The Joint Properties of Pure Copper by Friction Stir Welding

L. Suvarna Raju, Dr. Adepu Kumar and Dr. P. Indreswaraiah

Abstract--- In conventional welding process, copper and its alloys are very difficult to weld because of high thermal diffusivity and high melting point. To overcome the problems encountered in conventional welding process, friction stir welding (FSW) is used. FSW is a solid state welding process and the welding is done below the recrystallization temperature of the materials. The main objective of this investigation is to apply FSW for joining of 3 mm thick copper sheet using taper cylindrical tool pin profile. The defect free welds were obtained at a tool rotational speed of 900 rpm and traverse speed of 25, 31.5 and 40 mm/min respectively. Mechanical and microstructure analysis has been performed to evaluate the characteristics of friction stir welded copper. From the investigation it is found that the joints fabricated at traverse speed of 40 mm/min resulted in better mechanical properties compared to other traverse speeds. The tensile properties of all weld joints showed a relative correspondence to the variation of the hardness in the weld zone. The observed results were correlated with the microstructure and fracture features.

Keywords--- Friction Stir Welding, Copper, Mechanical Properties, Microstructures, Fractography

I. INTRODUCTION

Copper and its alloys are most important engineering materials due to their good ductility, corrosion resistance, electrical and thermal conductivity [1]. Welding of copper is usually difficult by conventional fusion welding processes because of copper's high thermal diffusivity (401 W/m. K). FSW is one of the solid state welding process in which a non-consumable rotating welding tool pin is plunged into the joint line between the two plates that are to be welded together. The shoulder makes firm contact with the top surface of the work piece, so that the frictional heat is generated by the tool shoulder. Due to this frictional heat, surrounding material softens and allows the tool to be involved along the joint line [2]. The material is plasticized and translated along the welding direction and this plasticized material is transported from the leading edge to the trailing edge of the tool where it is forged into a joint and leaving a solid phase bond between the two plates [3]. FSW is energy efficient, environmentally friendly, less distortion, faster welding speeds than traditional fusion welding techniques and to join materials that are difficult to fusion weld [4]. The copper is used in containment canisters for nuclear waste has been manufactured via FSW process [5]. Fabrication of backing plates of copper alloys were used for the sputtering equipments [6]. The shape of the tool pin profiles influences the flow of plasticized material and affects weld properties [7, 8]. Elangovan et al. [9] studied five tool profiles i.e Straight cylindrical, threaded cylindrical, taper cylindrical, square and triangular, for the welding of AA 60601 aluminium alloy and found that the square pin profiles tools produces defect free welds for all the axial forces used. Similarly, Lee et al. [10] achieved defect-free joining of 4-mm-thick copper plate at a rotation rate of 1250 rpm and a traverse speed of 61 mm/min. The investigation by Hautala and Tiainen [11] also indicated that 5-mm-thick copper plates could be successfully welded with rotational speed more than 800 rpm.

In this present study we explored the FSW of pure copper. This study specially characterized the friction stir welded joints and compared the microstructures of the copper base metal using optical microscopy. Microhardness profiles through the weld zone and corresponding tensile strength test data were also correlated with these microstructures and fracture features.

II. EXPERIMENTAL PROCEDURE

The base metal copper sheet of 3 mm thick and size 200 mm x 100 mm was welded by butting two plates and stirring them together with a rotating tool assembly by using vertical milling machine. Schematic sketch of weld joint and tool is shown in Fig. 2.1. H-13 tool steel is chosen as tool material because of its high strength at elevated temperature, thermal fatigue resistance and low wear resistance. The diameter of the shoulder and pin used were 24 mm, 8 mm respectively and length of the pin is 2.8 mm. The butted plates were clamped on a steel backing plate. The welding tool is tilted by 3 degree of angle with welded plates was rotated in the clockwise direction and plates, which are tightly fixed at the backing plate, were traveled. A constant axial force is applied for all the joints. The FSW joints were fabricated with taper cylindrical tool pin profile and found to be defect free welds, the surface morphologies of the FSW joints were shown in Fig 2.2. The joints were fabricated using different combinations of traverse speed with constant tool rotation speed. The welding joints were sectioned and then machined to the required dimensions to prepare tensile specimens and impact specimens as per ASTM standards in the transverse direction from the welded joints and are shown in Fig 2.3. Tensile test was carried out on servo controlled UTM. Tensile
specimens undergo deformation and the specimen finally fails after necking and the load versus displacement plots were recorded. The tensile properties such as yield strength, ultimate tensile strength and percentage of elongation have been evaluated. Charpy impact test is conducted at room temperature. For this investigation various joints are fabricated and it is found that the joints are free from external defects.

Figure 2.1: Schematic sketch of Friction Stir Welding showing the various characteristic regions

Figure 2.2: Typical photograph of a manufactured tool (a) Taper Cylindrical tool pin profile and Surface morphology of the joints at various conditions: (b) 900 rpm, 25 mm/min (c) 900 rpm, 31.5 mm/min (d) 900 rpm, 40 mm/min

Figure 2.3: Schematic Diagram of (a) Tensile Specimen and (b) Impact Specimen

III. RESULTS AND DISCUSSIONS

A. Microstructure Studies

In conventional welding of copper and aluminum alloys, the defects like porosity, slag inclusion, solidification on crack, etc. deteriorates the weld quality and weld joint properties. However, using FSW the joints are free from these defects since there is no melting takes place during the welding and metals are joined in the solid state itself due to the heat generated by the friction and flow of the metal influenced by the stirring action.

