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A COMPARATIVE STUDY ON SINGLE AND DOUBLE JOINTED CU-AL BIMETALLIC STRIPS USING FRICTION STIR SPOT WELDING PROCESS

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ABSTRACT

Welding is one of the best and quick process to join metals. In modern times, we concern more about environmental hazards due to hazardous gases liberated during conventional welding processes. Fiction Stir welding is a simple process in which a solid metal joint is produced by the heat of friction. In a similar technique, we can make spot welds of similar or dissimilar metallic joints by using Friction Stir Spot Welding. Since there is an absence of any liberation of poisonous gases, this method is safe to the environment and user. In this study, we made a dissimilar lap joint of Copper and Aluminium strips using an H13 steel tool. The pin profile of the tool is based on the thickness of the plate/weld. Weld based process parameters such as tool rotational speed, Dwell time and plunge depth. A lap joint with a desirable overlapping length between friction weld spots is compared and analyzed for mechanical bonding strength for both single and double joints. The results show a considerable increase in tensile strength for double-jointed specimen compared to a single-joint.

Keywords: *Friction stir spot weld; dissimilar weld joint; Bonding strength; green welding process*

1. Introduction

Friction stir spot welding (FSSW) has been developed based on the basic principles of linear FSW, without lateral movement of the tool. The FSSW process is illustrated in Fig.1[1]. The purpose is to spot weld two or more overlapping sheets by plunging the rotating tool at a specific rate until the shoulder makes contact with the upper sheet, while a stationary anvil provides backing support for the axial loads. In order to reach the desired temperature required for plastic flow, a short dwell phase is often useful, especially for high melting point materials. This dwell phase also increases the volume of deformed material and promotes material flow and mixing between the upper and lower sheet material [2]. The material around the tool is softened and plastically deformed to high strains during the plunge and dwell stages, and the tool movement in the vertical direction facilitates the flow of plasticized material in both circumferential and axial directions, which also helps to disrupt the oxide layer at the joint interface. Once the weld is formed, the tool is then retracted rapidly either once the target plunge depth is reached, or after a dwell period.

The combination of forging pressure, heating and material flow of the plasticized material produces an annular, solid-state metallurgical bond, which comprises a fine-grained microstructure with high-angle grain boundaries adjacent to the rotating tool. Similar to FSW, joining using FSSW also takes place by extrusion and forging of the material at high strain rates [3]. The complex interactions between the simultaneous thermomechanical processes which determine the heat and mass transfer, affect the heating and cooling rates, plastic deformation and flow, leading to recrystallization phenomena.

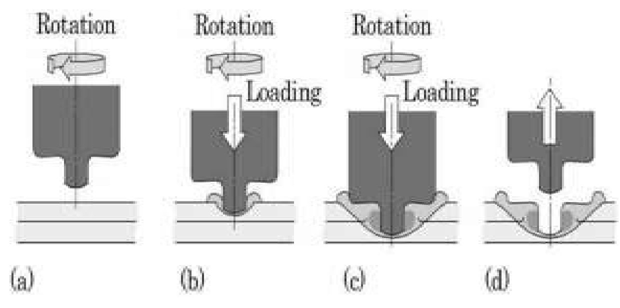

Fig. 1 Illustration of the FSSW process

The FSSW process is much more complicated in the sense that the actual welding time itself is shorter, but the process dynamics all focus on the transient stages of the tool plunge, material mixing and tool retraction. There is no tool advancing or retreating side, and the FSSW process can be considered to be

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axisymmetric due to the absence of the traverse movement.

1.1 Heat input during friction stir spot welding

During FSW, the tool moves over the base metal, stirring, deforming and mixing it. The parent material, the anvil and the tool increase in temperature due to the influence of the tool on the parent material. This variation in temperature is a clear indication of the heat generation caused by frictional contact that takes place during the welding process [4]. In FSSW welding, the heat input is calculated by integrating the torque curve, and then using the Equation 1 given below:

$$U = \frac{2\pi}{60}\omega\int_{t_0}^{t_s} T dt \qquad (1)$$

Where
ω: Tool rotation speed in rpm,
T: Torque in N-m
U: Heat input in Joules
t_0 and t_s: Tool contact and withdrawal time in seconds.

