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Influence of Welding Process on Microstructure & Mechanical Properties of Zinc Brasses

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Abstract- Dissimilar lap welded joints of copper and brass metals were fabricated by friction stir welding (FSW) method at various welding heat inputs. The effect of welding heat inputs on the microstructure and mechanical properties of overlap welded joints at two different join configurations (i.e. Advancing side and Retreating side joint configurations) was investigated. In both joint configurations, copper and brass plates are located on the top and bottom plates, respectively. Tensile-shear and wicker's micro hardness tests were conducted to evaluate the mechanical properties of dissimilar lap welded joint. In order to analysis of microstructure and fracture surface of lap welded joints, optical microscope (OM) and scanning electron microscope (SEM) were used. The obtained results showed that the weld surface of samples was appeared without groove defects, low superfluous flash and oxidation, when the welding heat input is increased. Onion ring pattern characterized by the stack of copper and brass metals is identified in the weld nugget zone (WNZ) where metal flow structures can be observed. With decreasing welding heat input, tensile-shear strength increased at both joint configurations. The highest hardness was exhibited in the WNZ with increasing welding heat input in both joint configurations.

Keywords: Friction Stir Welding; lap joint; Copper; Brass; Microstructure; Mechanical properties.

I. INTRODUCTION

Welding is one of the cheapest techniques of joining similar or dissimilar materials permanently using heat and pressure with or sometimes without a filler material.

During welding, the materials coalesce together at their contacting surfaces and a continuous metallic bond is formed. In other words, welding is defined as the homogeneous union of two or more surfaces under the influence of a thermal source.

Some factors like changes in the hardness due to rapid solidification in the weld zone, metallurgical changes and oxidation due to the reaction of atmospheric oxygen with the materials etc. effects the weld ability of a material.There are generally a number of welding processes that are used to join different materials, but are Broadly classified into two types.

1. Plastic/Pressure welding:
The work-piece metals are joined by heating to a plastically deformed state and then forcing them collectively by external pressure, example: resistance welding.

2. Fusion Welding:
The work-piece metals are joined by heating them to a molten state and allowing it to cool and solidify, example: arc welding.

3. Classification of welding processes:
- Gas Welding
- Arc Welding
- Thermo-Chemical Welding
- Resistance Welding

Friction Stir Welding (FSW), devised by W. M. Thomas et al. (PCT/GB92/02203 (Patent) December 1991) at

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The Welding Institute (TWI) Ltd. in 1991, overcome many problems associated with joining of materials using traditional welding techniques. FSW is a solid-state process that produces high quality welds in hard to weld materials like aluminium. It is emerging as a better alternate to fusion welding for fabrication of light transport structures like trains, boats and aircrafts.

Fabricators are under immense pressure to produce lighter and stronger products using less energy, at lower cost and avoiding environmental harmful materials at a fast pace. FSW works at a low energy input and is mechanically repeatable process highly proficient of generating high strength welds for a great range of materials and potentially at lower cost and environment friendly response to various challenges.

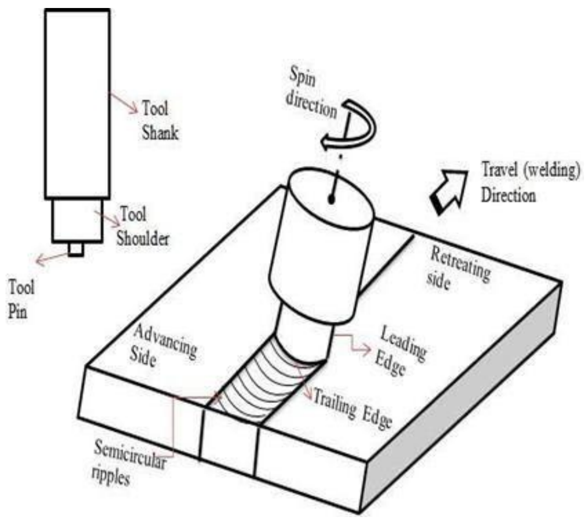

Fig 1. Principle of FSW for butt joints.

In FSW a cylindrical rotating tool having a concave shoulder with a profile pin/probe, is slowly inserted between two butted pieces along the joint line. The parts needed to be backed up by backing plates and properly clamped to withstand the welding forces. Frictional heat is created amid the tool and the work-piece material. Due to the heat generation the material gets softened and allows the movement of the tool pin alongside the joint line.

The maximum temperature that can be grasped/reached is about 0.8 time the melting temperature of the parent material. The plastically deformed material is transported from the front or leading edge to the back or trailing edge of tool pin and is forged by local contact of tool pin and its shoulder. A solid bond is left amid the two work-pieces.

