

Evaluation of Tensile Properties and Microstructural Properties of Friction stir welded AL-CU Lap Joints

GopalVanga¹, M. Srivatsava², G. Narendra Santosh kumar³

Associate Professor, Dept. of Mechanical Engg, GuruNanak Institutions Technical Campus, Hyderabad, India¹

Assistant Professor, Dept. of Mechanical Engg, GuruNanak Institutions Technical Campus, Hyderabad, India²

Assistant Professor, Dept. of Mechanical Engg, GuruNanak Institutions Technical Campus, Hyderabad, India³

ABSTRACT: Modern structural application demands reduction in both the weight and as well as cost of the fabrication and production of materials. Aluminium alloys are the best choice for the reduction of weight, cost and replacing steels in many applications and Friction Stir Welding (FSW) process efficient and cost effective process. FSW is solid state welding process in which material is not melted during welding process so it overcomes many welding defects compared to conventional fusion welding process which is initially used for low melting materials. This process is initially developed for low melting materials like Aluminium, Magnesium, Zinc but now process is useful for high melting materials like steel and also for composites materials. The development of sound joints between dissimilar materials is a very important consideration for many emerging applications, including ship building, aerospace, transportation, power generation, as well as the chemical, nuclear, and electronics industries. However, the joining of dissimilar materials by conventional fusion welding is difficult because of the poor weld ability arising from the different chemical, mechanical, and thermal properties of welded materials and the formation of hard and brittle inter metallic compounds. The Present work main focused on the Tensile Strength of Al-Cu weldments and their micro Structural behavior at different weld speeds and different spindle speeds.

KEYWORDS: Friction Stir Welding, Al- Cu Lap joint, Spindle rotation speed, Welding Speed, Plunging Speed, Dwell Time, Tensile Strength, Micro Structural behavior.

I. INTRODUCTION

Friction Stir Welding (FSW) is a solid state welding process developed and patented by The Welding Institute (TWI) in 1991. It is emerged as a novel welding technique to be used in high strength alloys that were difficult to join with conventional welding techniques[1]. The process was initially developed for aluminium alloys[2-10], but since then FSW was found suitable for joining other materials like magnesium, steel, titanium, copper and also composites. The basic principle of FSW process is remarkably simple. Instead of a conventional welding torch, friction stir welding uses a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edged of the two parts to be welded and traversed along the line of the joint[12]. The heating is localized and generated by friction between the rotating tool and work piece, with additional adiabatic heating from metal deformation.[13,14] The pin and shoulder of tool can be modified in number of ways to influence material flow and microstructural formation.

II. MATERIALS AND METHODS

2.1 Weld Plates:

The rolled plates of pure aluminum and pure copper were used as the top and bottom plates of the lap joints. The thickness of both plates were 3mm. Table 1&2 indicates chemical composition.

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Table 1. Chemical composition of the pure aluminium base metal (mass%)

Si	Fe	Cu	Mn	Mg	Ti	Al
0.12	0.54	0.12	0.01	0.03	0.03	Bal

Table 2. Chemical composition of pure copper base metal (mass %)

Cu	Fe	Si	Zn	Pb	Ni	Al
Balance	0.05	0.009	4.69	0.003	0.03	0.02

2.2 Tool Geometry

In this project FSW between aluminium and copper lap joint cylindrical shoulder and cylindrical pin used. The geometry of tool as shown in fig1

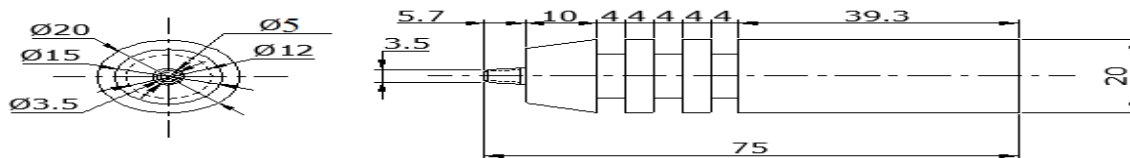


Fig1. FSW Tool Drawing

2.2.1 Tool Composition: The material used for the tool shoulder is typical tool steel. The tool pin material is a tool steel grade with a good balance of abrasive resistance, strength, and fracture toughness. The diameter of the stirring pin is about 8 mm. Tool material: H.S.S (M2), Chemical composition of tool (weight %) as shown in table 3

C	Si	Mn	Cr	Mo	W	V
0.8	0.4	0.4	4.1	5	6.1	1.9

Table 3. Chemical composition of tool (weight %)

2.3 FSW between aluminium and copper (lap joint)

Roller plates of 3mm in thickness were cut into the required size (100mm x 100 mm x 3mm) by power hacksaw cutting and milling. The experiments were conducted on the pure aluminium and pure copper. Before the friction welding, the weld surface of the base material was cleaned. Plate edges to be weld were also prepared so that they are fully parallel to each other. This is to ensure that there is no uneven gap between the plates which may not result in sound welding. Secondly surface preparation was also done so that the surfaces of both the plates are of equal level and footing. Aluminum and copper each 9 plates were prepared.

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Fig 2. Photograph of FSW Tool

Computer Numerically Controlled milling machine is converted in to friction stir welding machine to carry out welding process. Two aluminium and copper alloy plates of size 100X100X3 mm were perfectly clamped in CNC milling machine bed on a backup plate. The FSW tool is inserted into the tool holder. Tool is plunged into the joint in the downward direction with a feed rate of 10 mm/min in clockwise direction. Higher tool rotation generates temperature because of higher frictional heating and results more intense stirring of mixing material. Total 9 numbers of FSW experiments between pure aluminum to pure copper were carried out to obtain the optimum parameters by adjusting the rotational speed of the tool and the welding speed in the range of 700–1500 rpm and 30–70 mm/min, respectively. Other parameters including the tool geometry, plunge depth of the stir pin, plunging speed (10mm/min) were kept constant. Process parameters are as shown in table 4

Table 4. Process Parameters

Joint No	Welding speed	Spindle rotation speed	Plunging speed	Dwell Time
1	30mm/min	1500rpm	10mm/min	10sec
2	30mm/min	1100rpm	10mm/min	10sec
3	30mm/min	700rpm	10mm/min	10sec
4	50mm/min	1500rpm	10mm/min	10sec
5	50mm/min	1100rpm	10mm/min	10sec
6	50mm/min	700rpm	10mm/min	10sec
7	70mm/min	1500rpm	10mm/min	10sec
8	70mm/min	1100rpm	10mm/min	10sec
9	70mm/min	700rpm	10mm/min	10sec

2.4 Tensile testing

The tensile tests were conducted to determine the tensile properties of aluminium and copper joints by friction stir weldments at different rotational speed of the tool (700 rpm ,1100, 1500 rpm) in a Universal Testing Machine (UTM) as per ASTM standard



Fig 3.CNC Machine Fig 4.Setup

2.5 Microstructure in Stir Zone: According to tensile test, the joints were fractured in Cu side of the weld. Therefore, in the weld of Cu side, especially in the weld nugget zone, the microstructure has an important effect on mechanical properties of Cu/Al joints. The microstructure of the stir zone in the weld for Cu/Al joints was shown in fig. The distribution between Cu and Al has an obvious boundary. And the metal in stir zone shows obvious plastic combination.

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Fig5. bekalitemoulding samples

III.RESULTS AND DISCUSSIONS

3.1 Microstructures of Al-Cu joints: Spindle speed 1500rpm with welding speed 30mm/min (joint 1) produces high heat. Due to that heat, more aluminium grains (black shade) formed over copper in weld nugget. Microstructure illustrated due to spindle speed 1500rpm, welding speed 50mm/min as shown in fig (b). Compare to last microstructure here less heat develops in weld nugget. In this microstructure cavity defects observed at one portion. Spindle speed 1500rpm, welding speed 70mm/min microstructure as shown in fig (c). In this structure no defect observed. In this joint sufficient heat develop for joining of aluminium and copper joint.

Fig (d) shows microstructure illustration for 1100rpm spindle spinning speed with 30mm/min welding feed. In this experiment high heat develop due to high spindle speed and low welding feed. Generally high spindle speed produces high heat. If high spinning spindle moving with low welding feed that generate more heat in weld nugget. Due to that high heat low thermal conductivity metal aluminium grains (black shade) spread over copper grains as shown in fig d & e. Spindle speed 1100rpm, welding speed 70mm/min microstructure as shown in fig (f). In this structure some cavity defects observed. Defects can be control with the welding feed between 55mm/min to 65mm/min of 1100rpm spindle speed for 3.5mm diameter tool pin. Fig(g) shows 700rpm spindle speed with 30mm/min produce more heat than 50mm/min and 70mm/min. In this microstructure cavity defects observed. In between joint area is not uniform aluminium grains over heated and spread over copper grains. Some micro cracks observed over weld nugget. Fig (h) shows microstructure for 700rpm spindle spinning speed with 50mm/min welding speed. In this microstructure observed uniform weld joint and sound joint. Sufficient heat produced for making dissimilar joint.

Fig (i) shows microstructure for 700 rpm spindle speed with 70mm/min welding speed. In this microstructure very clearly observed that produced heat is not sufficient to weld sound joint. Joint area at aluminium side observed light black shaded area and copper side light gray shaded area. Without proper heating of material, 70mm/min welding speed is applied to the material so tool breakage chance more. In all experiments 3.5mm tool pin is used for joining of dissimilar metals. Due to that 3.5mm diameter tool could not carry 70mm/min movement. For applying more welding speeds large diameter is suitable compare to 3.5mm tool pin.



Joint1 (a) joint2(b) Joint3 (c)

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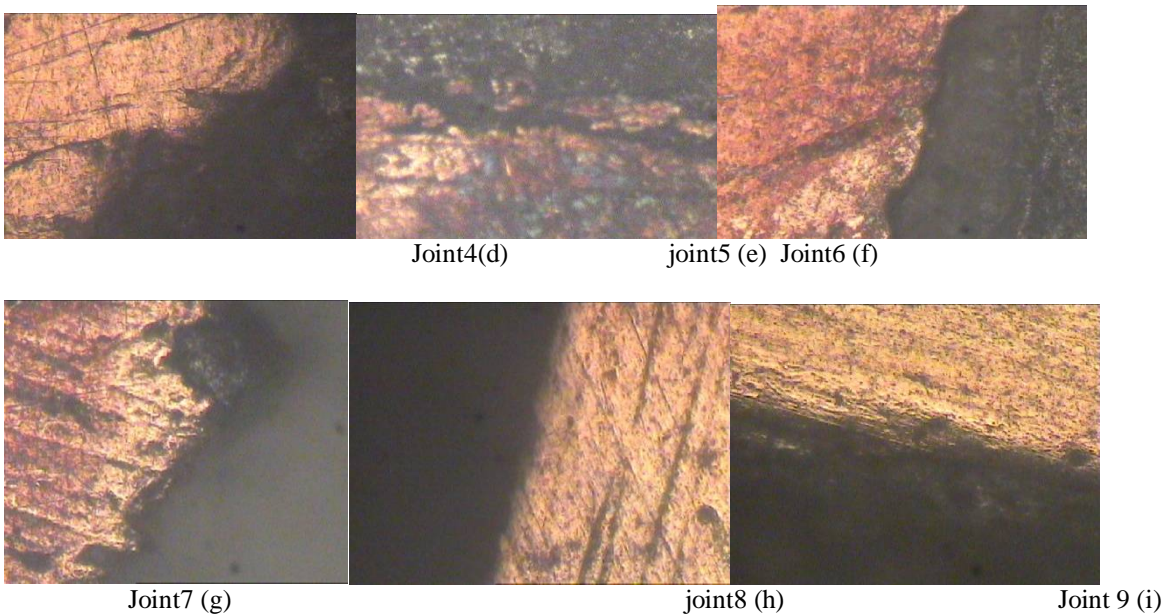


Fig 6. Various microstructures of Al-Cu joints at different Cutting Speeds

3.2 Tensile test results: Various tensile strength at different speeds are shown in table 5. From the Table 5 values various graphs plotted between welding speed and tensile strength and shown in figure 6,7,8. the out comes from the graphs are discussed below.

Table 5. Tensile Strength at different speeds

No of joint	Welding speed	Spindle rotation speed	Area of section	Ultimate load in N	Ultimate tensile strength in N/mm^2
1	30mm/min	1500rpm	26X6mm	1000	6.140
2	50mm/min	1500rpm	26X6mm	2000	12.82
3	70mm/min	1500rpm	26X6mm	4000	25.64
4	30mm/min	1100rpm	26X6mm	1400	8.97
5	50mm/min	1100rpm	26X6mm	2200	14.10
6	70mm/min	1100rpm	26X6mm	2600	16.66
7	30mm/min	700rpm	26X6mm	1400	8.97
8	50mm/min	700rpm	26X6mm	1800	11.53
9	70mm/min	700rpm	26X6mm	1000	6.41

From the graph Fig 7, it is clearly observed maximum tensile strength at 1500rpm with 70 mm/min. By seeing microstructure sufficient heat is developed, in this joint no cavity defects observed and in between weld nugget joint is uniform. Due to the above reasons 1500rpm with 70mm/min obtained high strength joint.