The specimens for metallographic examination were sectioned to the required size from the FSW joints transverse to the welding direction, polished and then etched with a solution of 100 ml distilled water, 15 ml HCl and 2.5 g ferric chloride, micro structural changes from the weld zone to the unaffected base metal were examined with optical microscopy (Model: NIKON; make Epiphot 200). The microstructure of the friction stir welded copper joint consists of different zones such as (a) base metal (b) thermo mechanical affected zone at advancing side (c) weld zone and (d) thermo mechanical affected zone at retreating side which are shown in Fig. 3.1. The formation of above regions is affected by the material flow behavior under the influence of welding speeds with rotating non consumable tool. The optical microstructure of the weld zone at different weld speeds with constant tool rotation speed are displayed in Fig. 3.2. From the observed microstructure, the joints fabricated at the condition of 900rpm as tool rotation speed and 40 mm/min as weld speed observed to be finer grains compared to other conditions. This refinement is due to the dynamic recrystallization caused by simultaneously received plastic shear deformation and frictional heat [12, 13]. Dynamic recrystallization is of great industrial interest due to the new grains being smaller than the initial grains and thereby having improved mechanical properties at room temperature.

Figure.3.1: Optical microstructure of the base metal and weld zones of copper (a) Base metal, (b) TMAZ at the advancing side, (c) WN and (d) TMAZ at the retreating side

Figure.3.2: Microstructure of stir zones of FSW joints at various conditions: (a) 900 rpm, 25mm/min, (b) 900 rpm, 31.5 mm/min and (c) 900 rpm, 40 mm/min

B. Mechanical Properties

Mechanical properties such as yield strength, tensile strength and percentage of elongation have been evaluated. At each condition three specimens were tested and average of the results of three specimens is presented. Table 1 shows the
tensile properties for base metal and Table 2 shows mechanical properties of the copper weldments.

<table>
<thead>
<tr>
<th>Material</th>
<th>UTS (MPa)</th>
<th>YS (MPa)</th>
<th>% EL</th>
<th>Micro hardness (HV)</th>
<th>Impact Strength (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure copper</td>
<td>260</td>
<td>231</td>
<td>31</td>
<td>110</td>
<td>18</td>
</tr>
</tbody>
</table>

Table II: Mechanical Properties of Friction Stir Welded Copper

<table>
<thead>
<tr>
<th>Tool rotation speed (rpm)</th>
<th>Weld speed (mm/min)</th>
<th>UTS (MPa)</th>
<th>YS (MPa)</th>
<th>% EL</th>
<th>Micro hardness (HV)</th>
<th>Impact Strength (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>25</td>
<td>121</td>
<td>95</td>
<td>8.8</td>
<td>62</td>
<td>8</td>
</tr>
<tr>
<td>900</td>
<td>40</td>
<td>108</td>
<td>109</td>
<td>12.5</td>
<td>85</td>
<td>12</td>
</tr>
<tr>
<td>900</td>
<td>31.5</td>
<td>105</td>
<td>102</td>
<td>9.1</td>
<td>71</td>
<td>8</td>
</tr>
</tbody>
</table>

The translation of tool moves the stirred material from the leading side to the trailing side of the tool pin. The rate of heating of thermal cycle during FSW is a strong function of the welding speed. The joints fabricated by tool rotation speed of 900 rpm and weld speed of 40 mm/min produced with higher tensile strength than other conditions. This is due to the intense plastic deformation and sufficient frictional heating generation in the weld zone. At lower welding speed (i.e., 25 and 31.5 mm/min) resulted in higher temperature and slower cooling rate in the processed zone causes grain growth which results in decrease in strength and hardness. Hence, the welding speed must be optimized to improve the joint properties. The percentage of elongation is lower than that of the base metal due to the increase of deformation resistance which is due to the microstructure changes in the weld zone. The fractural morphology of the tensile specimens of the fracture surface of the weld joints were studied using the SEM to understand the mode of failure. Fractured features of the weld joints are shown in Fig. 3.3 the dimple pattern is observed in the whole width of the specimen. All joints were failed on the retreating side during tensile testing. The fracture surface of the tensile specimens at the condition of tool rotation speed of 900 rpm and weld speed of 40 mm/min shows fine dimples than those of fractured surface of the other joint conditions.

The hardness profiles evaluated across the weld nugget at different conditions is shown in Fig. 3.4. The hardness of the base metal is 110 HV. The hardness of the nugget zone is influenced by annealing softening and grain refinement in pure metals [14]. The average hardness of weld zone is found to be significantly lower than that of hardness of base metal. In Harries and Norman’s work, it is suggested that the variation of the micro hardness values in the welded area and base metal is due to the difference between the microstructure of the base metal and weld zone [15]. However, in the present study the hardness of the weld zones fabricated by tool rotation speed of 900 rpm and weld speed of 40 mm/min found to be 85HV which is higher than that of other conditions. This is due to the presence of very finer grains at the weld nugget. The weld center has slightly lower hardness than that of the base metal in spite of smaller grain size.

![Figure 3.4: Microhardness of FSW joints for different weld speeds](image)

IV. CONCLUSION

The joint properties of pure copper by FSW was investigated. The main conclusions were drawn as follows:

- Defect free welds were obtained at all the conditions such as tool rotation speed of 900 rpm and weld speed of 25, 31.5 and 40 mm/min.
- The microstructure at the weld zone of FSWed joint at the condition of 40 mm/min as weld speed is observed to be finer grains than that of other weld conditions due to dynamic recrystallization.
- The joints made with tool rotation speed of 900 rpm and weld speed of 40 mm/min resulted in good mechanical properties as compared with other weld conditions due to sufficient heat generation and proper mixing of the material in the weld zone.

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REFERENCES