2. Literature Survey

Metallurgical Analysis of Al/Cu Friction Stir Spot Welding by Heideman [5] notified that when the rotational speed was increased from 1000 rpm to 2000 rpm, the weld strength was increased to 150% of the average weld strength. Also, when the pin length was increased from 1.83mm to 2.60 mm the weld strength was increased 70% of the produced average weld strength are produce at the rotational speed of 2000 rpm for the analysis of the high welding strength of the rotational speed.

Mukuna et al. [6] found that the copper ring length increased with the increase of the shoulder plunge depth, except for the spot welds produced at 1200 rpm, using a flat pin and shoulder, where a decrease was seen. It demonstrates that the welds produced at high rotational speed display either a decrease or a slight increase. It has been reported that the copper ring caused interlocking between the two plates and help the plates stick to each other through the tensile test, and this will result in reaching a high strength before failure. The shoulder plunge depth increased, the failure load increased, except for the weld produced at 800 rpm when using a conical pin and a concave shoulder. By increasing shoulder plunge depth, high strength welds were obtained.

Raheem et al. [7] stated that the heat generated equal to 50°Celsius in case of automatic process and 210°Celsius in case of the manual process. The dwell time to complete the welding process in case of automatic process reduced to be 14% of the time that consume in the case of manual welding process because the applied is twice the time of manual applied load.

From the literature survey, it is notified that there is a need for the comparative study of single and double-jointed strips to know whether any significant change in strength and stability while varying tool rotation speed.

3. Experimental Details

3.1 Design and Fabrication

Tool design features such as geometry or tool material, and process parameters including rotational speed, plunge rate, plunge depth and dwell time are critical to the success of the FSSW technology, since these factors significantly affect heat generation, material flow, torque, axial force, weld integrity and tool degradation mechanisms [8]. Low heat generation and insufficient material flow could result in defects such as voids, lack of bonding, incomplete refill, or inadequate bonded areas. However, with higher heat input, grain growth, or excessive softening of the surrounding HAZ occurs as a result of precipitate dissolution. In order to explore the optimum tool design and process [9] parameters, it is vital to gain a better understanding of mechanisms influencing these factors.

3.2 Tool

A unique tool with H13 was used as given in Fig. 2. The dimension of the tool is shoulder diameter 18mm, pin diameter 5.5mm, major diameter 20mm, pin length of 5mm. Milling machine type HMT Fn3V with a spindle rotation speed between 25.5 to 1800rpm with some modification in the vice to make the lap joint [10].

3.3 Materials Used

Copper (C11000) flat plat and Aluminium (AA1100) flat plat are been used for joining. Two different size of plates of 25mm*100mm for single spot weld and 25mm*120mm for double spot weld [11]. The flat plate of Cu alloy and Al alloy is of 3mm thickness each. Before welding, the specimens should be cut with shear off machine and surface grounded to remove unwanted layers of oxides and formed scales. The properties of base alloys are follows Cu (90.73% Cu, 9.15%Zn,0.01%Ti, 0.02% k) and Al (0.25% Zn, 0.15&Ti, 0.7%Fe, 0.15%Cu, 0.33% mm, 0.53% Si, 0.69% Mg, 95.8%Al) [12]. The material properties of Copper and Aluminium are shown in Table 1.

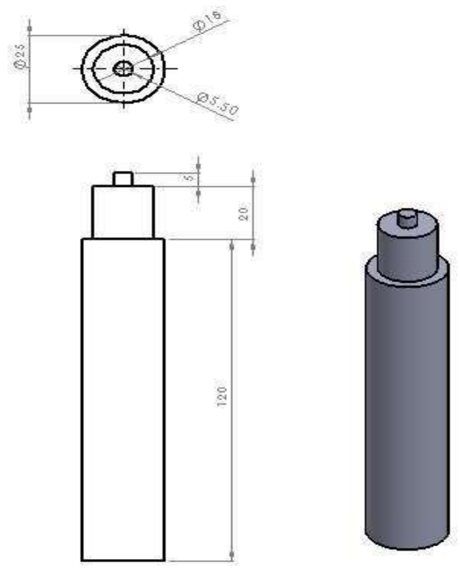

Fig. 2 Tool used to carry out the spot weld

Table 1 Mechanical Properties of Copper and Aluminium

Metal	Hardness HV	Tensile Strength Mpa	Yield strength MPa	Elongation %
Cu	50-65	90-135	34-150	9.9-25
Al	55-115	210-310	-	7-40

3.4 Design of Modified Fixture

For proper support and to tackle dynamic forces, it is essential to provide firm support to the metal pieces. A unique fixture, as shown in Fig. 3 has a vice-like arrangement firmly fixed with long bolt and nut and tightened to avoid lateral movement during high rotation of the tool. Since the process uses friction to produce joint, to give stability and withstand a high amount of vibration, a unique fixture is required [13].

