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Investigation of Mechanical Properties of Friction Stir Welded pure Copper Plates*

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Abstract

In conventional welding process, copper and copper alloys are difficult to welding because of high thermal conductivity and high melting point of copper. Due to high melting point, more amount of heat is required to weld the copper and due to high thermal conductivity, heat effected zone in the welded component increases so loses its mechanical and thermal properties. Friction stir welding is a new method that resoles the all above problems. Friction stir welding is a solid state joining process welding done at below the recrystallization temperature. The joint technique is a energy efficient, the environment friendly, easy and defect free welding process.

Purpose of this study is to find out the optimum mechanical properties of the friction stir welding of copper. Present study entails an attempt has been made to study the effect of tool rotational speed, traversing speed and tool pin profiles (straight cylindrical profile) on FSP zone transformation in copper. For two different tool rotational speeds, two different traversing speeds, one tool pin profiles have been used to fabricate the joints. The formation of FSW of copper of fusion zone has been evaluated and correlated with base metal. Tensile strength, toughness, hardness and microstructure of the joint evaluated and Tensile strength correlated with weld zone hardness and microstructures. The joints fabricated using rotational speed of 910 rpm, a welding speed of 30mm/min, tool pin with square profile, tool shoulder diameter of 34mm, (Ds/Dp)=3 showed higher tensile strength compared to other joints at a constant load.

The experimental results showed that the fracture locations of the joints are affected by FSW parameters, where copper joints are fractured in TMAZ and or in NZ/TMAZ interface on the retreating side of the welds and all fracture locations are nearer to the weld centres.

Keywords: : FSW, Welded joints, HS H13 tool, VMM, rotational speed and traverse speed

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1.Introduction

Fsw is a new technique developed by The Welding Institute (TWI) of UK in 1991. It is initially applied to the joining of aluminium alloys, and extended to copper alloys, steel alloys and titanium alloys.
The two primary functions of tool:

(a) Heating of work piece, and

(b) Material movement is to produce a joint.

Mishr et al. [1] Friction stir welding process and influence process parameters on mechanical properties
Won-Bae Lee, Seung-Boo Jung [2] studied mechanical properties of welded copper under various tools speed and feed. G.M. Xie, a, b Z.Y. Maa [3] studied the microstructure of welded copper under various process parameters Hwa Soon Park [4] studied he microstructure and mechanical properties of welded copper

2. Experimentation:

The main material used here is pure copper plates. The experimental study includes the butt joining of 5 mm pure copper plates. The welding process is carried out on a vertical milling machine (Make HMT FM-3, 10hp, 3000rpm). Tool is held in tool arbor. Special welding jigs and fixtures are designed to hold two plates of 130 mm X 70 mm X 5 mm thickness. These combinations are chosen based on the literature survey and the capability of the milling machine used for the experimental study. The schematic diagrams of tool used in this process. Welding speed and tool rotation speed are set on the machine. Table 2.1 shows the combinations of the tool rotational speed (RPM), welding speed (mm/min) and tool geometry and diameter of the tool shoulder to the diameter of the tool pin (Ds/Dp).Groove made on copper plate. The work material on which the friction stir welding is conducted is pure copper plates having 130 mm X 70 mm X 5 mm thickness dimensions.

Table 2.1 FSW process parameters of tool rotation, feeds, Traversing Speed, and pin profiles

Process Parameters	Values
Tool rotation speed (rpm)	910, 1130
Welding speed (mm/min)	30, 40
Axial force (KN)	Constant, 5KN
Pin length (mm)	4.5
Tool shoulder diameter, D (mm)	18mm
D/d ratio of tool	3
Tool pin geometry	straight cylindrical profile
Tool material	H13 tool steel

Non consumable tool made of H13 tool steel (Typical chemical composition is shown in the table3.3) is used to fabricate joints, and diameter of shoulder and pin used were 18 and 6mm and the length of the pin 4.5mm (depends on the plate thickness). The tools used for the present study are straight cylindrical pin with shoulder. A constant axial force is applied for the entire friction stir welding (FSW) experiments.

