Experimental Investigations of Mechanical and Microstructural Properties of FSWed Cu-Zn30 Joints

Pankaj, Ramesh Kumar Garg, Amit Goyal

Abstract*: The present work focuses on studying the effect of pin profile and tilt angle of the tool on the mechanical and microstructural characteristics of FSWed Cu-Zn30 brass joints. Three different pin profiles viz. Conical, threaded cylindrical and cylindrical were used to fabricate the joints at five different tilt angles viz. 0°, 1°, 2°, 3° and 4°. Fifteen joints were produced by different combinations of input parameters. The fabricated joints were tested for tensile, hardness and microstructural properties in order to explore the weld quality. The results of a current study clearly show that tool tilt angle and pin profile significantly affects the weld quality. Threaded pin profiled tool is observed to produce better quality joint at 3° tool tilt angle as compared to conical and cylindrical pin profiled tools. The results of mechanical testing were also correlated with the microstructural changes occur during the welding process.

***Index Terms*: FSW, Aluminium Alloy, Mechanical Properties, Microstructure.**

I. INTRODUCTION

Copper and its alloys, especially brasses (Cu-Zn alloys), are used in many of the industrial applications because of having combination of good mechanical, thermal and electrical properties like strength, wear resistance, conductivity, corrosion resistance, etc. [1-2]. Moreover, these properties may be easily altered as per the specific application by changing the Zinc content in the alloy. Thus, its demand for processing of brass parts is getting new peak day by day. Welding is one of the most commonly used manufacturing processes in the fabrication and processing of brass parts [3-4]. The joining of brass using conventional fusion welding techniques is a bit problematic, as it requires high heat input that can eventually lead to thermal distortion of the joints, higher oxidation rate and surface cracks [5]. Further, the Zinc content evaporates during the welding due to its low boiling point which consequently results in the formation of a weak copper oxide layer. Also, the vapors of zinc are toxic in nature and can be harmful to the person involved in the process [2]. The above discussed limitations and drawbacks motivate the technologists and researchers to develop alternate welding methods for joining copper-zinc alloys.

Friction Stir Welding (FSW) is a new welding method used to join light weight metals like magnesium, copper, aluminum and its compounds and furthermore thermoplastics. FSW was concocted by "The Welding Institute, Cambridge in 1991" [6]. It is a procedure of the joining of metals without filler materials beneath their liquefying point. A non-consumable cylindrical rotating tool is utilized in FSW, as shown in Fig. 1 [7].

