EFFECT OF PLUNGE DEPTH ON MECHANICAL PROPERTIES OF FRICTION SIR WELDED COPPER JOINTS

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Abstract- In this study different tool shoulder plunge depth was applied on the work surface during friction stir welding of copper. The hardness and tensile strength of welded joints were investigated. The welded joint prepared with 0.3 tool plunge depth exhibited better tensile strength and hardness with good bead appearance. The tool pin wear was also analyzed with the multiple distance of welding. The understanding of the plunge depth and tool wear would be advantageous to estimate the tool pin profile shape and weld parameters during welding of copper.

Keywords- FSW, Copper, Tensile, Hardness, Plunge depth, Tool Pin

I. INTRODUCTION

Copper and its alloys are widely in industrial and domestic applications due to their excellent properties such as high strength, wear resistance, corrosive resistance, heat conductivity and formability [1-2]. The welding of copper and its alloys are faced certain difficulties during fusion welding processes due to oxidation, hot cracking, insufficient penetration and loss of strength etc. [3-5]. In the FSW technique all the conventional fusion welding difficulties can be eliminated due to the work material is welded below the melting temperature of base alloy. The working principle of Friction stir welding and processing is explained elsewhere [6-8]. P. Sahlot et al., (2018) [9] studied the effect of tool rotational speed, tool traverse speed and tool traverse distance on tool wear of FSW of Copper. The maximum tool wear occurred on the tool tip and less wear was observed on the tool root. During higher rotational speeds and traverse speeds, the relative velocity between the tool and workpiece was higher and the severe stresses acting at the tip place. K. Jha et al., (2017) [10] FSWed Aged CuCrZr alloy with different process parameters and studied the mechanical properties. The defect free sound joint was produced at tool rotational speed range from 800 to 1200rpm and tool traverse speed range from 40 to 100 mm/min. The appropriate heat generation and fine refinement of grains in the stir zone are the reasons for enhancement of tensile properties of welded joints. The aged condition compromises the loss of weld strength due to dissolution of precipitates. A. Fattah-alhosseini et al., (2016) [11] reported that electro chemical behavior of FSW of copper was improved due to refinement of grain size in stir zone.

The tensile strength value of 530Mpa and uniform elongation of 15% was observed at FSWed joint prepared with lower rotational speed of 15rpm and lower traverse speed of 10mm/min [12]. The surface layer of the FSWed copper alloy mainly depends upon the tool shoulder forging force [13]. V. Shokri et al., (2017) [14] welded dissimilar metals i.e. DSS and Copper alloy by FSW technique and studied the effect of welding parameters. The highest tensile strength value of 279Mpa was achieved at joint fabricated at tool rotational speed of 1200 rpm, tool traverse speed of 30 mm/min and tool off set of 0.5. The formation of optimum intermetallic layer thickness(55µm) improved the strength of the dissimilar welded joint. The strength of friction stir welded copper joint was enhanced nearly equal to parent material via additional rapid cooling during welding. The tensile strength of the FSWed joint prepared at tool rotational speed of 400 rpm with rapid cooling by water and air cooling were 340Mpa and 270Mpa respectively. The base material tensile strength value was 350Mpa [15]. Various researchers reported on FSW of Aluminum and Magnesium and its alloys [16-
Less amount research work was carried out in the copper and its alloys. Still more studies required for understanding the various concepts in FSW of copper. In this paper effect of shoulder plunge depth on the weld bead appearance and mechanical properties were analyzed. The tool wear also studied with respect to welding distance.

II. MATERIALS AND METHODS

Pure cold rolled copper plates with 200mm long, 40mmm width and 4 mm were butt welded. The copper plates are shown in Fig.1. The FSW tool made up of hardened H13 steel with 4mm tool pin diameter & 3.7mm long and shoulder diameter of 15mm were used. The copper plates were mounted on the hydraulic fixture of FSW machine. The FSW machine capacity of 11kW, 40KN were used for conducting the experiments. The experimental set up is shown in Fig. 2. The tool rotational speed of 600 rpm, tool traverse speed of 40 mm/min and tool tilt angle of 1° were selected after number of preliminary trials. Different plunge depths of 0.05, 0.1, 0.2 and 0.3 were selected in this study. The ASTM tensile test specimens were cut from the welded joint in perpendicular direction by wire EDM. The tensile tests were conducted at speed of 1mm/min in room temperature by using Tinius Olsen (H50KS) tensile testing machine. Cross section of welded specimen’s microhardness tests was executed with 100gm load and 10 secs dwell time in microhardness tester.