2.1 Experiment Process:

FSW is a solid state joining process carried out on a vertical milling machine. The plates to be welded are initially machined to the required dimensions and the process operations. Prior to welding initially, a hole is made using a drill bit that is fixed in the tool holder then the drill bit in the tool holder is replaced with the weld tool. Then the shouldered pin is rotated at constant speed and plunged into the joint line between the two metal sheets butted together. The direction of welding is normal to the rolling direction. Single pass welding procedure is used to fabricate the joints. Mechanical properties of base metal are shown in table 2.3.The welding parameters are presented in table3.4.Joints were fabricated using different combinations of rotational speed and welding speed. The photographs of the fabricated joints are shown in fig 2.2.1, 2.2.2, 2.2.3, 2.2.4.

Once the tool probe has been completely inserted the shoulder base will be in contact with the base metal surface so that it can take part in heating the metal surface for proper weld to occur. It is moved at constant advancing velocity along the welding line while rotating.

There are two tool speeds to be considered in friction-stir welding how fast the tool rotates and how quickly it traverses the interface. These two parameters have considerable importance and must be chosen with care to ensure a successful and efficient welding cycle. Due to the rotation and the advancing motion of the pin, the material close to the tool, in the so called stir-zone, is softened by the heat generated by the plastic dissipation (stirring effect) and the heat induced by the contact friction between the probe, shoulders and the sheet. As a consequence, the material is stretched and forged around the rotating probe flowing from the advancing side to the retreating side of the weld, where it can rapidly cool down and consolidate, to create a high quality solid-state weld. Each weld combination has been given its own nomenclature in order to avoid confusion of the weld speeds on the welds conducted.

2.2 FSW by applying Silicon Carbide as an Additive

.Silicon Carbide which is meant for its hardness is used here in two samples. Sic here helps in improving the hardness of the welded samples. Sample 3 and Sample 4 are welded with the use of additive. Sic here is taken in the form of powder. Groove is made in which the Sic is filled and then welding is conducted on the plates.

Figure 2.2.1Welded copper Plate at condition 1

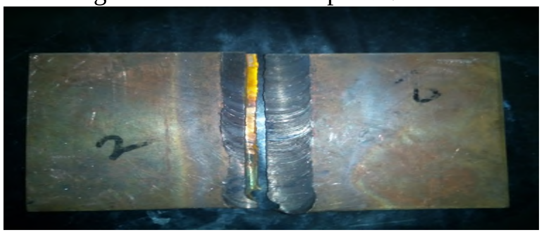


Figure 2.2.2 Welded cu plate at condition 2

Figure 2.2.3 Welded cu plate at condition 3

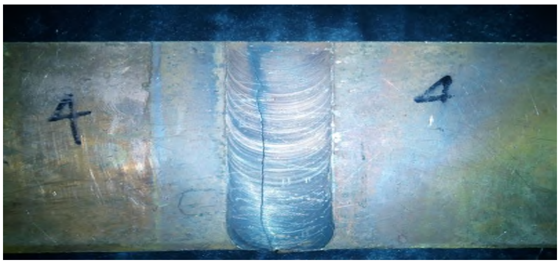


Figure 2.2.4 welded cu plate at condition 4

Table: 2.4 – welded conditions

Condition	Tool rotating speed(rpm	Welding speed (rpm)	Tool profile	Axial force(KN)	Joint status
1	910	30	Straight Cylindrical	5	Welded
3	1130	40	Straight Cylindrical	5	Partially Welded
3	910 Sic used	30	Straight Cylindrical	5	Welded
4	1130 Sic used	40	Straight Cylindrical	5	Welded

3.0. RESULTS AND DISCUSSIONS

During FSW, the material flow around the tool pin is due to the heat generated by the friction and stirring action. In fusion welding of copper, defects like porosity, slag inclusions solidification cracking etc., deteriorates the weld quality and joint properties. Usually, friction stir welded joints are free from these defects since there is no melting takes place during welding and the metals are joined in the solid state itself due to heat generated by friction and flow of the metal by the stirring action.