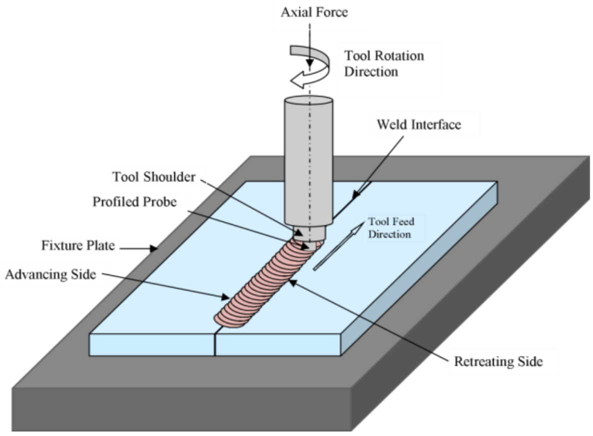

Fig. 1: FSW Principle - Schematic View

The tool has a round cross-segment at the shoulder and stick profile toward the end. The pin/probe dives into the workpiece and the shoulder is exposed to the top surface of workpiece. The rotating tool produces heat because of friction and softens the work piece materials. The welds are produced between the workpieces due to combine action of material flow mechanical deformation in this process. There are numerous components in charge of sound weld like welding speed, rotational speed, probe/pin profile, tilt angle of the tool, etc. The problems associated in joining the brasses with conventional fusion welding can be overcome using FSW as the heat input and peak temperature attained during the welding is much lower in FSW. Park et al. [8] investigated the impact of welding, tool rotational speed on the mechanical characteristics of FSWed CuZn40 joints, and reported a significant increase in the nugget zone hardness as compared to base alloy. Further, the grain refinement in nugget zone was observed at a rotational speed of 1000 and 1500 rpm. Meran and Kovan [9] analyzed the microstructural and mechanical behavior of FSWed copper and brass plates through tensile testing, microstructural observations and micro hardness testing of the joints. Emamikhah et al. [10] explored the influence of pin profiles of the tools during FSW of high zinc brass plates. The threaded pin profiled tool was reported best among all profiles used in the study. Sun et al. [4] investigated the effect welding and rotational speed of the tool on the weld characteristics of FSWed cu-Zn30 alloy.

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The rotational speed was varied between 750 rpm to 1200 rpm while the welding speed was varied from 200-800 mm/min at a constant heap of 1000 Kg. Emami and Saied [11] explored the impact of rotational and welding speed on FSWed joints of single-stage CuZn33.8 brass alloy. The joints were fabricated at welding and rotational speed of 100-300 mm/min and 400-800 rpm respectively. The results revealed that a rise in the rotational speed and simultaneous decrease in the welding speed increases the weld nugget grain refinement. The thorough review of literature reveals that FSW is having all the potential to be a better alternate in the joining of brass. Most of the research in this field is limited to studying the impact of rotational and welding speed on the FSWed joints of the brasses having different composition in terms of wt% of the zinc. The effect of tool pin profile and tilt angle on the cu-zn30 brass is yet to be studied. So the present work focuses on the analysis of influence of pin profile and tilt angle on the FSWed joints of 4 mm thick Cu-Zn30 brass plates. The mechanical and microstructural properties of the joints produced using different combination of input parameters are investigated in order to explore the weld quality.

II. MATERIALS AND METHODOLOGY

In the present work, 4 mm thick a Cu-Zn30 brass plate is used as the base material. Table I presents the chemical composition of the Cu-Zn30 alloy.

Table I: Chemical Composition of base Material

Element	Zn	Ni	Si	Sn	Fe	Mn	Cu
Wt%	29.91	0.002	0.008	0.001	0.004	0.013	70.06

H13 tool steel is used for the fabrication of the welding tools with three different pin profiles viz. Conical, threaded cylindrical and cylindrical. Six tools, two tools for each profile, are fabricated, as shown in Figure 2.

Figure 2: FSW tools

The specifications of the tools are presented in Table II. The tools were fabricated using CNC turning machine to ensure the tool parameters within allowable tolerances. After fabrication, the tools were hardened to 50 HRC by heat treatment to improve the wear resistance and life of the tool during FSW.

Table II: Specification of the Welding Tools

Tool Material	Diameter (mm)			Length (mm)		Profile of the pin
	Shoulder	Pin	Shank	Tool	Pin	
H13 Tool Steel	20	4	16	100	3.75	Conical, Cylindrical, Threaded Cylindrical

The workpiece of the size 130 mm x 75 mm were prepared for the experimentation. A special fixture was used to hold and positioned the workpieces during the welding. The welding was done on a vertical milling machine having auto feeding facility. The welding setup is shown in Figure 3.

Figure 3: FSW setup

Table III presents the combination of input parameters used for fabrication of the joints. The FSW parameters other than these two were kept constant as 900 rpm rotational speed, 0.1 mm plunge depth, 63 mm/min welding speed and 10 s delay/dwell time. Figure 4 shows all the 15 joints fabricated with different combinations of input parameters.