III. RESULTS AND DISCUSSION

3.1 Macrostructure

Fig. 3 shows welded bead appearance of joint prepared by different tool plunge depths. The welding not (Fig. 3(a)) occurred on the lowest plunge depth (0.05mm) due to inadequate forging pressure. Increase in plunge depth of tool the generation of heat also more due to sufficient friction created between tool shoulder and work piece.

The weld bead appearance (Fig. 3(b)) improved marginally and further increase in plunge depth to 0.2mm the welding bead (Fig 3(c)) improved significantly. But some of micro cracks were appeared on the surface and material was not plasticized uniformly in the nugget zone. For sound joint adequate heat required for uniform mixing of the two joints in the nugget zone due to dynamic recrystallization [19].

The smooth weld bead appearance (Fig. 3(d)) was formed on the welded specimen prepared with 0.3mm plunge depth. Further increase in plunge depth the force generated more and the material were remove excessively from the surface due to higher frictional force and excessive heating. The continuous plunge depth control method was adopted by J. Teimurnezhad et al., (2016) [13] for finding the effect of the shoulder plunge depth on copper joints.
3.2 Mechanical Properties

The tensile test specimens were taken out from the welded joint and it shown in Fig. 3(a). Typical tensile test specimens were shown in Fig. 3(b). The tensile and micro hardness test results are presented in Table 2. The maximum hardness and tensile strength were observed on the 0.3mm tool shoulder plunge depth fabricated specimens. This was attributed due to dynamic recrystallization and grain refinement [20-21]. Process parameters and tool parameters are important for generation of heat during friction stir welding [22-23]. For generating the appropriate heat generation suitable process parameters have to select in order to get sound welded joint with enhanced mechanical properties. For heat generation during tool shoulder plunge depth is an important process parameter.
Table 1. Test Results

|                         | Tensile Strength (Mpa) | Micro hardness (Hv) |
|-------------------------|------------------------|---------------------|
| Pure copper             | 302                    | 82                  |
| Friction Stir welded copper Joint (0.2mm shoulder plunge depth specimen) | 204 | 48 |
| Friction Stir welded copper Joint (0.3mm shoulder plunge depth specimen) | 252 | 54 |

3.3 Tool Pin Profile

Fig. 4 (a) shows the FSW tool pin profiles used for welding of copper joint before welding. After welding of 800mm length the tool pin acquired marginal wear. Still the tool has sufficient strong enough to weld more distance. More studies required to analyse the tool wear with respect to weld distance. The tool wear mainly depends upon on hardness of the tool tip. As per Archard’s wear model [24] given below the wear depth (h) is directly proportional to normal stress (σn) acting on the surface.

\[ h = \frac{k(\sigma_n \times V_r)}{H} t \ldots \ldots (1) \]

Where H = hardness of wear out material, V_r = relative sliding velocity, k = wear coefficient and t = contact time. The model can be used for to effect of tool geometry and process parameters on tool wear. Similar type of results was reported by P. Sahlot et al., (2018) [9] for effect of process parameters on tool wear.

IV. CONCLUSIONS

In summary, the effect of different tool shoulder plunge depth on mechanical properties of friction stir welded pure copper joint were studied and the following conclusions are derived.

1. The appropriate tool plunge depth fabricated weld joint has pleasing weld bead appearance. Lesser plunge depth generating inadequate friction between tool shoulder and workpiece which results in poor welding joint.
2. The optimum plunge depth of 0.3mm produced welded joint has highest tensile strength value of 252Mpa and maximum hardness value of 54Hv.
3. The tool wear mainly depends upon the hardness of the tool material and the welding process parameters.

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