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Influence of Process Parameters And Tool On Mechanical And Metallurgical Properties of Pure Copper And Aluminum Alloy AA7075 Dissimilar Friction Stir Welded Joints

Supraja Reddy.B[1], Ram Gopal Reddy.B[2]

[1]*Research Scholar, Mechanical Engineering, Acharya Nagarjuna University, Guntur and Assistant professor, Mechanical Engineering, V R Siddhartha Engineering College, Vijayawada, India.*
[2]*Professor, Mechanical Engineering, RVR&JC College of Engineering, Guntur, India.*

[1]supraja@vrsiddhartha.ac.in., [2]brgreddy73@gmail.com.

***Abstract** - The joining of dissimilar Aluminium combinations and pure copper is needed in many Engineering industries. For Al/Cu dissimilar welding, the fusion welding techniques are not adequate in light of the fact that after-effects of formation of thick and brittle inter metallic compounds, high residual stresses, blending of material and micro cracks. Keep away from these sorts of imperfections for Al/Cu dissimilar joints utilizing grating mix welding measure Friction stir welding (FSW). This investigation experts to examine the impact of the tool shape and rotational speed on dissimilar joints of 5mm thick AA7075 to pure copper plates. This work is done at four rotational tool speeds of 450 rpm, 560 rpm, 710 rpm, and 900 rpm with a constant feed of 16mm/min utilizing the Tungsten carbide tool (WC). In this examination, the tool pin geometry assumes a significant part in tensile strength and considered two shapes to be specific tapered (cone) tool and cylindrical tool. The performance of the tool shape demonstrated that the pin shape could, in fact, improve the joint strength of the dissimilar welded joint acquired with a tapered pin and furthermore saw that a rotational speed increases formed thick and brittle intermetallic layers and diminishes the rotational speed shaped passage deserts that is tunnel defect at the interface of the weld. Microstructure and SEM pictures of different zones are seen in Al/Cu dissimilar welded joints.*

Keywords - *Friction Stir Welding, Tool shape, Mechanical properties, dissimilar welded joints, AA7075, Pure copper.*

I. INTRODUCTION

Presently dissimilar welded joints are utilized in many engineering industries like marine, aviation, automobile, and petrochemical fields due to shows the great performance of welding attributes. Copper and Aluminum are exceptionally planned materials and most engrossing minerals in various industries. Particularly the Aviation industries are utilized pure copper for various properties like electrical and thermal conductivity, erosion safe, and Al for lightweight with high strength. Joining Cu/Al dissimilar joints are extremely troublesome in fusion welding since the improvement of brittle and thick layered intermetallic mixtures and helpless capacity results. FSW is getting these two materials together with less weldability to be associated well together, as demonstrated in Fig.1.