3.1 Effect of process parameters on mechanical properties of pure copper

The welding speed, the tool rotational speed, the vertical pressure on the tool, the tilt angle of the tool and the tool design are the main independent variables that are used to control the FSW process. The heat generation rate, temperature field, cooling rate, x-direction force, torque, and the power depend on these variables. Generation of temperature increases with increasing rotational speed and decreases with increasing welding speed. Peak temperature also increases with increase in the axial pressure.

3.2 Effect of tool rotational speed:

In FSW, tool rotation speed results in stirring and mixing of material around the rotating pin which in turn increase the temperature of the metal. It appears to be the most significant process variable since it tends to influence the translational velocity. In order to find the effect of tool rotational speed on the mechanical properties, two different speeds (910rpm, 1130rpm) were selected keeping in view of the speeds available in the retrofitted vertical milling machine at traversing speeds of 30mm/min, 40mm/min. At rotating speed 910rpm and traversing speed 30mm/min the joint was too good compared to other combinations.

3.3 Effect of Welding Speed:

The metal flow phenomenon in friction stir welding (FSW) comprises two modes of metal transfer. The first mode of metal transfer takes place layer by layer and is caused by the shearing action of the tool shoulder, while the second mode is caused by the extrusion of the plasticized metal around the pin. The rate of heating of thermal cycle during FSW is a strong function of the welding speed, to understand the effect of traversing speed on the weld quality and mechanical properties two different welding speeds were used to fabricate the joints. As the welding speed increased the mechanical properties obtained were very poor, due to the insufficient heat generation. The best mechanical property was achieved at 30mm/min.

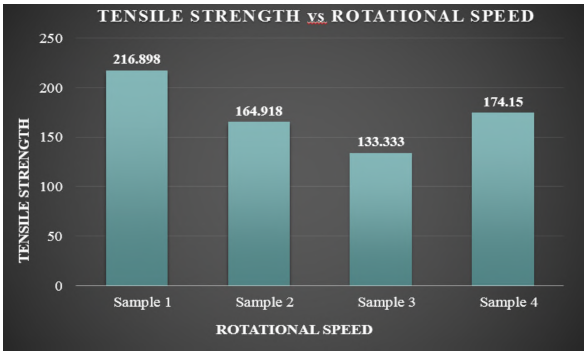
3.4 Mechanical Properties

3.4.1 Tensile Properties

The transverse tensile properties such as yield strength, tensile strength and percentage of elongation of the copper joints were evaluated. Various conditions at which the copper plates are welded are mentioned below in the table 5.1. Tensile strength & yield stress was observed at the fusion zone of copper welds at different tool rotation speeds i.e. 910rpm (1^{st} and 3^{rd} Samples with and without Silicon Carbide) and 1130rpm (3^{nd} and 4^{th} Samples with and without Silicon Carbide) and welding speeds of 30 mm/min (1^{st} and 3^{rd} Samples with and without Silicon Carbide) and 40mm/min (1^{st} and 3^{rd} Samples with and without Silicon Carbide).

Table 3.2.1 Various Conditions in welding the copper plates

Weld Samples	SAMPLE 1	SAMPLE 3	SAMPLE 3	SAMPLE 4
Tool Rotational Speeds	910 rpm	1130 rpm	910 rpm	1130 rpm
Traverse Speeds	30mm/min	40 mm/min	30 mm/min	40mm/min
Usage of Sic	–	–	Sic Used	Sic used



Graph 3.2.1 Tensile strength vs Rotational speed

The tensile strength of the unwelded parent metal is 334mpa of the joints fabricated by FSW process exhibited higher values compared to GTAW. The formation of fine grain microstructure, uniformly distributed fine precipitates and higher stir zone hardness are the main reasons for superior tensile properties of FSW joints.

