MECHANICAL PROPERTIES OF FRICTION STIR WELDED DISSIMILAR METALS

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Abstract
The aim of present study was to analyse the influence of the microstructures and mechanical properties of friction stir welded butt joint of 6101 aluminium alloy and pure copper plates in 3 mm thickness. With this aim, welds were produced using Tungsten Carbide tools, with a cylindrical pin tool having 5 mm and 20 mm diameter of pin and shoulder respectively. Copper plates were kept in advancing side of weld. The microstructure of weld was studied by optical microscopy and grain size in different regions were analyze. Vicker’s microhardness test (as per ASTM E384-89) were done in transverse direction of weld to check the hardness distribution in weld nugget. Transverse tensile test (as per ASTM E8 M) were performed to evaluate the weakest portion of weld joints. Scanning Electron Microscope were used to observe the fracture surfaces. EDAX analysis were done to find out the mixing characteristic of two metals.

Key words: Friction Stir Welding, Aluminium alloy, Pure Copper, Hardness, Tensile testing

1. Introduction
The joints of dissimilar materials are widely used in industrial applications due to their technical and beneficial advantages [1]. Aluminium and copper are two common metals in the electric power industry, and the Al–Cu transition pieces are widely used to Transmit the electricity. Due to the difficulties in making an electrically stable bolted joint between these two dissimilar metals, much effort has been focused on welding aluminium to copper in the last decades [2]. However, the dissimilar combination of aluminium and copper is generally difficult for fusion welding. This is because of the wide difference in their physical, chemical and mechanical properties, and the tendency to form brittle intermetallic compounds (IMCs). Therefore, the solid-state joining methods, such as friction welding, roll welding, and explosive welding have received much attention [2–7]. These methods, however, have a few drawbacks. For example, friction welding and roll welding lack versatility, and explosive welding involves in the safety problems. In the past decade, much attention has been directed towards friction stir welding (FSW) [8]. Recently, attempts have been made to join dissimilar materials through FSW, such as aluminium to steel, aluminium to magnesium, and aluminium to copper [9–16]. It was reported that sound dissimilar FSW Al–Cu joints were difficult to achieve, and the joints usually failed at the nugget zone or along the TMAZ.

2. Difficulties in Welding of Copper to Aluminium
Copper and aluminium are widely applied in engineering structure due to unique performances such as higher electric conductivity, heat conductivity, corrosion resistance and mechanical properties. However, the melting points of both materials have a significant difference (nearly 400 °C). This may lead to a large difference in microstructure and performance of Cu–Al joints if copper and aluminium would be joined. Moreover, the Al was easily oxidized at an elevated temperature, and some welding cracks existed easily in a joint of brazed or fusion welding Cu [1]. Therefore, a high quality weld joint of Cu/Al was difficult to obtain by means of conventional welding methods. During fusion welding or pressure welding (brazing, diffusion bonding, etc), the Cu-Al intermetallics, which resulted in decreased mechanical properties of joints, is very difficult to be avoided in Cu/Al dissimilar materials joint [2,3].

3. Experimental Setup
The plate size of aluminium and copper are same and having 150 mm length, 50 mm width and 3 mm thickness. Tungsten Carbide tool having shoulder diameter of 20 mm and pin diameter of 7 mm. Detail of Tool are given in Table 1. Two welding sets were taken for welding of aluminium-copper plates as given in Table 2.

4. Welding
Prior to welding, joint preparation were used when needed by machining, grinding and cleaning (with acetone) of the surfaces to be weld. The plates were clamped tightly against each other by indigenously designed and fabricated fixtures and on the backing plate. The axial plunge depth was manually controlled by dial gauge
indicator. tool tilt angle were kept constant and it is around 1.5°. Initially trial welds were conducted with bead on plate configuration using different welding parameters to set a range of suitable welding parameters for our final welds.

5. Sample preparation
The welded pieces are first cut in the transverse direction of weld in required dimensions. Sample for microstructural analysis were polished with different grades of waterproof SiC polishing paper ranging from grade 220 to grade 2000 and finally polished on soft cloth with alumina paste.