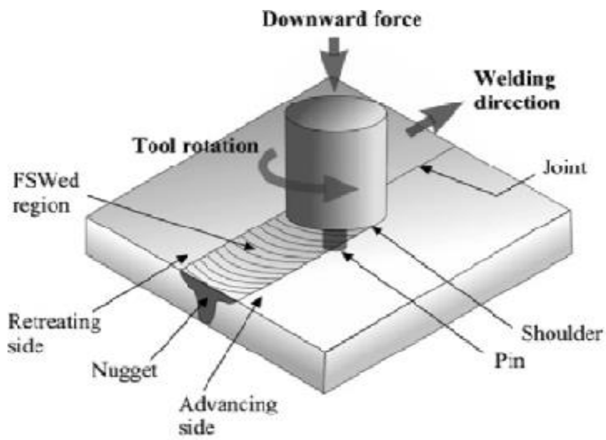

Fig. 1 Friction stir welding process

Friction stir Welding is the solid-state welding and least energy situated green welding process due to its flexibility, energy productivity, and natural cordiality and furthermore overcome surface oxidation, solid inclusions, solidification cracking, enormous distortions, macro, and micro isolation, development of brittle intermetallic mixtures between dissimilar metals, wide heat affected zone, gas and shrinkages porosities [1, 2]. In this process, the tool geometry, tool materials, and process parameters are assumed a significant part on weld quality. A. Heidarzadeh et al. [3] were seen that the primary challenges in FSW of dissimilar welded joints with various properties is the absence of inhomogeneous blending of metals and the arrangement of intermetallic mixtures in the stirred zone and happens because of deficient heat input and low plasticity of the metals to be joined. Another justification arrangement of intermetallic compounds is the high heat input applied to the metal during welding. Shabbir Memon et al. [4] examined the impact of stir time on the metallurgical and mechanical behavior of the AA6061-T6 and AA7075 – T6 modified friction stir clinching welded tests and observed at low mixing time, the MFSC welding brought about the formation of geometric differential stream shortcomings at the shoulder-incited cavitation and recharged finishes of the keyhole and furthermore the mixing time altered the internal intermixing of the materials during the MFSC interaction nonetheless, a few imperfections were shaped at lower and higher stirring times. Sipokazi Mabuwa et al. [5] studied comparative examination between normal and submerged friction stir processed friction stir welded AA6082 and AA8011 dissimilar joints also saw that because of the water rapid cooling system, the grain size is better contrasted with the normal friction stir processing, and the grain refinement contributed enormously toward the joint tensile properties. Likewise, the material position assumes a significant part in the strength of the joint. Mohamed M. Abd Elnabi et al. [6] examined the impact of tilting angle and pin length on 1050 pure aluminum and toughened low carbon steel dissimilar friction stir welded joint. They have examined the higher pin length and lower tilt angle delivered higher strength welded joints, and the higher tilt angle causes the higher the thickness of the IMC at stirred zone. Anton Naumov et al. [7] explored metallurgical and mechanical properties of Al-Cu-Li compound sheets of 1.4 mm thick after hot rolling and ensuing quenching friction stir welded joints and saw that the grain size in the stirred zone was expanded; the width of the mollified region was limited with the diminishing of linear energy and the fracture of high direct energy welded joints happened in the stirred zone along the remainder oxide line and at the low linear energy welded joints raptured in progress between heat-affected zone, and Thermo Mechanical affected zone on the advancing side. Chenghang Zhang et al. [8] explored the impact of post-weld heat treatment on microstructure and mechanical properties in dissimilar AA2024, and AA7075 friction stir welded joints and concentrated fine equiaxed grains are created in the nugget zone, while huge estimated grains are shaped after PWHT, and the grain development happens in the thermomechanical affected zone, while Strange Grain Development happens in the nugget zone of the dissimilar joints after PWHT. The level of grain development of the AA2024 side at the interface of the joint is clearly higher than that of the AA7075 side. Bruna Fernanda Batistao et al. [9] explored mechanical and metallurgical properties of AA5083 to GL D36 steel dissimilar friction stir welds in joint lap configuration. They have examined the formation of the tunnel defects caused by an increase in the feed or decrease in the rotational tool speed and also observed that tool rotational speed increases found thick intermetallic layers in the joint interface due to high hardness and brittleness of the FeAl and Fe_3Al phases. Velaphi Msomi et al. [10] covered the impact of metal position during friction stir processing of dissimilar AA1050 to AA6082 friction stir welded joints and noticed AA6082 on advancing side shaped refinement of grain size at the stirred zone and furthermore noticed microhardness is higher at stirred zone. H. Khatami et al. [11] conducted an analysis of variance to identified effective parameters and contribution on the mechanical performance of Al/Cu friction stir dissimilar welded joints by using the Taguchi method and observed that the rotational speed was more effect on maximum tensile force and this force improved by the increases the dwell time and decreases the penetration depth. M.GoliBidgoli et al. [12] studied the bonding of carbon fiber reinforced polymer composite friction stir welded joints, and they were observed that increases the rotational speed and feed the carbon particles distributed uniformly in the polymeric field and also observed decreases in the face reinforcement of the welded joint in the face and root face area and excess rotational speed caused the melting of polymer. Mohammed et al. [13] examined the connection between the design of the tool and material flow of dissimilar AA7075-AA6061 friction stir welded joints and saw that the cone-like tool pin shown superior outcomes to material flow at stirred zone shaping of onion rings. N.Ethiraj et al. [14] studied the impact of rotational tool speed on microstructural and mechanical properties of dissimilar austenitic stainless steel AISI 304 and AISI 316 friction stir welded joints and summarized that in all rotational speeds of joints had external weld defects were not found in visual inspection, fine grain structures observed in the stirred zone with a negligible amount of transformation of austenite into martensite and also observed the average microhardness at the stirred zone is lower than that of base metal and heat-affected zone. N.Kaushik et al. [15] investigated the effect of AA6063 reinforced with 7wt % SiC particles composite friction stir welded joints on microstructure and mechanical properties and the ultimate tensile strength of joint as compared to base composite, observed that the ductility of the joint is less and after welding coarse size SiC particles cracked into fine particles and observed that increased the dislocation density and hardness. Even more, investigations need for better comprehension of intermetallic layers of Al/Cu dissimilar welded joints. P. Irshad Khan et al. [16] reported mechanical and metallurgical properties of aluminum AA6061-T6 friction stir welded joints with the thickness of 3mm and observed that using the conical tapered pin found defect-free and quality welded joints. Raju Kamminana et al. [17] studied regression models developed for FS Welded AA2050-T84 joints and observed that the speed and tool pin geometry were the most significant process variables for all responses, but the width of the heat-affected zone most significant process parameters are tool shoulder and tilting angle. This investigation discussed the effect of a process parameter, tool material, and tool shape on Al/Cu welded joints.