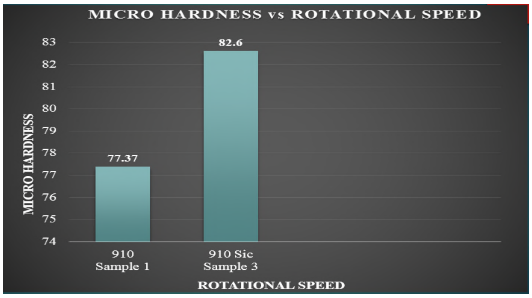
3.2.2 Hardness

The Brinell hardness tabulated below is the average of three impressions observed on each sample by using Brinell hardness machine (RAB-350) with the load applied of 350kgs.The Brinell hardness (BHN) is determined across the width of the transverse-sections of the copper weldments. There is a steadily decreasing hardness from the parental metal across the HAZ, minimum hardness near the HAZ/TMAZ interface. Hardness value reduces with increasing of tool rotational speed due to grain size increases.

The purpose for which the Sic is used is fulfilled. Highest hardness is recorded at the third sample where Sic is used. All the hardness values are tabulated below. The comparison graphs are also drawn for easy understanding as shown in Graph that shows the increased hardness while using Sic powder. Here the tool rotation speed and the welding speed are similar i.e. 910 rpm and 30 mm/min.

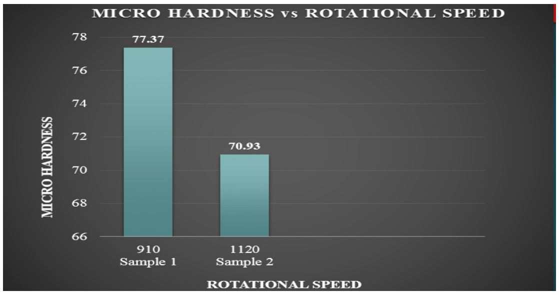
Table 3.2.2(a) Hardness values

Sample	Hardness
Weld Sample-1	77.37
Weld Sample-3	70.93
Weld Sample-3(Sic Used)	83.60
Weld Sample-4(Sic Used)	67.93

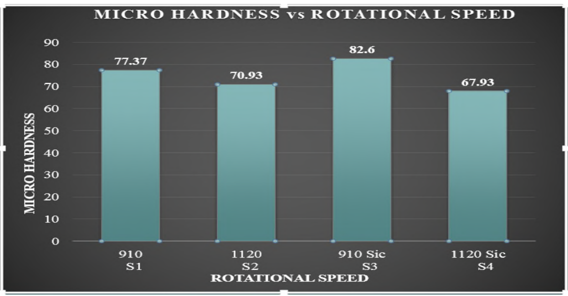


Graph 3.2.2(a) Sample 1 vs. Sample 3 (with Sic)

Graph 3.2.2(a): denotes that hardness value reduces with increasing of tool rotational speed and this is due to grain size increases.



Graph 3.2.2(b) Sample 1 vs. Sample 3 (Hardness Comparison)



Graph 3.2.2(c) Hardness by varying the Tool Speed

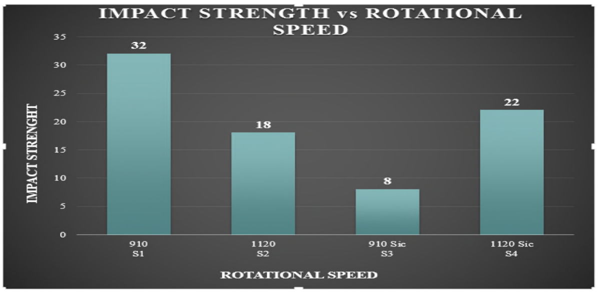
From the above graph we conclude that the hardness of the third sample where Silicon carbide is used has highest micro hardness when compared to other samples which are welded without the use of Sic powder.