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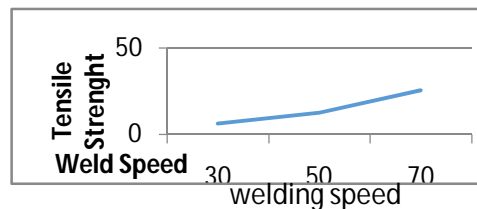


Fig No 7. Tensile test results for 1500 rpm spindle speed

At 1500rpm with 30mm/min and 50mm/min welding speed observed very low tensile shear strength. In this joints high heat produced due to low welding speed. On the other hand, some micro cracks were found around these particles especially coarse particles, which may be attributed to the different flow of copper fragments and surrounding aluminum during high deformation and intense mixing of materials in the FSW. Microstructure observations revealed that the frequency of such micro cracks was considerably decreased with increasing welding speed.

In the spindle spinning speed 1500rpm with 50mm/min observed cavity at one portion in the weld nugget center line due to that low tensile strength observed than 70mm/min. However, in 30mm/min welding speed, over heating of material observed micro cracks in weld nugget and uneven joining of grains in weld nugget observed very low tensile strength.

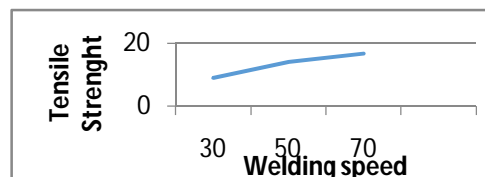


Fig No 8. Tensile test results for 1100 rpm spindle speed

From Fig 8 it is clearly observed maximum tensile strength at 1100rpm with 70 mm/min. By seeing microstructure sufficient heat is developed, in this joint only one small cavity defects observed. Due to the above reasons in 1100rpm spindle spinning speed with 70mm/min welding speed obtained high strength joint than remaining welding speeds.

At 1100rpm with 30mm/min welding speed observed very low tensile shear strength. In this joint high heat produced due to low welding speed. Due to formation of high amount of micro cracks in the dark area at welding speeds of 30 and 50 mm/min, the tolerable tensile shear was lower than that of 70mm/min.

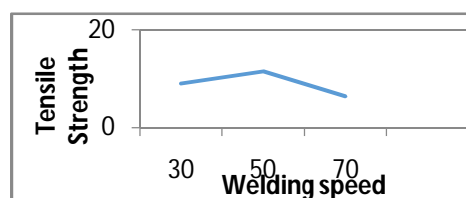


Fig 9. Graph shows Tensile test results for 700 rpm spindle speed

Fig. 9 illustrates the failure loads of the joints as a function of welding speed in tensile shear test. One can find that with increasing the welding speed, failure load increases up to a maximum value and then decreasing behavior is appeared. The shear load of the joint is probably affected by two factors: the amount of micro cracks, and cavity formation.

Decreasing the welding speed of a tool due to higher amount of micro cracks reduces the tolerable shear load. The reason for this behavior is the increasing volume of copper particles in the dark area, which increases the amount of micro cracks. As explained before, these cracks are nucleated heterogeneously at copper particle aluminum interfaces where compatibility of deformation is difficult.

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Under straining conditions, micro cracks grow and coalesce into a main crack, which later grows and leads to the formation of fracture surface. Thus, the frequency of occurrence of micro cracks should have a strong influence on fracture strength. Furthermore, lower welding speed caused more vertical transport, while a higher welding speed caused less vertical transport on the retreating side.

In the results of tensile shear test in this study shows that the maximum strength has been achieved at welding speed of 50 mm/min. This welding speed refers to a balance between cavity defects and the micro crack formations.

By observing the microstructure at welding speed of 70mm/min less vertical transport of material taken place and low heat developed in nugget zone. Due to that low tensile shear strength joint obtained. And also tool breakage chances more due to low heat input.

IV. CONCLUSION

In summary, the following conclusions are reached.