II. MATERIALS AND METHODS

A. FSW & Process Parameters

A vertical milling machine was utilized to butt welded 150 mm x100mm x 5mm thick AA7075 to pure copper plates along their lengths. A tungsten carbide tool was utilized for welding with the shape of cone and cylinder. The tool's shoulder breadth and pin length were 20mm and 4.8 mm individually, and a conical tool with the pin measurement 6 mm at the top and 4 mm at the bottom, and a cylindrical tool with the pin diameter of 6 mm was utilized in this report. The chemical compositions of the two materials have appeared in Table 1 and Table 2.

TABLE I

Chemical Composition of AA7075	
Al	89.56%
Cu	1.302%
Mg	2.378%
Zn	6.096%

TABLE II

Chemical Composition of Pure copper	
Cu	99.96%

The positioning of the plates was pure copper at the advancing side and AA7075 at the retreating side with a tool tilting angle of 2^0. The test arrangement has appeared in fig. 2, and the process parameters have appeared in Table 3.

Fig. 2 FSW Setup

TABLE III
Process parameters

S. N O	Tool Shape	Tool Material	Speed (Rpm)	Feed (mm/ min)	Tilting Angle
1	Cone	WC	450	16	2^0
2	Cylinder	WC	450	16	2^0
3	Cone	WC	560	16	2^0
4	Cylinder	WC	560	16	2^0
5	Cone	WC	710	16	2^0
6	Cylinder	WC	710	16	2^0
7	Cone	WC	900	16	2^0
8	Cylinder	WC	900	16	2^0

B. Metallographic Examination

The welding tests were metallo graphically set up with standard interaction. The samples were etched with the solution of HNO_3 (25ml) + H_2O (75ml) was utilized on the Aluminum side for 60 seconds, and Fe $(NO_3)_3$ (5mg) + HCL (25ml) + H_2O (75ml) was utilized on the copper side for 60 seconds. The grain structure, joint interface, and material flow were seen by utilizing an optical microscope and SEM.

C. Mechanical Testing

The strength of the dissimilar welded joints was researched with ASTM E8 norms, as demonstrated in Fig. 3. The hardness is additionally utilized to build up the relation between joint strength and intermetallic layered formation.

Fig. 3 Tensile Test samples

III. RESULTS AND DISCUSSIONS

A. WELD APPEARANCE

Fig. 4 shows the top surface of the AA7075 to pure copper FS welded joints at various process parameters and tool geometry.

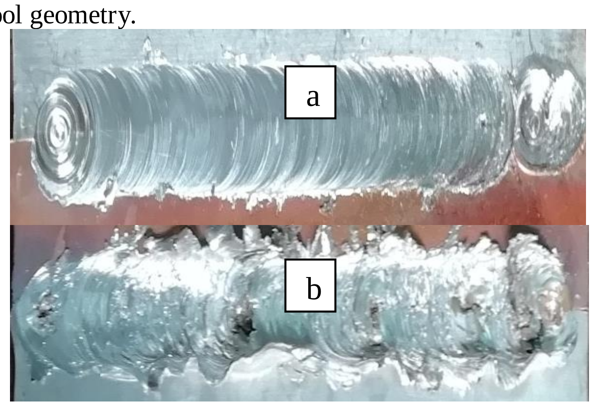

Fig. 4 Top surface of FSW welded joints using (a) tapered tool (b) cylindrical tool (b)