3.5 FSSW PROCESS PARAMETERS:

Dwell Time: The period of time after the rotating tool has been plunged into the work, and for which it remains stationary, generating frictional heat and plasticizing the materials, before commencing the traverse along the joint (seconds).

Axial Load: The Load with which the tool is pressed towards the specimen.

Overlapping Length: This amount of overlapping between two bars is called “lap length”. Lapping is usually done where minimum bending stress is encountered. Overlapping length for the single spot is 25mm whereas in the double spot is 45 mm.

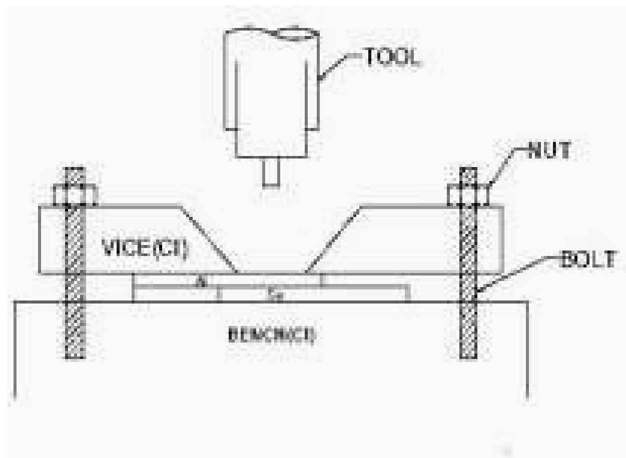

Fig. 3 Schematic diagram of the modified fixture.

Speed (rpm): It is defined as the number of revolutions at which the spindle rotates per minute. 900, 1120 and 1400 rpm speeds are used for both single and double joints.

Single spot: There will be only one weld spot with the overlapping length of 25mm.

Double spot: There will be two spots with an overlapping length of 45 mm.

The single and double spot welded pieases are illustrated in Figs. 4 and 5 respectively.

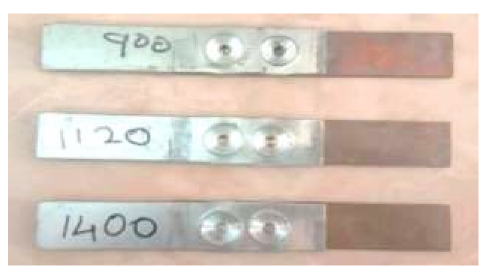

Fig. 4 Single spot-welded pieces at the speeds of 900, 1120 and 1400 rpm

Fig. 5 Double spot-welded pieces at the speeds of 900, 1120 and 1400 rpm

4. Results and Discussion

From the SEM images and the result of transverse tensile strength, analysis results are made and discussed as follows. For easy identification and good understanding, the samples with different speeds are named and identified as below:

A-900 rpm Single Spot
B-900 rpm Double Spot
C-1120 rpm Single Spot
D-1120 rpm Double Spot
E-1400 rpm Single Spot
F-1400 rpm Double Spot

4.1 Comparison of (A) And (E)

While comparing the maximum and minimum speed of Single spot weld, we see the images of SEM analysis of 900 rpm single spot (A) and 1400 rpm single spot (E) are compared below.