The better hardness we get at 910 rpm and just reduced at 1130rpm but comparing microstructure of fine grain size is observed at 1130 rpm.

3.2.3 Charpy impact test:

Table:3.2.2(b) Impact strength

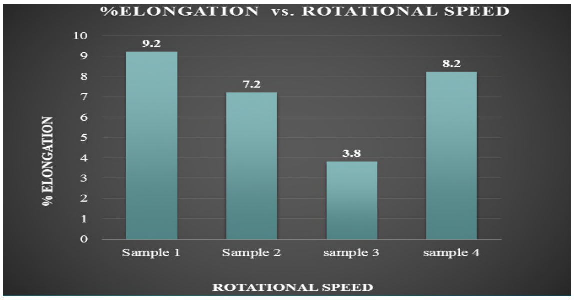
Sample	Value(Joules)
Weld Zone Sample-1	32
Weld Zone Sample-2	18
Weld Zone Sample-3	8
Weld Zone Sample-4	22



Graph 3.2.2(d) Rotational Speed vs. impact strength

Table:3.2.2(c) % Elongation

Sample	%Elongation
Weld sample-1	9.200
Weld sample-2	7.200
Weld sample-3	3.800
Weld sample-4	8.200



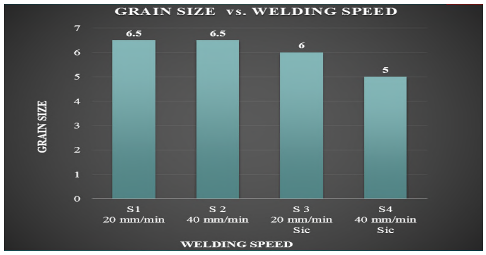
Graph 3.2.2(e) % Elongation vs. Rotational Speed

3.3 Microstructure study:

The sight of the top surface of the weld bead shows semicircular rings referred as banded microstructure. The deformed microstructure of the base material has been replaced by equiaxed grains with little substructure.The following results shows the microstructure analysis of the welded samples

Table 3.3(a) Grain sizes

Sample	ASTM Grain Size(μm)
Weld Sample-1	6.5
Weld Sample-3	6.5
Weld Sample-3	6
Weld Sample-4	5



Graph 3.3(a) Grain size vs. Welding Speed

The tool rotation speed and welding speed are the important factors that influence e the microstructure grain size. The following observations were studied:

Microstructure Results - Effect of Welding on Structural Properties of copper Assessment of structural properties at different zones of the weldments using optical microscope was carried out. Microstructure of base metal consists of fine precipitates. figure shows that the microstructure is having fine grains and the structure shows that the grains are equi-axed and equally spaced.

The small size grains are obtained in case of tool rotation speed of 1130rpm as compared to 910rpm in correlation with Tensile strength properties. Small sized grains crosswise over entire weld shows that, high friction input is responsible for heating the weld over the temperature of recrystallization where the grain development happens

If welding speed increases, generation of heat input decreases during welding. But grain size is depends on the developed heat input. From this information, grain size is increasing with decreasing welding speed. The below graph describes the information.

The microstructures of the four samples are shown below in the Fig 3.3.1, 3.3.2, 3.3.3, and 3.3.4