The welded surface has demonstrated the propensity for volumetric imperfections to be created as a result of over flash formation development just as material discontinuity. Fig. 4 shows the performance of rotational tool speed, feed, and tool shape on the weld appearance. At the point when the rotational speed fluctuated 450 rpm, 560 rpm, 710rpm, and 900 rpm and the tool shape cone and round and cylindrical with constant feed 16 mm/min, outwardly adequate welded joints were acquired. At the rotational speed of 710 rpm and feed of 16 mm/min with cone-shaped tool got surface defects free welded joint and at 450 rpm and feed of 16 mm/min with cylindrical tool got material discontinuity welded joint. Figure 5 shows the different imperfections at various process parameters. Fig. 5(a) addresses the macro cracks towards the Aluminum side, (b) addresses tunnel defects observed at stirred zone, (c) addresses surface deformities formed towards the copper side, and (d) addresses voids shaped inappropriate material flow.

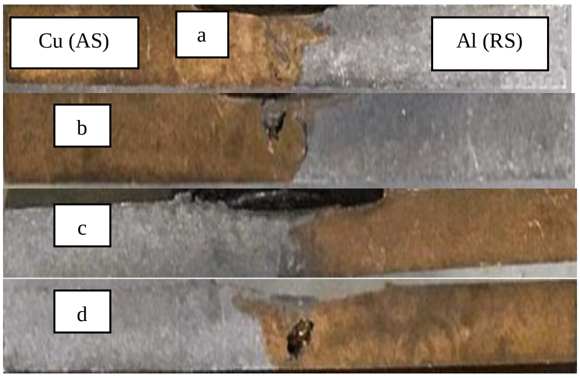

Fig. 5 Defects in various welding process parameters

B. Metallurgical analysis

In dissimilar F S welded joints, the lamella structure, a whirl-like structure, and vortex type microstructure are formed in the stirred zone, heat-affected zone, and thermomechanical affected zone. Figure 6 addresses dissimilar pure copper to AA7075 welded stirred zone at 450 rpm and 16mm/min with the conical tool. In this zone, the sporadic enormous copper particles were deposited on the Aluminum side and towards the bottom of the interfacial zone to stirred zone and the Aluminum side and shaped whirl-like structure.

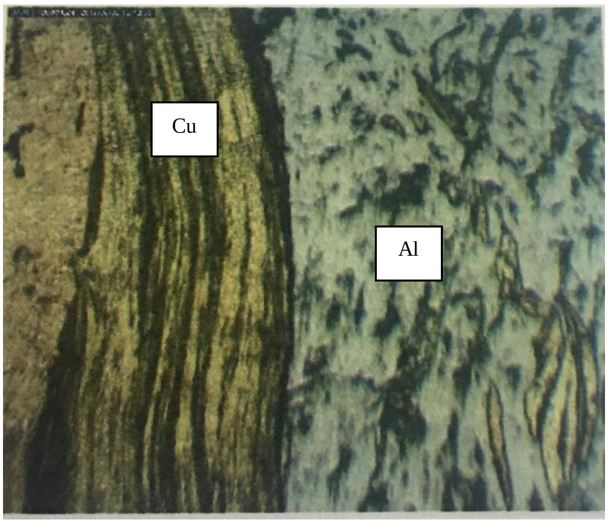

Fig. 6 Microstructure conditions of the welded joint at 450 rpm and 16 mm/min with the conical tool.

Fig. 7 addresses Cu/Al welded stirred zone at 560 rpm, and 16mm/min with the conical tool and saw that the dim concealed encompassing the copper and Aluminum particles and this intermixing layer was formed intermetallic Al/Cu compounds and framed vortex-like design.