<table>
<thead>
<tr>
<th>Weld</th>
<th>Rotation Speed (rpm)</th>
<th>Welding Speed (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld 1</td>
<td>125</td>
<td>50</td>
</tr>
<tr>
<td>Weld 2</td>
<td>710</td>
<td>355</td>
</tr>
</tbody>
</table>

6. Optical Microscopy
Optical microscopy was performed using Leica microscope. Samples were first dipped in a polishing solution containing 55ml orthophosphoric acid, 25ml acetic acid and 20 ml nitric acid heated to 70 °C. Then the polished sample were washed in water and then etched with a solution containing 100 ml water, 50 ml hydrochloric acid and 5gm ferric chloride.

7. Hardness Measurements
Leica’s Vicker’s micro hardness tester was used to measure the micro hardness of welded samples. The hardness were measured along the transverse direction of the weld in centre. Indentation force used was 100 gm and indentation time was 10 seconds, step size used was 0.3 mm (as per ASTM E384-89).
8. Tensile Tests
The transverse tensile tests of 3 mm thick Cu/Al FSW welds were performed using an MTS 810 testing machine according to the standard SFS-EN 895. The standard is for fusion welds, but it is applicable also for friction stir welds. Subsize transverse test specimens according to ASTM E8M-11 were used. The strain rate was $1.6 \times 10^{-3}$/s. Three samples were tested in each of weld and average is presented. Fig.1, shows the geometry and dimensions of the sub-size transverse tensile test specimens.

![Fig.1 Sub-size transverse tensile test specimens.](image)

9. Results and Discussion
9.1. Welds Obtained
Welds were obtained according to the experimental design. All welds were defect free. The intermixing of metals were also found in the welded samples. During the FSW process, the materials were transported from the retreating side to advancing side behind the pin where the weld was formed. Hardness of the copper was larger than the aluminium, and due to the pin stirring action the aluminium get displaced in the weld.

9.2. Microstructural Characteristics
Microstructure of weld shows distinguish feature in different zone (Fig.2). At the weld centre line mix region of Aluminium and copper were found. Small particles of aluminium and copper were distributed in opposite side by the stirring forces of tool. Thermo mechanically affected zone (TMAZ) is clearly obtain in Copper but it were not found in aluminium. In both the metals Heat affected zone (HAZ) is not clear.

9.3. Hardness Measurements
Fig.3 shows the horizontal hardness profiles of the Cu/Al FSW welds. In the horizontal hardness profiles the hardness values were found to be around 106 for copper base metal & 110 for aluminium base metal. The hardness value was stable for the both metal in HAZ and tendency to increase in the nugget zone and it may due to the formation of intermetallic compound. Sample 1 showed the highest hardness values for the nugget zone, which was found to be around 127. Other samples had hardness values of around 85-120 in nugget zone.

![image](image)
Fig. 2 Microstructure of (a) NZ and (b) TMAZ.

Fig. 3 Hardness profiles horizontally along the centre line of the sample.

9.4. Tensile Test
Average tensile properties of friction stir weld joints of Cu/Al are given in Table 3. Sample 1 has the higher ultimate tensile strength of 138.7 MPa than sample 2 (135.5 MPa). Sample 2 had the higher strain of 3.1% while sample 1 have lower strain of 2.4%.

<table>
<thead>
<tr>
<th></th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Yield Strength (MPa)</th>
<th>Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>138.6</td>
<td>100.31</td>
<td>2.4</td>
</tr>
<tr>
<td>2</td>
<td>135.5</td>
<td>91.92</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 3: Tensile test data
10. Conclusions
All welds were defect free and no tool metal inclusions were seen by optical microscopy. Microstructures of weld were shown different regions, like TMAZ and Nugget Zone. Microhardness in weld nugget is higher than base metal and no significant difference found in other regions. Tensile strength of weld is very poor as compare to both of the base metals and all welds were fail from nugget zone. The ductility of is also very poor and comparable to the base metals.

References: