Investigation of Mechanical Properties on Non-Ferrous alloys of Copper and Brass Joints made by Friction Stir Welding

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Abstract. Friction Stir Welding (FSW) and Friction Welding (FW) are the most popular emerging solid welding techniques in aircraft and shipbuilding industries. FSW is mainly used for the joining of metal plates and FW is mainly used for the joining of rods. Both techniques are suitable for high strength material having less weight. These techniques are environmentally friendly and easy to execute. Hence, study on these techniques can contribute much to the field of green technology. There is wide variety of tool pin profiles such as cylindrical, cone and frustum and these are available without and with threaded portion. Considering the work piece materials, the feasibility of this process depends mainly on the properties. Present work deals with welding the copper to copper and brass to brass specimens using cylindrical friction stir weld tool. The weld zones of the specimens were further tested to study tensile strength, hardness and impact strength. A comparative analysis was done to know the impact of friction stir welding on brass and copper material. Based on the comparative analysis prediction can be done for the feasibility of this process to the investigated materials.

1. Introduction

In solid welding techniques, the joining of surfaces is occurring at a thermoplastic state developed by the heat energy due to friction between joining surfaces or with any external tool. FSW and FW are the two important types of solid welding techniques. Both are now used extensively in aerospace and shipbuilding industries, where high strength and light weight material like aluminium and steel alloys are commonly used for structural fabrication [1]. In general FSW makes use of a non consumable which on rotating moves down and at the point of contact it plasticizes the material. The process is shown in Figure 1. Various process parameters which determine the strength characteristics of friction welded joints are geometry of the tool, tool material, tool traversing speed, rotation of the spindle, orientation of spindle, axial load on the tool, tool tilt angle, position of the tool, tool heat input, cooling rate, plates thickness and material of the specimen [2]. Many research publications are available on almost all these aspects. Major publications include design of experiment-based optimization of process parameters, numerical study on heat generation while FSW process, dissimilar metal joining and characteristics of FSW joint from AA2219 material compared to conventional welded joints from Direct Current [3-4]. As per AWS, it is strong joining process which bonds the base metals below their melting and it is a solid state bonding process. Rotary Friction Welding are linear friction welding,
inertia friction welding and rotary friction welding. Most common technique which is used to join specimen with circular cross section are rotary friction welding [5].

![Friction stir welding process](image)

**Figure 1.** Friction stir welding process

Some of them are linear friction welding, inertia friction welding and rotary friction welding. Most common technique which is used to join specimen with circular cross section are rotary friction welding. In all these cases at the work piece interface under pressure during rotation energy due to mechanical is converted into heat & plastic deformation. As a result of which at less temperature a metal bonding is produced between base metals represents the various stages in a rotary friction welding process [6]. Initially, the two specimens are aligned. From these, one specimen rotated and the other is subjected to axial load. Due to both of its relative motion and axial loading, the interface gets heated due to friction [7]. As a result, the interfaces turn into a plasticized stage. At that time the tool is stopped and a sudden upsetting axial pressure will be applied on stationary specimen. On cooling a strong bond between mating surfaces will be resulted [8].

2. Materials and Method

The very first stage under this section is the development of a FSW setup from a vertical milling machine attached with a suitable friction stir welding tool. In addition a suitable fixture is also required to fix the specimen suitably for the FSW operation. A friction stir welding tool is always subjected to static and dynamic loading due to tool axial forces, its stirring effect at the joining faces of work piece, frictional effect due to the initial piercing into the work pieces, frictional force due to its own rotation and traversing along the joining line of work pieces and the high thermal loading occurred at the time of FSW process. To withstand all this static, dynamic and thermal loading and the material selected tool must be hard & tough [9, 10]. The tool selected for the work should have low thermal conductivity & good resistance due to oxidation in order to prevent the damage to machinery components. Hence for the present work, a friction stir welding tool has been made from hot-worked tool steel named AISI H13. The main purpose of a fixture is to hold the work piece during machining operation. In FSW process, the types of forces which act on work piece are lateral forces, traverse force, downward force and their reactive forces. To withstand all the above said forces adequate fixture has been made by special purpose C-clamps, nut and bolt arrangements and additional plates. Fixture is strong enough to protect the specimen motion from all the loadings.
2.1. Tool Material Selection

In general tool wear rate and quality of welding depends on the type of material selected as a tool in FSW, so the tool also significantly affects the microstructure, mechanical and thermal properties. When the properties of the tool gets varied which leads to change their hardness, toughness, reactivity and ductility. Hence the tool material selection is very important in FSW to join base metals. A good tool material should have the following properties like “Good wear resistance, High temperature strength, temper resistance, Good toughness”.

2.2. Tool Materials

The tool material used for making friction stir welding was M2 tool steel. M2 is a "standard" HSS tool used in industrial applications in recent days. It consists of very thin distributed carbides providing good decarburization sensitivity and good resistance to wear. Due to the heat treatment process bending strength and plasticity of the tool significantly changes when compare to T1 heat treatment, here the bending strength changes to 4700 MPa and plasticity changes to 50% of T1. In this study, they were hardened and tempered to HRC 60, following the making of tool pins.

2.3. Tool Geometry

Geometry of the tool is the commonly influential factor in the FSW. Tool geometry plays a crucial role in the movement of material that governs speed of the traverse where FSW can be done. Friction is generated between workpiece and pin due the rotation of tool when it is in contact directly with workpiece, producing localized heating which deforms the material and further allows the tool to plunge into the workpiece. The friction between the shoulder and workpiece is the biggest factor governing heat generation. The heating aspect shows the importance of the relative size of pin and shoulder, while the other design features are not critical [11]. Stir and Move are the two important functions of tool in FSW. A concave shoulder and threaded cylindrical pins have the most used shape as shown in Fig. 2.

![Figure 2. Modelled FSW Tool Profile](image)

2.4. Selection of Workpiece Material

In this study, the materials selected for FSW investigation were Copper and Brass plates having 6 mm of thickness which were used for making friction stir welds. Usually leaching & smelting are the two different processes to get Cu and which also came from its carbonates, sulphides by electrolysis [9].
Brass is an alloy of copper and zinc, in the brass crystal structure some of the Cu atoms are replaced by Zn atoms. The composition of brass is generally 66% of copper and 34% of zinc. The melting point of brass is in a range of 900 to 940 °C and by changing the proportions of Cu & Zn in brass alloy its flow characteristics also changed [12].

2.5. Friction Stir Welding Process

2.5.1. Copper plates joining

Welding was done on cold rolled ½ H copper plates of 6 mm thickness. The base metal plates were 200 mm length and 100 mm width. The plates were longitudinally butt-welded. Faying edges of copper plates were first machined and then cleaned by acetone before clamping on backing plate with the help of a clamping fixture. The welding tool was tilted at 3°. The work piece was clamped rigidly, and all six degrees of freedom were arrested. The top surface of both plates should be evenly flat after clamping the workpiece. The tool pin rotation was then started and touched the work piece. Heat was generated by friction between the tool pin and work piece [13]. The work piece plasticized after which the tool was plunged to full penetration. At this stage the shoulder touched the workpiece and heat was generated. The work piece got plasticized by the tool joins. During the above operation, the welding parameters like tool rotational speed, traverse speed and tool tilt angle were varied.

![Figure 3. FSW joint between two copper plates](image)

2.5.2. Brass plates joining

FSW experiments were done on 5 mm thickness, 150 mm length & 75 mm width of brass plates. In this work brass plates welded longitudinally by using FSW machine [14]. For the experimentation, the FSW tool rotates with the speed of 1000 rpm with the transverse movement of work piece 20 mm/min.
Figure 4. FSW joint between two brass plates

3. Results and Discussion

The following mechanical tests were carried out at the joints of Cu and brass plates after FSW process.

3.1. Tensile Test

An investigation was conducted to define the relationships between the frictional property & strength ideal strength and friction properties of elemental metals. The coefficients of friction for metals are all relevant to tensile strength. If higher the coefficient of friction, the lower the strength of the metal. The variation in tensile strength values of “Cu and Brass” work pieces with respect the change in speed as prescribed in the following Table 1 and Table 2.

3.2. Hardness Test

Weld zone hardness was measured using HTM (Hardness Testing Machine, Mitutoya, Japan) of Model no HM113 with HV 0.05 load and diamond indenter is used. The indentation time for hardness measurement was 15 sec. An experimental study concluded that whenever there is an increase in temperature of the body due to the machining, the hardness of the metal increases [15, 16]. In this experiment due to increase in the tool speed in each set, the heat generation rate increases, and which results in increase of the work. Hence the variation in tensile caused to change the hardness values of “Cu and Brass” work pieces with respect the change in speed which are shown in Table 1 and Table 2.

3.3. Impact Test

Impact strength of both “Cu and Brass” friction stir welded samples were carried out on the joints and this “Charpy test” was performed to ASTM E23 standard. Whenever hardness of the metals increases its brittleness will increase which results in fast breaking of the work. So, by this we can say that impact strength is always inversely proportional to the friction and hardness. Hence the variation in hardness caused to change the impact strength values of “Cu and Brass” work pieces with respect the change in speed which are shown in following Tables 1 & 2. The change in properties of both ‘Cu and Brass’ joints at rotational speed of 1100 rpm as shown in Fig. 5. Hence, at this speed the brass joint exhibiting high mechanical properties than the copper joint.
Table. 1 Influence of tool speed variation on mechanical properties of “Copper” joint by FSW

| Sample Type | Tool rotational Speed | Transverse speed (mm/min) | Tensile strength in (MPa) | Hardness in (BHN) | Impact strength (Joules) |
|-------------|-----------------------|---------------------------|---------------------------|-------------------|--------------------------|
| Sample 1    | 1000                  | 20                        | 222.15                    | 74.21             | 29                       |
| Sample 2    | 1050                  | 20                        | 179.61                    | 79.98             | 21                       |
| Sample 3    | 1100                  | 20                        | 124.71                    | 87.53             | 14                       |

Table. 2 Influence of tool speed variation on mechanical properties of “Brass” joint by FSW

| Sample Type | Tool rotational Speed | Transverse speed (mm/min) | Tensile strength (MPa) | Hardness (BHN) | Impact strength (Joules) |
|-------------|-----------------------|---------------------------|------------------------|----------------|--------------------------|
| Sample 1    | 1000                  | 20                        | 271.2                  | 127.1          | 43                       |
| Sample 2    | 1050                  | 20                        | 264.4                  | 133.8          | 39                       |
| Sample 3    | 1100                  | 20                        | 247.3                  | 142.1          | 31                       |

Figure 5. Variation in mechanical properties of Cu and Brass joints at 1100 rpm of tool
4. Conclusion

From the Experimental Results and by comparing both the materials we have concluded that:

- Both the Materials are exhibiting better properties at less rotation of the tool.
- Due to high speed of the tool, tensile strength and impact strength are reduced but hardness value increased for copper.
- Brass showed only slight variations in its results and good change in increased value of hardness.
- So when we compare copper and brass, brass showed better results in every test.
- Tool material found to withstand for copper and brass base metal without tool breakage.
- Increase in tool rotation speed causes more heat generation.

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