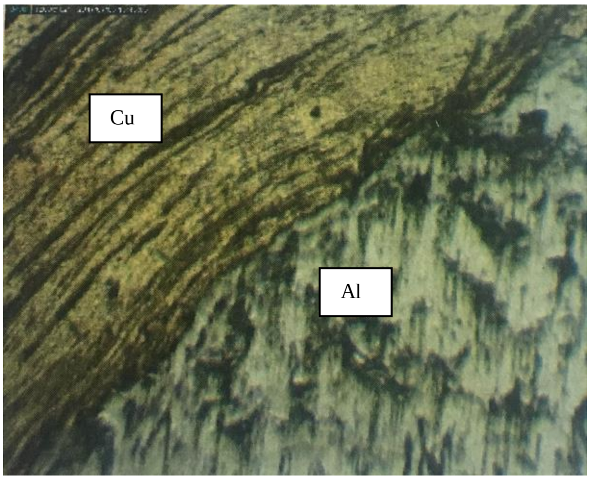

Fig. 7 Microstructure conditions of the welded joint at 560 rpm and 16 mm/min with the conical tool.

Fig. 8 addresses Cu/Al welded stirred zone at 710 rpm and 16mm/min with the conical tool and saw that the blending of Al/Cu particles is acceptable, and furthermore, a few voids are shaped on the Aluminum side.

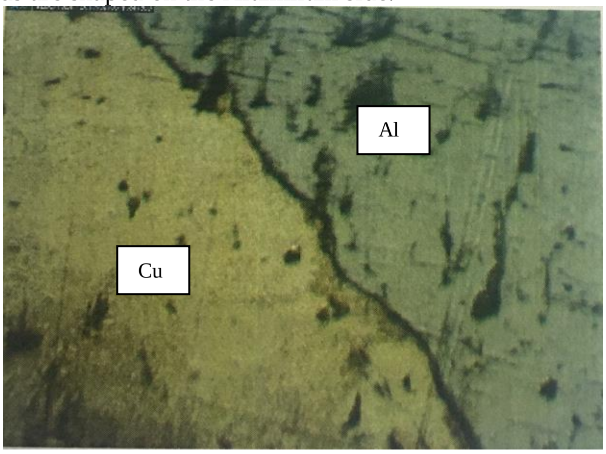

Fig. 8 Microstructure conditions of the welded joint at 710 rpm and 16 mm/min with the conical tool.

Figure 9 represents Cu/Al welded stirred zone at 900 rpm, and 16mm/min with the conical tool and dull shades are framed on the Aluminum side on account of higher speed with non-homogeneous solid solutions.

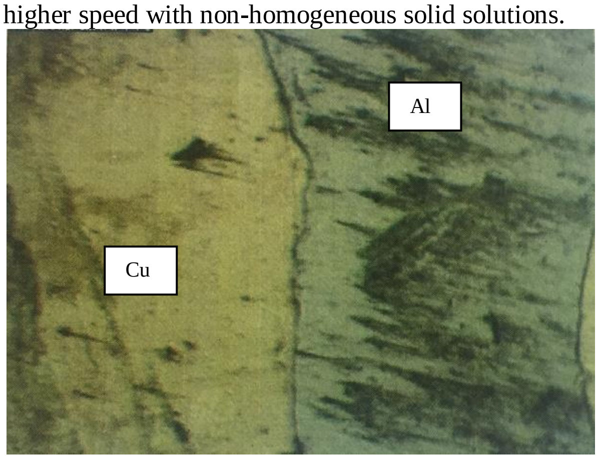

Fig. 9 Microstructure conditions of the welded joint at 900 rpm and 16 mm/min with the conical tool.

Fig. 10 addresses Cu/Al welded stirred zone at 450 rpm, and 16mm/min with the cylindrical tool and saw that inappropriate blending of Cu/Al isolates the Aluminum particles neglected to respond to the copper matrix on the advancing side.

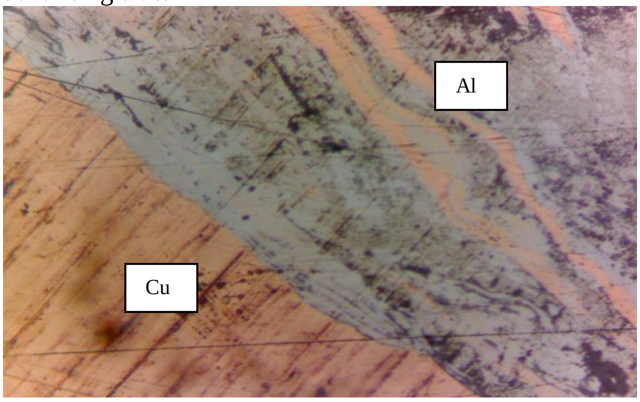

Fig. 10 Microstructure conditions of the welded joint at 450 rpm and 16 mm/min with the cylindrical tool.