Table III: Combination of Input Parameters for Experimentation

Exp. No.	Tool Tilt Angle	Tool Pin Profile	Exp. No.	Tool Tilt Angle	Tool Pin Profile
1.	0°	Conical	9.	3°	Threaded Cylindrical
2.	1°	Conical	10.	4°	Threaded Cylindrical
3.	2°	Conical	11.	0°	Cylindrical
4.	3°	Conical	12.	1°	Cylindrical
5.	4°	Conical	13.	2°	Cylindrical
6.	0°	Threaded Cylindrical	14.	3°	Cylindrical
7.	1°	Threaded Cylindrical	15.	4°	Cylindrical
8.	2°	Threaded Cylindrical			

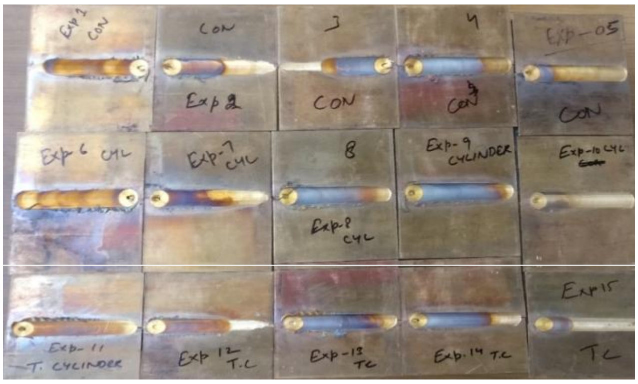

Figure 4: Friction stir Welded Joints of Cu-Zn30 Brass

The tensile test specimens were sliced out of the welded joints in a direction normal to the direction of welding so as to obtain tensile properties of the joints. Two specimens were prepared from each welded joint so as to minimize the experimental error.

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The mean value of two readings for a parameter is considered for further analysis. Figure 5 presents the prepared tensile test specimens. A hydraulic assisted UTM was utilized to perform tensile testing of prepared specimens. The tests were carried out at a low crosshead speed to ensure the uniform strain rate of the material. Ultimate tensile strength (UTS), Yield Strength (YS) and percentage tensile elongation (EL) were noted.

Figure 5: Tensile Test Specimens before and After Test

The fabricated joints were severed transversely to get the specimens for microhardness testing. The severed sections were polished to get a fine surface for the hardness testing. A semi-automatic Vickers's micro-hardness tester was used to perform the hardness test on the prepared samples. The diagonal of the indent made by the indenter, as shown in Figure 6, were recorded and hardness was calculated using the formula shown in equation 1.

$$HV = \frac{1.854 \quad F}{d^2} \quad \text{.....(1)}$$

Here F is load in, Kgf, d is the average length of the diagonal.

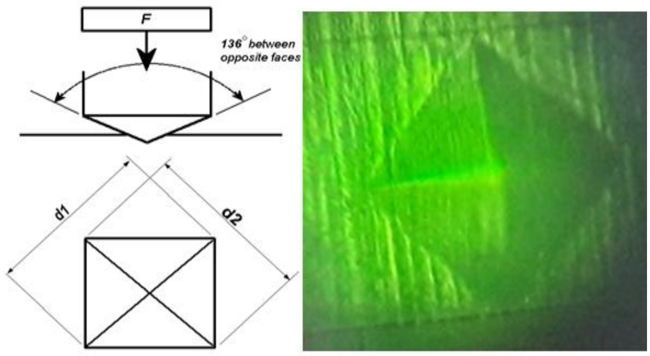

Figure 6: Indent Showing the Diagonal Length During Hardness Testing

The microstructural investigations of the fabricated joints were also carried out using optical microscopy. The samples for microstructural observation were prepared using a double disc polishing machine with emery sheets of different grit sizes, i.e. C400, C800, C1000, C1500, C2000. The final polishing of the samples was done using velvet cloth and alumina powder of very fine mesh of 1-3 µm. The polished samples were etched using a specially prepared etchant, having 50% of concentrated HNO_3 and rest 50% of de-ionized water, for 25 seconds.

III. RESULTS

The present work focuses on investigating the impact of tilt angle and pin profile on FSWed joints of 4 mm thick Cu-Zn30 brass. The weld quality of the fabricated joints was analyzed in terms of mechanical properties like tensile strength, microhardness and microstructure of weld nugget zone. The results of tensile testing of the specimens are depicted in Table IV.

