameter will play a major role on the morphology and intermetallic mixture of the welds nugget. The AA 5083-copper joints were shown excellent surface finishing, but highly defective nugget[8].

Studies also reveals that, flaw free joints could be attained when Cu plate was kept at advancing side” and offset of 1mm to the Al side resulting in good tensile properties. Very poor tensile strength results due to the inadequate response between the Cu and Al particles when the pin offset is large and/or low rotation speeds [9].

FSW of aluminium and copper are based on both butt and lap joint arrangements in most studies. Al-Cu butt welding joints were less explored than lap joints, so far, very limited studies for this combination have been conducted. In particular, tool offsetting effect on the material flow configuration and the subsequent properties are yet to be examined in-depth for Al-Cu materials.

Present study, AA6082 to pure copper plates of 4mm thick is friction stir welded by using the parameters, constant tool rotation speed of 1000rpm, three different tool traverse speeds (16, 20, 24mm/min), and tool positioning of 1mm towards advancing side, and for same speed and feed rates taking offset on retrieving side. Finally, mechanical and microstructural properties of joints are evaluated.

EXPERIMENTAL PROCEDURE

FSW is conducted on Vertical Milling Machine with suitable attachments. Aluminium 6082 alloy and pure copper materials of dimensions 100mmx50mmx4mm (lxbxh) were used in this work. The workpiece dimensions were selected for convenience to suit the fixtures, which were attached to the longitudinally traversing table of the FSW. The work pieces were thoroughly cleaned before they mounted on fixture by different grade emery paper and acetone in order to remove the residues.

A cylindrical taper unthreaded pin made of HcHcr steel having 5mm major diameter and 3mm minor diameter and shoulder diameter of 20mm is employed by keeping the tool rotational speed constant, varying feed rate and offsetting the tool towards advancing and retrieving side while other parameters were kept constant. In this experimentation work, a butt weld preparation was used and copper plates were kept on Advancing Side(AS) and Aluminium plates were kept on Retrieving Side(RS).

A schematic of the vertical milling machine and tool employed in this study are shown in Figure 1 and Figure 2. The Table 1 shows the specification of Vertical Milling Machine. The Table 2 to Table 4 indicates physical properties and chemical composition of Al 6082 and Pure Copper. The Figure3 shows the welded joints for selected parameters.

Figure 1: Vertical Milling Machine

Figure 2: Tool used for FSW process

Table 1: Milling Machine Specification

Make	BFW
Model	UF-1
Table clamping area	1000×230mm ²
No. of T- slots	3
Width of T- slots	14mm
Centre distance	45mm
No. of speeds	45 – 2000RPM
Power of Main motor	3HP
Motor speed	1500rpm

Table 2: Physical Properties of Al 6082

Density	2.7 g/cm ³
Melting Point	555°C
Modulus of Elasticity	90 Gpa
Poisson's ratio	0.33

Table 3: Physical Properties of Copper

Density	8.96 g/cm ³
Melting point	1083°C
Modulus of Elasticity	113 Gpa
Poisson's ratio	0.35

Table 4: Chemical Composition of Al 6082 and Copper

	Si	Cu	Mg	Cr	Fe	Mn	Zn	Al
Al 6082	0.7-1.3	0-0.1	0.6-1.2	0.25	0-0.5	0.4-1	0-0.1	Balance
Cu	-	99.99	-	-	-	-	-	-

Figure 3: FSW Welded Joints.

RESULTS AND DISCUSSIONS

Tensile Strength

To assess the tensile strength of produced joints, the tensile test is conducted. The test samples are prepared with the help of wire EDM based on ASTM standards shown in Figure 4. The obtained results are presented in Table 5.

Figure 4: Tensile Specimen as per ASTM Standard.

Table 5: Tensile strength

Trial No.	Tool Rotational Speed (rpm)	Tool Travel Speed (mm/min)	Tool offset (mm)	UTS (Mpa)
1	1000	16	+1	63.8
2	1000	20	+1	67
3	1000	24	+1	75.1
4	1000	16	-1	100.8
5	1000	20	-1	97.7
6	1000	24	-1	121

Figure 5: Variation of Tensile Strength.

Figure5 shows the tensile strength of welded joints. It is seen that, the strength of joints increases when the tool is offset towards retrieving side. Maximum tensile strength of 121MPa is obtained with 24 mm/min traverse speed. Though, it is also witnessed that, the tensile strength is reduced for tool traverse speed of 16 mm/min and tool offset on advancing side. This is due to lack of creation of any similar mixture at the nugget section and also the inadequate temperature supply at the joint.