The SEM pictures of stirred zones addresses at various process parameters have appeared in Figures 11. a, 11. b, 11. c, 11.d and 11.e. Metallurgical properties show the great connection between Aluminum alloy and intermetallic, whereas the powerless connection between intermetallic and copper. In friction stir welding, enormous strain and strain rate alongside the high temperatures because of high pressures are included. This explanation advances the thick intermetallic layers in welded joints.

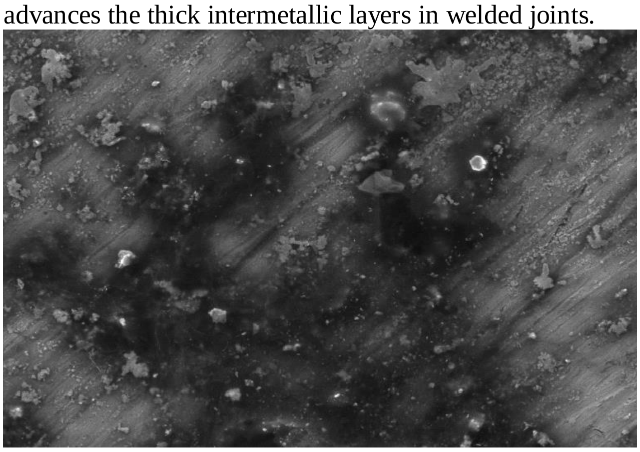

Fig. 11.a SEM image welded joint at 450 rpm and 16 mm/min with the conical tool.

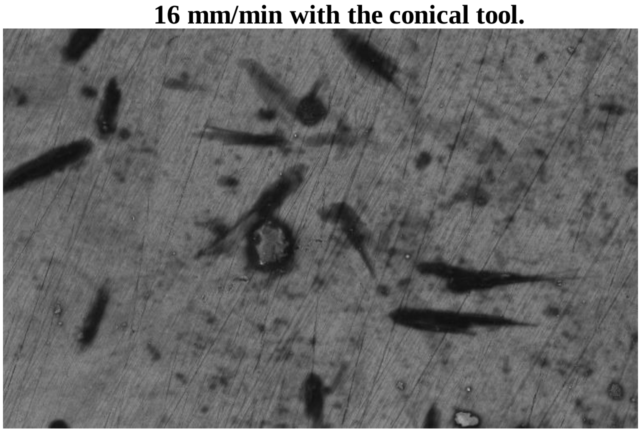

Fig. 11.b SEM image welded joint at 560 rpm and 16 mm/min with the conical tool.

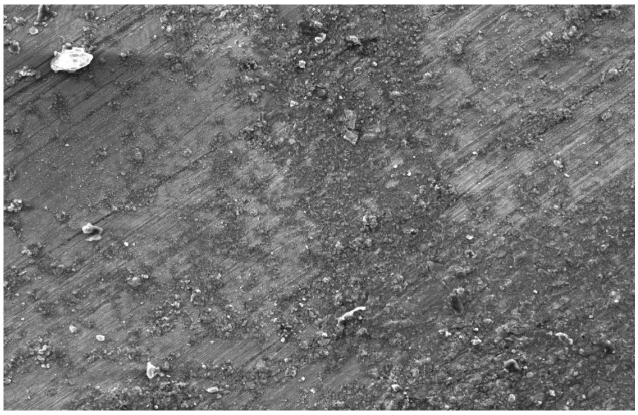

Fig. 11.c SEM image welded joint at 710 rpm and 16 mm/min with the conical tool.

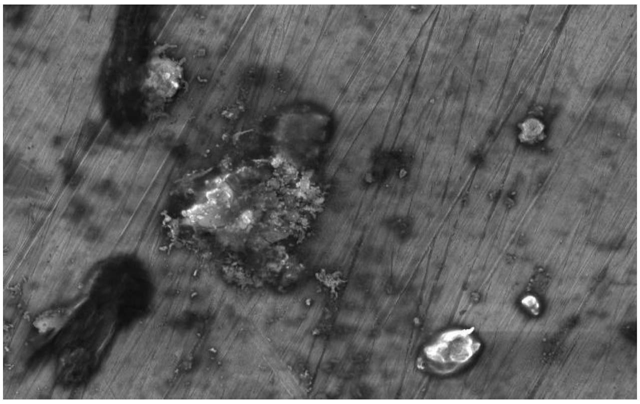

Fig. 11.d SEM image welded joint at 900 rpm and 16 mm/min with the conical tool.