Table IV: Tensile Test Results

Exp. No.	UTS (MPa)			YS (MPa)			EL (%)		
	S1	S2	Avg.	S1	S2	Avg.	S1	S2	Avg.
1.	317.6	315.1	316.35	240.4	244.9	242.65	4	5	4.75%
2.	327.9	340.8	334.35	248.3	255.8	252.05	4.5	6	5.25%
3.	330.8	342.9	336.85	251.5	258.3	254.9	6	5.25	5.62%
4.	332.7	344.6	**338.65**	267.8	262.6	**265.2**	7	6	**6.5%**
5.	344.8	329.9	337.35	266.1	261.4	263.75	6	6	6%
6.	298.8	305.8	302.3	248.5	241.8	245.15	6	4	5%
7.	337.7	324.8	331.25	257.5	262.6	260.05	5	6	5.5%
8.	325.7	340.5	333.1	276.8	279.9	278.35	5.5	6.5	6%
9.	343.4	353.5	**348.45**	303.4	308.2	**305.8**	8	8	**8%**
10.	340.9	328.2	334.55	281.7	275.1	278.4	6.5	7	6.75%
11.	265.7	252.8	259.25	240.8	243.9	242.35	4	5	4.5%
12.	309	330	319.5	241.4	246.5	243.95	5.5	5	5.25%
13.	342.7	334.7	338.7	243.3	247.7	245.5	5.5	5.25	5.62%
14.	354.4	340.5	**347.45**	271.4	273.7	**272.55**	6.5	5.5	**6%**
15.	349.3	343.4	346.35	273.8	267.1	270.45	5.8	5.6	5.7%
Parent	434.7	433.9	434.3	305.5	296.1	300.8	9	9	9%

Figure 7 shows the variation of UTS of the joints with pin profile and tool tilt angle. The UTS was observed to be lower at 0° tool tilt angle for all three pin profiles. It is also observed that UTS of the joints increases as the tilt angle increases from 0° to 3° irresepective of the tool pin profile. For conical pin profile, a very small increase in the UTS is observed for tool tilt angle 1° to 4°. The joint fabricated with a threaded pin profile at 3° tilt angle exhibited highest UTS among all the joints. At lower tool tilt angles, the joints fabricated with conical pin profile show higher UTS while at higher tool tilt angles threaded cylindrical profile have better joint strength.

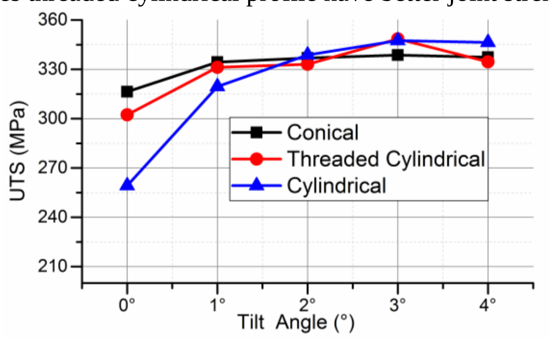

Figure 7: Effect of Input Parameters on UTS

Figure 8 shows the YS of the joints fabricated with different combinations of tilt angles and pin profiles. The joints made by threaded cylindrical pin profiled tool show better YS as compared to the counterparts for all values of tool tilt angle. For tool tilt angle <2°, the joints fabricated with conical pin profiled tool exhibits better YS than that of fabricated with cylindrical pin profiled tool. But for tilt angle 3° and 4°, the situation becomes reverse means, cylindrical pin profile performs better than conical pin.

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The joints produced at 3° tool tilt angle shows highest strength among their counterparts for all three pin profiles. The overall highest YS is observed with the threaded pin profiled tool at 3° tool tilt angle.