Bending Test

Bend tests are used to understand about the ductility and toughness of welded joints. The “test specimens” are cut as per the ASTM standard for selected thickness as shown in Figure 6. Bending tests are conducted using three point bend test procedure on the test samples cut by wire EDM .The results are tabulated in Table 6.

Figure 6: Bending Test Specimen.

Table 6: Bending Stress

Trial No.	Bending Stress (Mpa)
1	17.3
2	18.4
3	20.8
4	19.5
5	21.1
6	24.3

Figure 7: Variation of Bending Stress.

Figure7 shows the bending strength of produced welds. The samples are loaded until U-shape is produced or a failure is caused. Highest bending stress of 24.3 Mpa is obtained for the traverse speed 24 mm/min and the tool is offset towards retrieving side. Fractures are found in welded zones and HAZ, especially on the joints that have less tensile strength.

Micro Hardness Test

To know the strength of FSW joints for various parameters the hardness test may be considered. The Vickers hardness test is conducted on nugget zone of the specimen. Table 7 shows obtained results. Figure 8 shows the variation of hardness on nugget zone.

Table 7: Vickers Hardness Number on Nugget Zone

Trial no.	Vickers Hardness (Nugget zone)
1	66
2	69
3	77
4	95
5	97
6	100

Figure 8: Variation of Hardness Number on Nugget Zone.

Hardness value of welds in transverse direction are illustrated in the Figure8. It shows that, increase in hardness value at the weld zone is mainly because of intermetallic phases between the Al –Cu on the top surface. Highest hardness value of 100 HV is obtained at the nugget zone for transverse speed 24mm/min and tool positioning towards retrieving side.

Microstructure

Microstructure evaluation is done using “Scanning Electron Microscope (SEM)” with different magnification to know the quality of mixing of materials at nugget zone. Since, it is directly impact on mechanical properties of prepared joints. To understand the amount of material present at weld nugget, results of this test is considered.

In this work, microstructure of weld nugget zone of all the joints are studied. The SEM images and EDS analysis of welded joints are give in Figure 9 to Figure 20

Figure 9: SEM Images of Trail 1.

Figure 10: EDS Analysis of Trail 1.

Figure 11: SEM Images of Trail 2.

Figure 12: EDS Analysis of Trail 2.

Figure 13: SEM Images of Trail 3.

Figure 14: EDS Analysis of Trail 3.

Figure 15: SEM Images of Trail 4.

Figure 16: EDS Analysis of Trail 4.

Figure 17: SEM Images of Trail 5.

Figure 18: EDS Analysis of Trail 5.

Figure 19: SEM Images of Trail 6.

Figure 20: EDS Analysis of Trail 6.

The microstructure images reveals that fine Cu particles are detached and spread in the nugget zone and also Al and Cu matrix interface exists at the nugget zone. It is clear that the uniform distribution of Cu particles in Al results good mechanical properties and non “uniform” distribution of Cu particles in Al side results in poor mechanical properties. EDS analysis is also suggest that, if amount of copper at weld nugget is less and if mixing of materials is not sufficient, has a lower strength.

CONCLUSIONS

The influence of process parameters for Al-Cu FSW joints was analyzed by conducting 6 sets of experiments. The following inferences can be made after the study.

- Joints are successfully produced for the selected parameters.
- Selected material for tool and profile can be used for Al-Cu FSW.
- Experimental investigation reveals that the ultimate tensile and bending strength is maximum 1000rpm, 24 mm/min and offsetting towards retrieving side.
- Maximum hardness is reported for defect-free dissimilar joint for parameter “1000rpm, 24 mm/min and offsetting towards retrieving side. Due to presence of intermetallic mixtures in the nugget zone results higher hardness.
- Microstructure and EDS Analysis reveals that for parameter tool “rotational speed” 1000rpm, “tool travel speed” 24 mm/min and offsetting towards retrieving side, more number of copper particles were present in the aluminium section. Higher tensile, bending strength and hardness is credited to the presence of adequate Cu particles in Al material at nugget zone.
- Microstructure also reveals that, offsetting of tool towards retrieving side yields the good results. On the other hand, offsetting the tool towards advancing side yields poor results. This is due to improper mingling of Al-Cu particles in the weld zone.

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