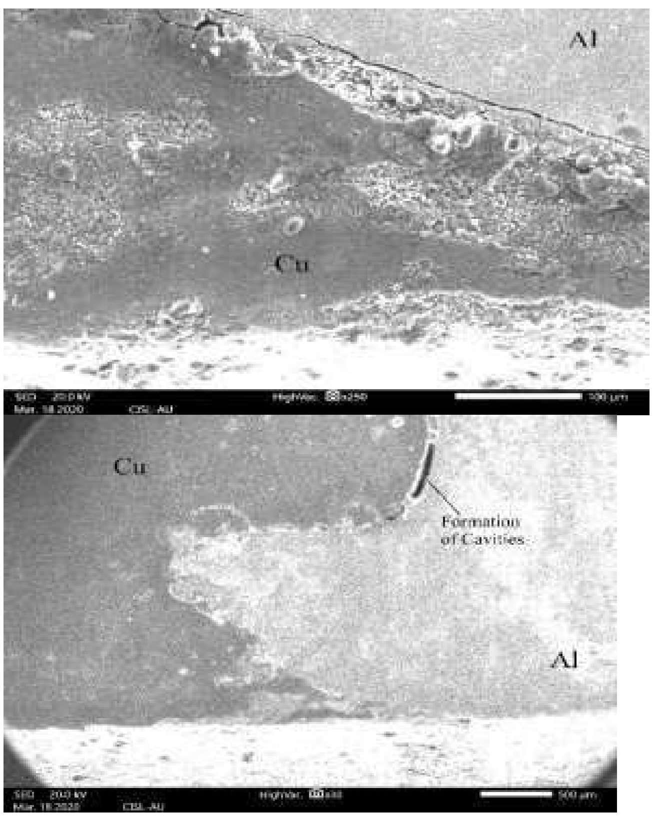

Fig 6. A (900 rpm single)

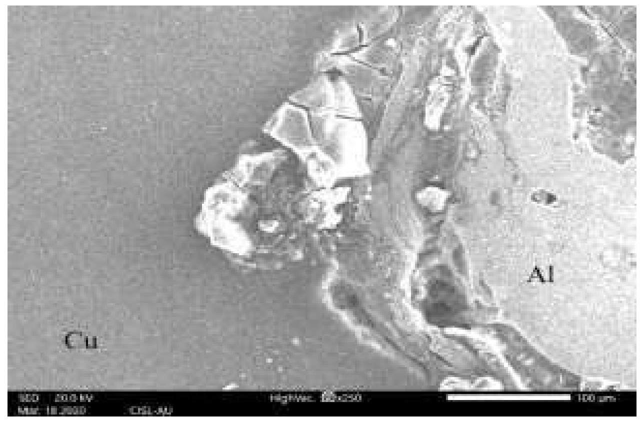

Fig 7. E (1400 rpm Single)

The formation of cavities and unsatisfied bonding is seen in Fig. 6 than Fig. 7. The transverse tensile strength result of (A) and (E) is 29.20 N/mm^2 and 38.27 N/mm^2 respectively. From this comparison of tensile strength report and SEM images, it is found that more diffusion and good bond strength is occurred in (E) than (A) due to increasing the speed of tool rotation. Hence, it is studied that tensile strength increases in increasing tool rotation.

4.2 Comparison of (A) and (B)

While comparing Single and Double welds at the minimum speed of 900 rpm, we observe that the image of SEM of 900 rpm single spot (A) and 900 rpm double spot (B) weld is compared below:

From these images, Fig. 7 has more cavities, oxide layers are present at the interface and micro-cracks are formed near the nugget or hook region than Fig. 8. The tensile report also says that the tensile strength of (A) is 29.20 N/mm^2 and (B) is 78.40 N/mm^{2,} respectively.

From this comparison of tensile strength report and SEM images, it is seen that the cavities, cracks and weld defects are less in (B) than (A) which shows that (B) is with good strength and gives satisfactory weld.

Hence, it is observed that strength and efficiency increase with the increase in the number of welds.

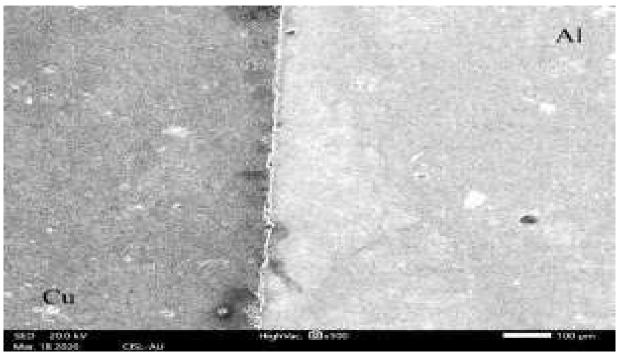

Fig 8. B (900 rpm double)

4.3 Comparison of (B) and (F)

The SEM images of 900 rpm double spot (B) and 1400 rpm double spot (F) is seen as follows:

From the Fig. 9 and Fig. 10, it is seen that better diffusion took place and mechanical interlocking is more in Fig (F) due to increase in speed and due to the increase in the number of welds. On comparing the tensile strength of (B) and (F), (B) has 78.40 N/mm^2 and (F) has 80.80 N/mm^{2,} respectively. From these results of tensile strength report and SEM images, it is found that (F) has better mechanical interlocking, good strength than (B). Hence, among all-welded samples (F) has a better diffusion process, proper bonding and high tensile strength due to an increase in the tool rotation speed and a greater number of welds.