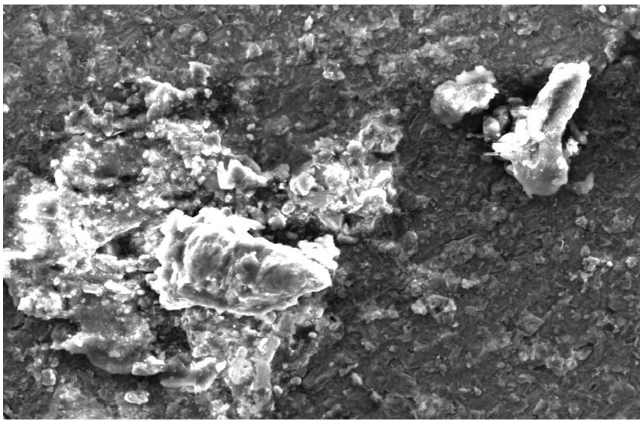

Fig. 11.e SEM image welded joint at 450 rpm and 16 mm/min with the cylindrical tool.

C. Mechanical strength

Mechanical properties have appeared in Table 4. The dissimilar welded joint efficiency rely upon tensile properties, and this can be connected to proper material blending, and intermetallic layer thickness, and, furthermore, the softer material consistently positioned at the advancing side. The performance of the tool pin rotational speed is higher than the feed, as this builds the heat and improves the degree of mixing happens at 710 rpm and 16 mm/min with the conical tool. The tool pin rotational speed is lower than feed, as this created ill-advised blending of materials happens at 450 rpm and 16 mm/min with the cylindrical tool.

TABLE IV
Mechanical properties

S. NO	Tool Shape	Speed (RPM)	Tensile strength (MPA)	Hardness (HBN)	Elongation (%)
1	Cone	450	27.696	114	1.4
2	Cylinder	450	24.706	117	1.2
3	Cone	560	48.776	102.3	0.84
4	Cylinder	560	38.89	145.33	0.36
5	Cone	710	66.667	95.47	0.94
6	Cylinder	710	64.777	102.03	1.74
7	Cone	900	66.434	103.33	1.68
8	Cylinder	900	58.129	98.3	1.62

The crack surfaces have appeared in fig. 12 at different conditions. Figure 12. shows the failure at the retreating side at the lower speed of 450 rpm. The failure area moved to RS by speeding up 710 rpm and 900 rpm, as demonstrated in 12. b, 12. c.

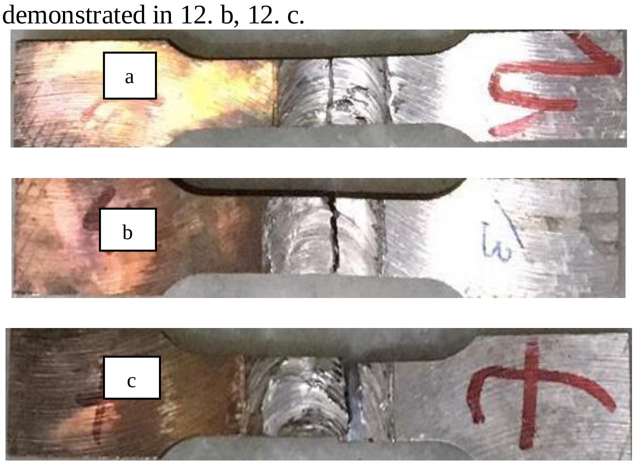

Fig. 12 (a, b, c) Fratography at various conditions

Fig. 13 shows a tensile strength at various conditions. The acknowledged welded joint is found at 710 rpm, and 16 mm/min with WC conical tool, and the tilt angle is 2^0. Tensile strength is got at this condition is 66.7 MPA. The imperfection welded joint is found at 450 rpm and 16 mm/min with WC cylindrical tool, and the tilt angle is 2^0.