It can be compared to keyhole welding as a hole is generated to give path to the tool pin and later filling the hole in the course of the welding sequence.

The rest of the paper is organized as follows. Section II introduces previous work & achievement of previous researchers and III gives the details of experimental work & IV tell results analysis of the proposed welding are discussed in Section IV. The conclusions are given in Section V.

II. RELATED WORK

Afshin Emamikhah et al. (2013) studied friction stir welding of high zinc brass. Micro structural tests were executed using optical microscopy (OM) and also the scanning electron microscopy (SEM) for assessing the morphology of the material. Also, temperature was calculated as function of time during welding. The results pointed a close correlation between the temperature and micro-hardness distribution as well as the consistency of microstructure. The study showed no dezincification and produced fumes.

Mehmet Erdem (2014) studied FSW of 3 mm thick copper and brass plates at varying rotational and welding speeds. A tunnel defect was observed in the SZ and on decreasing the heat input the micro-strain and mechanical properties were increased. Micro-hardness values were in the range of 87 HV – 255 HV in the SZ.

W.F. Xu et al. (2014) conducted strain-controlled fatigue tests on 2219-T62 aluminium alloy and evaluated the joints made with FSW at different welding parameters. The fatigue life slightly decreased with increasing welding speed from 60-200 mm/min. The rotational speed has a little effect on the fatigue life of the welded alloy.

Young Gon Kim et al. (2014) investigated the optimal welding conditions and the effect of the FSW factors on weld joint quality. The experiments were completed on a stir plate by using a Si_3N_4 tool on 1.4 mm thick steel (DP590) sheet. The relationship between the heat input for a unit length and development of the FS welded zone was meticulously analysed.

Gihad Karrar et al. (2014) presented the outcomes of studying FS butt welding of pure copper plates by means of both finite element analysis and experimental methods. The experimental research work of FSW of 4 mm Cu plates at a constant rotational speed was done to evaluate weld quality at different welding speeds. Weld superiority was evaluated by, micro-hardness, UTS and evolution of the developed microstructure. A finite element model had developed to mimic the FSW process for estimating the temperature distributions through the weld line and also the welding stresses. Temperature measurements and outcomes from the research had been used to authenticate the finite element model.

Esther T. Akinlabi et al. (2014) studied the influence of FSW factors on unlike joints between Al-alloy (AA5754) and pure Cu (C11000). The welds were formed by changing the feed rate from 50 to 300 mm/min and the rotational speed from 600 to 1200 rpm. The corrosion properties and the microstructure of the weld joints were investigated. The corrosion resistance of weld plates was enhanced with the increasing rotational speed. Rate of corrosion of the welds was improved as compared to the parent metal Cu and slightly decreased as compared to Al-alloy. The rate of corrosion was lowest at rotational and traverse/feed speed of 950 rpm and 300 mm/min respectively.

Y.F. Sun et al. (2014) examined the micro structural properties and mechanical properties of a FS welded CuZn30 brass alloy. The optimum FSW condition for the CuZn30 brass, which was resulted for a load of 1000 kg, involves a rotation speed ranging between 750 to 1200 rpm, and a feed speed ranged from 200 to 800mm/min.

S. Mironov et al. (2014) employed electron backscatter diffraction (EBSD) to examine the microstructure during FSW CuZn30 brass for a variety of welding temperatures. For all the cases, the microstructure was found to be administered by discontinuous re-crystallization followed via the bulging of the grain boundary and successive re-crystallization nucleation. This resulted in severe grain enhancement and substantial strengthening.

M. Felix Xavier Muthu and V. Jayabalan (2015) carried out FSW of aluminium and copper at several welding speeds in range of 500 mm/min – 90 mm/min. The defect free SZ was formed at welding speed of 70 and 80 mm/min at an optimal range of heat input. The tensile strength was observed as 113MPa with a joint efficiency of 70%. The high strength was because of the presence of Cu element above the Al material.

A. Salemi Golezani et al. (2015) done FSW of 7020-T6 Al alloy plates at varying rotational speeds (400, 600, 800 and 1000rpm) and a constant welding speed (100mm/min). At lower rotational speeds, hardness values and tensile strength increases but heat input decreases which in turn reduce the ductility.

Sajjad Emami et al. (2015) focused on the study of rotation and feed speeds on the microstructure properties and on the hardness of welds in FSW single-phase CuZn33.8 brass alloy. The welded joints were attained at rotation and welding/traverse speeds of 400 to 800 rpm and 100 to 300 mm/min respectively under low heat input. For weld characteristics, optical microscopy and Vickers hardness tests were performed on the weld sections. From the outcomes, decreasing the rotational speed and increasing the welding speed led the size of the grains in the stir zone (SZ) to reduce and had enhanced the mean hardness of this region.

Heidarzadeh et al. (2016) compared the micro structural and mechanical properties on both single and double phase FS welded brass (CuZn33) alloys. Microstructure of joints was inspected using scanning transmission electron microscope (STEM), optical microscope, X- ray diffraction, and scanning electron microscope (SEM).The end results had displayed that the size of the grains in SZ for single phase joint was greater than double phase alloy. The double phase joints had better strength but poor elongation as compared to the single phase joints.

Biranchi PANDA et al. (2016) introduced an experimental procedure to measure the tensile properties, explicitly the UTS and percentage elongation of weld AA7020 Al alloy. They suggested that at low heat input high UTS of the weld can be achieved as compared to weld at high heat input. Numerical models were used based on genetic programming and a functional relationship was produced between the tensile strength and three inputs (the rotation speed, the axial force and the welding/tool traverse speed). At 1050 rpm rotation speed and a feed speed of 95 mm/min high UTS was achieved with 8 KN axial forces fixed previously to

FSW.

Mica Grujicic et al. (2016) carried out combined numerical and experimental investigations of the mechanical properties of work metal existing in different zones of FS welded joints of AA2139-T8 Al plates. The weld region obtained in FSW of the metallic materials like aluminium and its alloys comprises typically demarcated zones, each characterised by fairly distinctive microstructures and properties.

Z. Zhang et al. (2016) concluded that the fatigue life for the tools used in FSW can be decreased by increasing the welding speed and increased by increasing the rotational speed using computational fluid analysis and finite element method. Also by increasing the shoulder diameter and the pin diameter fatigue life of the tool, used in FSW can be increased.

S. Shashi Kumar et al. (2016) investigated impact of tool material for FSW on the mechanical and microstructure properties of FS welded 316L stainless steel butt joints. The FSW experiments were conceded out using 600 rpm tool rotation speed, 45 mm/min feed speed, 11KN axial force and 1.5° tool tilt angle. The results had showed that the welds formed by using tungsten-lanthanum oxide tool had impressive mechanical and microstructure properties as compared to tungsten heavy alloy tool.

L.V. Kamble et al. (2017) explained that the FSW process is adopted for various non- ferrous metals like copper, aluminium and brass etc. and experiments are performed in a good manner but a rigid clamping is most important. They want to throw some light on systematic design of the fixture used for FSW. A flexible fixture should be fabricated considering various requirements of design and to accommodate different sizes and thickness of the material facilitating the researchers in performing FSW successfully.

S. Emamian et al. (2017) reviewed the development of the tool pin design and its effect on the micro structural and mechanical properties of the FS welded joint. After reviewing the papers, they observed that the square pin profile produces sound weld joints but threaded cylindrical pin profile was equally able to produce sound joints. FSW using threaded cylindrical profile provides better weld joints and are most effective in terms of tool performance.

Kush P. MEHTA, Vishvesh J. BADHEKA (2017) investigated FSW of dissimilar metals i.e. Cu and Al using nine distinct tool designs keeping other parameters constant. Metallurgical and mechanical tests were done to evaluate the properties of weld joints. The results revealed that the maximum weld strength was obtained by cylindrical tool pin profile. The polygonal tool pin profiles were found unsuitable for dissimilar friction stir welded butt joints. But tensile strength was increased if the number of polygonal edges were increased. Polygonal tool pin profile produces hard and brittle stir zone in comparison to cylindrical pin profile having same shoulder diameter. The maximum value of hardness was found i.e. 283 HV using square pin profile.

Suresh D. Meshram et al. (2017) welded merging steel and ultra-high strength steel using FSW process. Main problems occurring in fusion welding of steel were removed using FSW. It was found that friction stir welded joints showed higher resistance to stress corrosion cracking equated to both the base metal and the gas tungsten arc welded joints. Grain structure obtained was fine and there was no segregation of alloying elements as compared to conventional fusion welds. Thus FSW can be used as an alternative to the fusion welding process.

III. EXPERIMENTAL DETAILS

The material selected for FSW is high zinc brass (CuZn40) having dimensions 150 × 75 × 5 mm3. The material is tested at Narang Metallurgical and Spectro Services for its chemical composition. The properties of the work material are presented in Table 1 respectively.

Table 1. Mechanical & Physical properties of CuZn40 brass.

Sr. no	Property	Specification
1.	Density	8.41 g/cm^3
2.	Hardness	133.21 HV
3.	Ultimate Tensile Strength	472.75 MPa
4.	Yield Strength	358.05 MPa
5.	Percentage Elongation	28.5 %
6.	Young's Modulus	102 GPa

7.	Melting Point	904 °C

Fig 2. Work-piece Material.

FSW process is good enough to produce high quality welds but a number of process parameters are needed to be controlled for proper execution of the FSW process. From the literature, we come to know that the process parameters affect the material flow in FSW.

Tool geometry, design, welding parameters, heat input and forces acting on the tool etc. are important factors that influence the microstructure and mechanical properties of the work- piece. The important process parameters that are used in the FSW process for the project are given in Table 2

Table 2. Process parameters.

Parameters	Values
Tool tilt angle	0º to 3.5º (Variable)
Tool rotation speed	1120 rpm (constant)
Welding speed	50 mm/min (constant)
Delay time	10 sec (constant)
Plunge depth	0.1 to 0.2 mm

V. RESULT ANALYSIS

The tensile test was performed on UTM in the structural lab of the university; the I- sections were held in the jaws of the UTM with the help of a remote control. On successful holding the I-section samples, the load is applied gradually and the UTS and the percentage elongation of the samples are computed until it fails.

The results are shown in Table 4.2, i.e. the variation of the ultimate tensile strength (UTS) of different welds at different tool tilt angles. From the result, it is seen that at 0° and 0.5° the tensile strength of the FS welds is too low and the joint efficiency is also lower than 50 % of the parent metal. This was due to the presence of a tunnel defect in the weld plates joined at tool tilt angles 0° and 0.5°.

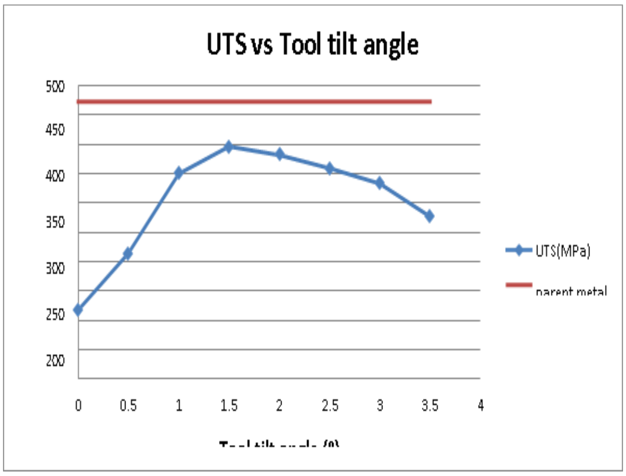

Fig 3. Variation of UTS w.r.t Tool tilt angle.

From the plot, it is seen that at very low tool tilt angles the tensile strength is low and it increases with the increase in tool tilt angle and is maximum for the welded joint at an angle 1.5°. We can also see that tensile strength is more than 70% of the parent metal for welds joined at tool tilt angles in range of 1° to 3°.

On further increasing the tilt angle, there is a decrease in the tensile strength i.e. at 3.5°. Thus, we can say that the high zinc brass (CuZn40) plates of thickness 5 mm at a tool rotation speed of 1120 rpm and welding speed of 50 mm/min should not be welded at tool tilt angles below 1° and above 3° i.e. a workable range for FSW of CuZn40 plates is between tool tilt angles 1° to 3°. Now we will see the variation of joint efficiency with tool tilt angle in comparison with the parent metal.

VII. CONCLUSION

The experiments performed using the tool pin design i.e. threaded cylindrical was successfully employed for the FSW of the CuZn40 brass plates. A tunnel defect was observed in the FS welded brass plates with 0° & 0.5° tool tilt angles caused due to improper forging force.

Therefore, resulting in poor tensile strength and joint efficiency less than 50%. The results from the tensile test showed that the tensile samples had a superior tensile strength and joint efficiency ranging from 270MPa – 396.1MPa and 50% – 83.8% respectively for all the tool tilt angles used except 0° & 0.5° (Due to presence of the tunnel defect). All tensile samples were failed at the thermo-mechanically affected zone (TMAZ) of the weld nugget except the sample welded at 0°.

The maximum tensile strength i.e. 396.1MPa and maximum percentage elongation i.e. 11.4% (for gauge length= 50mm) were observed for the weld joint fabricated with tool tilt angle 1.5°. The percentage elongation in the weld samples was less than that of the parent metal.

The maximum hardness i.e. 187.63 HV was observed for the weld joint fabricated with 2.5° tool tilt angle. The microstructure displays a basin like shape of the weld nugget. The grain size in the SZ and the TMAZ is finer in comparison to the parent metal and thus explains the increase in hardness of the weld zone than the parent metal. The microstructure shows a triangular shape void in the sample welded at 0° tool tilt angle resulting in a tunnel defect.

It is recommended to join CuZn40 using FSW in range of 1.5°–2.5° tool tilt angle at rotational speed and welding speed of 1120 rpm & 50 mm/min respectively.

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