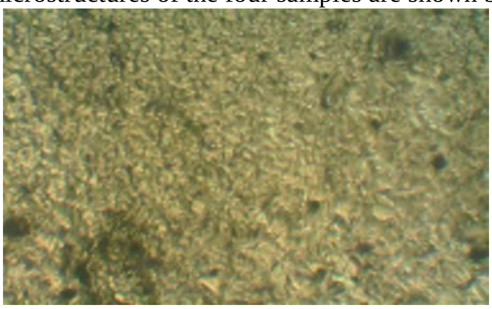


Fig 3.3.1.Micro Structure at 910rpm and feed 30mm/min

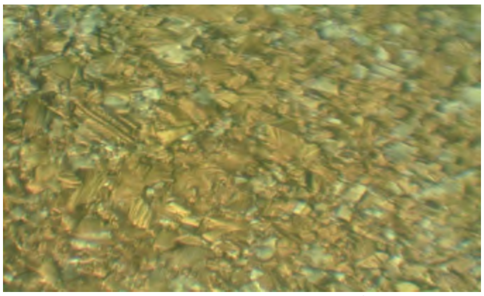


Fig 3.3.2.Micro Structure at 1130rpm and feed 40mm/min

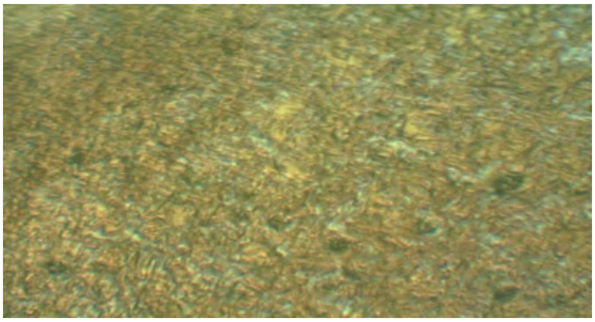


Fig 3.3.3 Micro Structure at 910 rpm and feed 30mm/min sic used

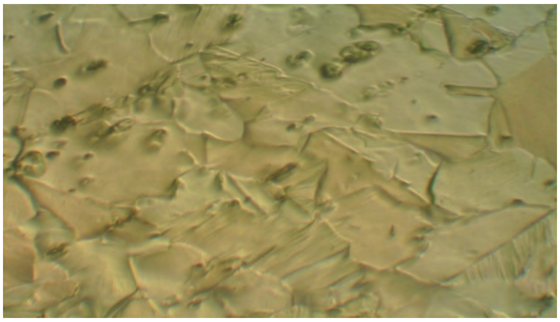


Fig 3.3.4 Micro Structure at 1130rpm and feed 40mm/min sic used

IV..CONCLUSIONS:

Friction stir Welding of pure copper was successfully obtained for different welding speeds, rotation speeds and the straight cylindrical tool profile.

At 910rpm tool rotation speed and 30mm/min traverse speed with straight cylindrical pin profile good mechanical properties were obtained. Joint efficiency is above 90%.

From the above graphs it is to be clear that the ultimate tensile strength is more at a tool rotational speed of 910rpm, because the heat input is sufficient at that condition and the grains were recrystallized and equi-axed.

From the graph the % Elongation is more for 910rpm i.e., 9.300% and it is less for 1130rpm.

The hardness value varied after the usage of Sic powder. Sample 3 recorded highest hardness which is welded by using the additive Sic.

Small grain sizes are obtained in case of 1130rpm when compared to 910rpm.

Highest Impact strength value is recorded for low tool rotation speed i.e. 910 rpm.

5. SCOPE OF FUTURE WORK:

The present investigation can be further extended to FS welding of other copper alloys, by adopting similar procedure.

Effect of other process parameters such as shoulder geometry, shoulder to pin diameter ratio, tool material etc. can be investigated.

The effect of multi-pass FS welding of various alloys and the characterization of the weldments can be done.

Tensile and wear behaviour of the FS welded joints can be investigated by using other tool pin profile such as threaded cylinder and try flute etc.

Further investigations on the forces generated during single and multiple passes for different alloys at different conditions and for different process parameters might be very beneficial.

The FS welding process can be simulated using finite element software's and the corresponding temperature distribution can be evaluated. Based on the effect of frictional heat generated on mechanical properties of FS welded joints can be investigated.

Corrosion behaviour on FS welded joints can be investigated.

Genetic algorithm may be used to optimize the process parameter of FSW.

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