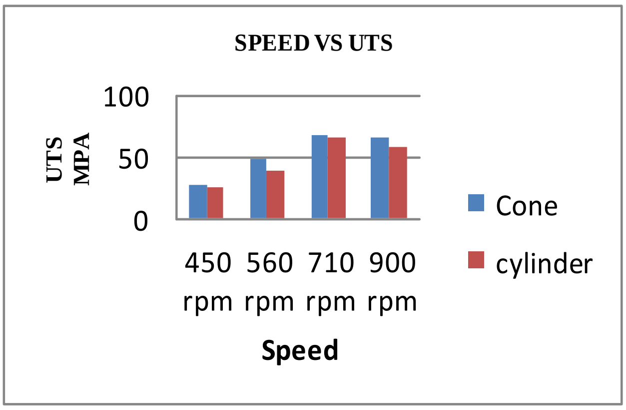

Fig. 13 UTS at various speeds

The tensile strength is acquired at this condition is 24.7 MPA. Fig. 14 addresses the elongation of different conditions.

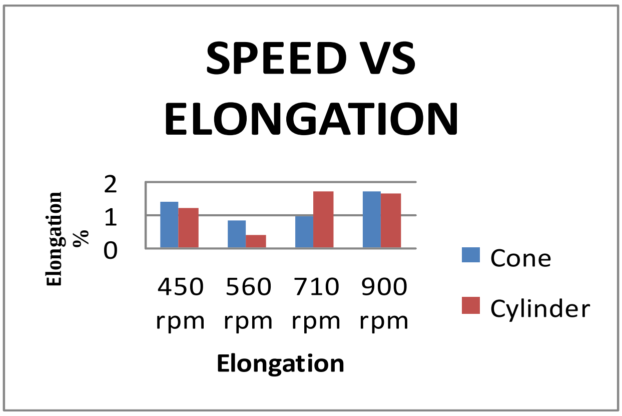

Fig. 14 Elongation at different speeds

Fig. 15 shows the hardness of welded joints at different conditions. The most extreme hardness is formed at the cylindrical tool in the stirred zone. In this condition, thick IMC layers are framed and diminished the strength of the joint. The minimum hardness is formed at conical tool, in this dainty IMC layer formed contrasted with the cylindrical tool and got sound welded joints.

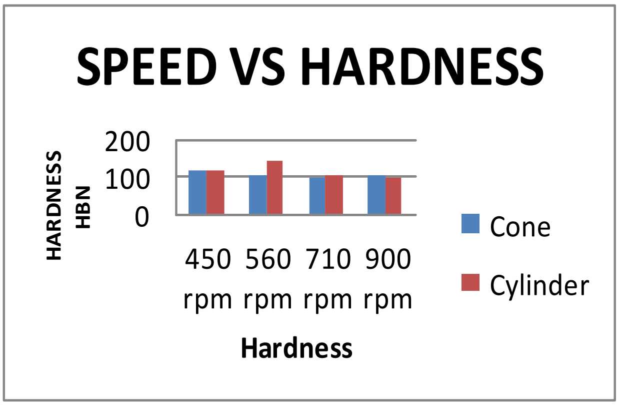

Fig. 15 Hardness at different speeds

IV. CONCLUSIONS

Dissimilar FSW of pure copper to AA7075 joints was tentatively examined at different conditions that brought about adequate joints were distinguished.

- From microstructure, investigation saw that in the stirred zone of different conditions, inhomogeneous designs are shaped on account of inappropriate blending of Al/Cu that impact the tensile strength of the welded joint.
- Inter metallic mixtures are thin in the stirred zone of the utilized tapered tool, whereas brittle mixtures are found at the utilization of a cylindrical tool with a low rotational speed of 450 rpm.
- This report is tracked down that the tool pin geometry influences the nature of the dissimilar joint through the limit of mixing of material

between two dissimilar Al/Cu metals and demonstrated that blending of material more compelling when a tapered tool pin is utilized contrasted with a cylindrical tool pin.

- The most elevated tensile strength was acquired for welding states of tapper shaped WC tool with the speed of 710 rpm and feed rate 16 mm/min when pure copper is set on advancing side and least strength was found at cylindrical WC tool with the speed of 450 rpm and feed rate 16 mm/min.

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