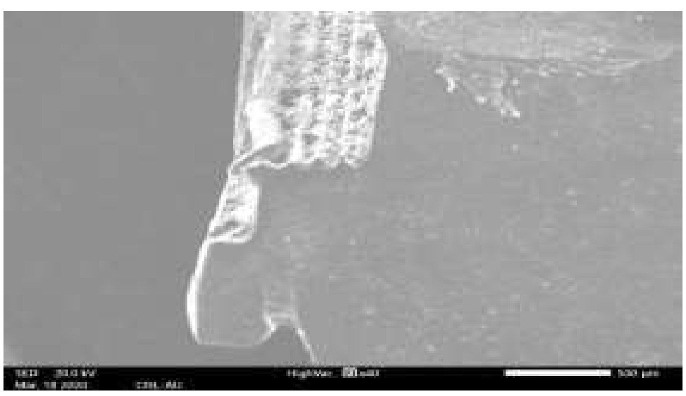

Fig 9. B (900 rpm Double)

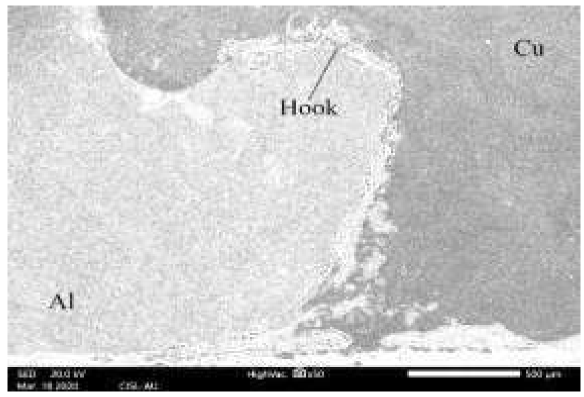

Fig 10. F (1400 rpm-Double)

4.4 Comparative Graph Between Single and Double Spot Welds

Table 2 illustrate the Tensile strength for the various rotational speed.

Table 2 Speed Vs Tensile Strength

Speed	Tensile strength (N/mm^2)	
	Single	Double
900 rpm	29.2	78.4
1120 rpm	43.6	84.4
1400 rpm	38.27	80.8

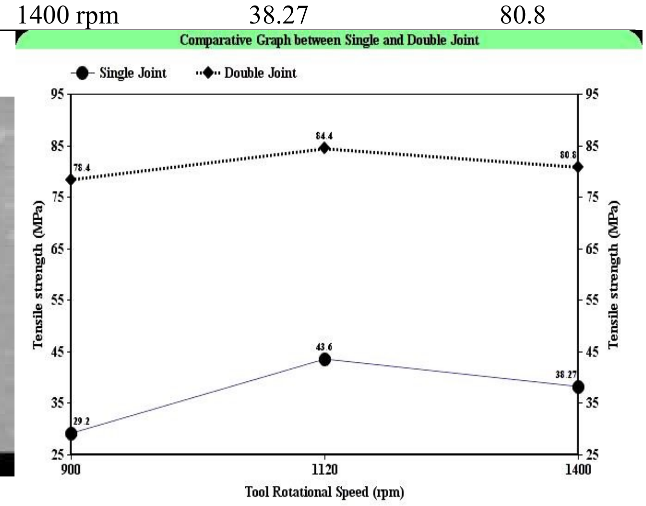

Fig. 11 Tensile strength Vs Tool Speed

Fig. 11 shows that the tensile strength and tool rotational speeds are directly proportional to each other. However, we see that the strength is maximum at a tool rotational speed of 1120 rpm.

5. Conclusions

The inferences of the microstructure analysis of Cu and Al bimetallic lap joint using Friction Stir Spot welding process with the help of Transverse Tensile testing, Scanning Electron Microscopy and Energy Dispersive spectroscopy are presented below.

i. Increase in tool rotation speed will increase in mechanical strength and high transverse tensile strength.
ii. Increase in a number of welds will give more mechanical interlocking and also more tensile strength.
iii. The optimum distance between the two consecutive welds in the case of double Joint can be tested and verified by conducting a greater number of experiments to fix the strength factor as future scope of work.

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