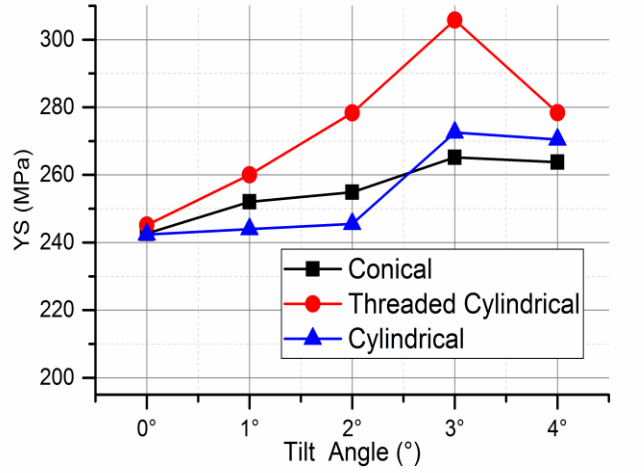

Figure 8: Effect of Input Parameters on YS

Figure 9 shows the % EL of the joints fabricated with different combinations of tilt angles and pin profiles. The joints made by threaded cylindrical pin profile tool shows better % EL as compared to the counterparts for all values of tool tilt angle. For tool tilt angle <2°, the joints fabricated with conical and cylindrical pin profiled tools shows approximate equal % EL that was less than that of joint made by the threaded pin profile. But for tilt angle 3° and 4°, the joints fabricated with conical pin have higher % EL than the joint made with the cylindrical pin profile.

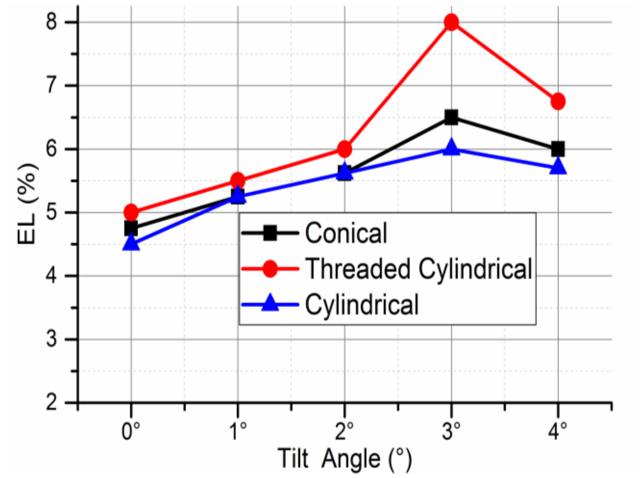

Figure 9: Effect of Input Parameters on EL

The microhardness test was performed on the welded joints to observe the length of the diagonals and finally the microhardness of the nugget zone. The indent was made at five different locations in the weld nugget zone; each time shifting the location by 1 mm. Table V shows the results of hardness test of the specimens. Figure 10 presents the microhardness of the weld nugget of the joints produced by different combinations of input parameters. It can be observed from the figure that weld nugget hardness increases with increase in tool, tilt angle from 0° to 3°, followed by a slight decrease in microhardness of weld nugget for further increase in tool tilt angle and this pattern is common for all pin profiles.

Table V: Results of Microhardness Test

Exp. No.	Avgerage diagonal 'd' (mm)					Mean Value "d"	Micro-hardness (HV)
	L1 (-2)	L2 (-1)	L3 (0)	L4 (+1)	L5 (+2)		
1.	.0815	.0807	.08	.08	.08	.0805	142.741
2.	.078	.0792	.0805	.08	.0795	.0793	147.094
3.	.0785	.0792	.08	.0787	.0775	.0786	149.725
4.	.0763	.0762	.0761	.0763	.0765	.0763	**158.00**
5.	.0785	.0767	.075	.0772	.0795	.0776	153.609
6.	.077	.0767	.0765	.0775	.0785	.0773	154.804
7.	.0781	.0776	.0771	.0767	.0763	.0771	155.608
8.	.0758	.0774	.0791	.0770	.075	.0766	157.646
9.	.0748	.0737	.0727	.0716	.0706	.0727	**175.014**
10.	.0747	.0753	.076	.0746	.0733	.0746	166.212
11.	.0777	.0775	.0774	.0775	.0777	.0776	153.609
12.	.0777	.0776	.0776	.0776	.0777	.0774	154.404
13.	.0772	.0771	.0770	.0770	.0771	.0771	155.006
14.	.075	.0752	.0755	.0770	.0786	.0763	**158.888**
15.	.0769	.0763	.0757	.0763	.077	.0765	158.058
Parent	.0772	.0771	.0770	.0770	.0771	.0771	155.006