1. The aluminium and commercially pure copper were successfully friction stir lap welded using a small pin 3.5 mm in diameter at different spindle spinning speeds with different welding speeds.
2. It was clearly observed that, for making FSW high spinning speeds suitable. And suitable welding speed is depends on the spindle spinning speed.
3. The maximum tensile shear load reached up to 4000 N at the 1500rpm spindle speed, 70mm/min welding speed with 3.5 diameter tool. So maximum tensile strength 25.64MPa observed in this joint

4.1 Tensile strength. 1. Tensile shear strength point of view 30mm/min welding speed is not suitable for 700, 1100rpm and 1500rpm spindle spinning speeds. In 30mm/min low welding speed produce more heat that leads to formation of micro cracks in microstructure and also not obtained uniform welding.

2. In 700rpm spindle spinning speed with welding speed 50mm/min joint observed high tensile strength 11.53MPa (2600N load) observed compare to 30mm/min and 70mm/min.

3. For low spindle speed (700rpm) with high welding speed (70mm/min) causes less vertical transport of material, more cavity defects observed and insufficient heat produced. Due to the reasons very low tensile strength 6.410 (at 1000N load) obtained in that joint.

4. High tensile strength 16.6 MPa (2600N load) observed in 1100 rpm spindle speed with 70mm/min welding speed compare to 30mm/min and 50mm/min welding speeds. In 30mm/min, 50mm/min low welding speeds produce more heat that leads to formation of micro cracks in microstructure and also not obtained uniform welding.

5. In 1500rpm spindle speed with 70 mm/min welding speed joint observed maximum tensile Strength 25.64MPa observed. In 30mm/min, 50mm/min low welding speeds produce more heat leads to formation of micro cracks in microstructure and also not obtained uniform welding.

6. In 1500rpm spindle speed with 70mm/min welding speed observed some minor cavity defects. And also observed that in 1500rpm spindle speed we can able to apply more than 70mm/min welding speed up to suitable welding speed for getting high strength joint.

REFERENCES

- [1] Mandeep Singh Sidhu, Sukhpal Singh Chatha "Friction Stir Welding – Process and its Variables: A Review" IJETAE Volume 2, issue 12, 2012
- [2] Rajiv S. Mishra, Murray W. Mahoney, Friction Stir Welding and Processing, 2007 pp. 1-5
- [3] Friction stir welding, http://en.wikipedia.org/wiki/Friction_stir_welding
- [4] P.L. Fan, C.H. Lin "Experimental study on Friction Stir Welding of copper metals", Journal of Materials Processing Technology 210 (2010) 1667–1672
- [5] R. Rai, A. De, "Review: friction stir welding tools" Science and Technology of Welding and Joining (2011) VOL 16 NO 4 325
- [6] R. Nandan T, Debroy H.K., "Recent advances in friction stir welding process, weldment structure and properties", Volume 53, Issue 6, August 2008, Pages 980-1023
- [7] M. Sivashanmugun, T.kumar, "A Review on Friction Stir Welding for aluminium alloys" ,IEEE 2010
- [8] Leal RM, Sakharova N, Vilaça P, Rodrigues DM, Loureiro A. "Effect of shoulder cavity and welding parameters on friction stir welding of thin copper sheets". SciTechnol Weld Joining 2011;16:146-52.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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- [9] Abdollah-zadeh A, Saeid T, Sazgari B. "Microstructural and mechanical properties of friction stir welded aluminum/copper lap joints". J Alloys Compd 2008;460:535-8.
- [10] Saeid T, Abdollah-Zadeh A, Sazgari B. "Weldability and mechanical properties of dissimilar aluminum-copper lap joints made by friction stir welding". J Alloys Compd 2010;490:652-5.
- [11] Xue P, Xiao BL, Wang D, Ma ZY. „Achieving high property friction stir welded aluminium/copper lap joint at low heat input". SciTechnol Weld Joining 2011;16:657-61.
- [12] Leitão C, Loureiro A, Rodrigues DM. "Influence of base material properties and process parameters on defect formation during FSW". International Congress on Advances in Welding Science and Technology for Construction, Energy and Transportation Systems. Antalya, Turkey, 24-25 October 2011.
- [13] Rodrigues DM, Leitão C, Louro R, Gouveia H, Loureiro A. "High speed friction stir welding of aluminium alloys". SciTechnol Weld Joining 2010;15:676-81.
- [14] Leitão C, Louro R, Rodrigues DM "Analysis of high temperature plastic behaviour and its relation with weldability in friction stir welding for aluminium alloys" AA5083-H111 and AA6082-T6. Mater Des 2012;37:402-9.