The weld nugget hardness of the joint made by threaded pin profile was detected to be higher than rest two for all corresponding values of tool tilt angles. The highest weld nugget hardness was observed for the joint produced at 3° tool tilt angle with threaded pin profiled tool.

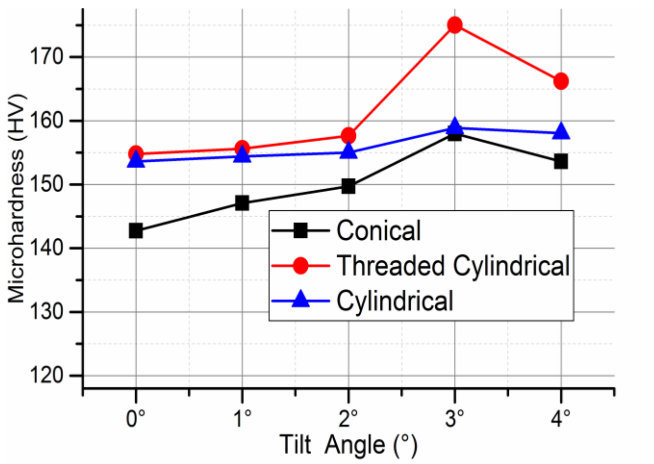

Figure 10: Effect of Input Parameters on Weld Nugget Microhardness

The quality of the joints fabricated with FSW technique mainly depends upon the softening and transporting of the material. The dynamic recrystallization of the soften material governs the grain refinement in the weld nugget area, which in turn controls the weld quality. At lower tool tilt angles, the excessive amount of heat input and turbulence in the flow of softening material results in deterioration of the strength properties. Also coarser grains were observed for the joints fabricated at lower tool tilt angles, as shown in Figure 11, which ultimately lowers down the weld nugget hardness and joint strength. At the high tool tilt angle i.e. 4°, the soften metals coming out of the nugget zone in the form of thin splashes creates tunnel defects in the weld bead which also deteriorates the weld quality.

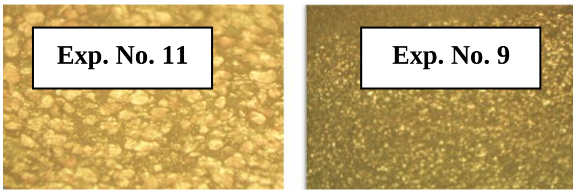

Figure 11: Nugget Grain Structure of Joint Fabricated in Exp. 11 and 9

For conical pin profile, lack of upward movement of the plasticized material lowers down the joint strength. Therefore, the proper combination of heat input and material movement during FSW, as obtained with threaded cylindrical tool at 3° tool tilt angle, leads to the formation of defect free joint exhibiting better harness and strength.

IV. CONCLUSIONS

The current research focuses on studying the impact of pin profile and tilt angle on the mechanical and microstructural properties of FSWed Cu-Zn30 brass joints. 4 mm thick Cu-Zn30 brass plates has been successfully welded using FSW technique. The fabricated joints were tested for tensile, hardness and microstructural properties in order to analyze the weld quality. The studied input parameters showed significant effect on the weld quality. Out of 15 joint produced with different combinations of input parameters, the joint produce with cylindrical pin profiled tool at 0° tool tilt angle showed least strength and weld nugget hardness. Threaded pin profiled tool is observed to produce better quality joint at 3° tool tilt angle as compared to conical and cylindrical pin profiled tools.

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