Analysis on effect of using different tool pin profile and mechanical properties by friction stir welding on dissimilar aluminium alloys Al6061 and Al7075

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Abstract. The FSW is one of the latest advanced methods of joining the aluminum in a quicker and effective manner. The quality and the strength of the weldment depends on the tool pin profile, Thickness of weld, speed at which tool moves and the mechanical behavior of aluminum alloys used in the process. Early literature studies shows that developments are required in the field of welding in aerospace, trains and marine Engineering. The literatures show apparent void spaces in improving the strength, quality and weight of the weldment. In this work, an evaluation is made to improve the performance of different profile of tool pin and mechanical characteristics of fsw on dissimilar aluminum alloys. Two alloy compositions say Al 6061 and Al 7075 were selected and three tool pin profiles are developed to study the behavioral pattern of the welded joint. The mechanical properties say tensile strength, yield stresses and micro hardness tests will be conducted using computerized UTM and Micro Vickers hardness testing machine. The mechanical properties were studied from each specimen and correlated to highlight the qualities and characteristics. Hence this paper can form a bridge in filling up the space in finding the suitable mechanical properties for aluminum alloys in specific application. Out of three different tools pin design straight cylinder is selected by having Al6061 on advancing side and Al7075 on receding side based on mechanical properties for the application of tension and it has been proved that straight square is selected for microhardness.

1. Introduction

FSW is a solid-state welding joining process (the metal is not melted) that uses a foreign metal body tool to join two similar or dissimilar metals. For aluminum alloy. To have a higher understanding of the effect of tool pin profile and process parameter, there is a number of researches have been done. Most of the research has been done towards to find the dimension characteristics and effective process parameter for tool pin on FSW briefed below. R.Palanivel et al [1] investigated Mechanical Properties of Five various tool pin profile for dissimilar aluminium alloy and better mechanical properties obtained from square pin profiles. K.ELangovan et al [2] influenced the post welded heat treatment process on FSW. The welded plates prepared by solution treatment and artificial aging treatment. By this tensile properties are enhanced. S.Malarvizhi et al [3] projected frictional heat is decreased by...
increasing shoulder diameter. Greater tensile strength is augmented for D/d ratio 3.5 is used. H.Jamshidi et al [4] experimented using 3D-FEA software ABAQUS for creation of fine grains and recrystallation, highest temperature found in combination of similar materials.

Profile using conventional welding process may cause poor weld zone because of various chemical properties. As Friction stir welding is a solid-state welding, it is well suited for dissimilar aluminum alloys. The tensile strength for various aluminum alloys were already reported by varying different tool pin design [2], [3] and [6] but for dissimilar aluminum alloy Al6061 and Al7075 and varied receding and advancing side is not attempted by any researchers so far. In our approach to find the relation among different tool pin profiles, tensile properties and micro hardness

2. Experimental procedure

The following will explain the design of tool pin profile, selection of materials, properties of materials and procedure of finding the characteristics of tool pin profile by friction stir welding.

2.1 Design of tool pin profiles

Three various FSW tools pin profiles are designed using the following configuration,

1. Tool pin profiles - straight cylinder, straight square and tapered hexagon
2. Tool pin diameter D/d ratios of 3

The methods of tool pin profiles, one is straight and other one is taper by considering D/d ratio of 3. From the literature it is known that Amount of heat generation in taper tool is more when compare with normal straight profile, there are chance of melting on tool pin profile. The measurement used for manufacturing the tool pin profile explained in following figure 1. and figure 2.

![Figure 1. Dimensions for straight tool pin profile](image1)

![Figure 2. Dimensions for taper tool pin profile](image2)

The FSW tools are manufactured using CNC Turning center. The manufactured tools are shown in Figure 3.
2.2 Preparations and welding of Dissimilar plates

The test plated of aluminium alloys prepared from the rolled sheet of 100 X 50X 6 mm size is machine. Table 1 presents the mechanical properties of these materials.

| Table 1. Mechanical properties of the Al6061 and Al7075 materials |
|---------------------------------------------------------------|
| **Mechanical Properties** | **Base element** |
|---------------------------|-----------------|
| Tensile strength          | 300 MPa | 572Mpa |
| Yield stress              | 241 MPa | 503MPa |
| Elongation                | 8%     | 11%   |
| Micro hardness            | 107     | 175   |

By placing Al6061 on receding side and Al7075 on advancing side the dissimilar joint is produced [7]. This dissimilar joint is made by the friction stir welding machine named RVS machine tool, Coimbatore for identifying the feasible limit within the parameter [4],[5], trial experiments are carried out. After finishing the set 1 trail experiments, set 2 are carried by placing Al7075 on receding for the same feasible parameters. They are given below in table 2.

| Table 2. Feasible Parameters |
|------------------------------|
| **PARAMETERS**               | **Maximum Limit** |
| Tool Rotation Speed          | 16.67 rps         |
| Welding Speed                | 1.05 x 10^{-3} m/s|
| Force Applied                | 1500kg            |

The FRICTION STIR welded plates is shown in following figures.
After the welding process over, the welded materials are subjected to find the tensile strength.
To carry out the test the materials are machined as per standards. The following figure 10 shows the materials after the test is done.

![Figure.10. Specimen after finding tensile strength](image)

**Table 3. Mechanical properties of the friction stir welded Al6061 with Al7075**

| Tool pin profile | Sample | Position of plates | Tensile Strength (Mn/mm²) | Improve ment in tensile stress (%) | Yield Stress (Mn/mm²) | Improve ment in yield stress (%) | Elong ation (%) | Improve ment in elongation (%) |
|------------------|--------|---------------------|---------------------------|-----------------------------------|----------------------|----------------------------------|----------------|-------------------------------|
| Straight cylinder | Sample 1 | Receding side - Al6061 Advancing side - Al7075 | 140.21 | 124.53 | 3.20 |
|                  | Sample 2 | Receding side - Al7075 Advancing side - Al6061 | 196.96 | 174.13 | 8.80 |
| Straight square  | Sample 3 | Receding side - Al6061 Advancing side - Al7075 | 168.03 | 151.65 | 4.40 |
|                  | Sample 4 | Receding side - Al7075 Advancing side - Al6061 | 181.20 | 163.76 | 9.20 |
| Tapered hexagon  | Sample 5 | Receding side - Al6061 Advancing side - Al7075 | 184.55 | 164.15 | 6.00 |
|                  | Sample 6 | Receding side - Al7075 Advancing side - Al6061 | 171.41 | 152.11 | 6.40 |

From the table 3, it is clear that tensile stress and yield stress are enhanced for sample 2. In straight tool pin profile, it is observed that positioning of the plates of same nature (sample 2 and sample 4) gives better tensile, yield stress and elongation, when compared to reversing the position of the plates (sample 1 and sample 3) due to rapid solidification because of its profile configuration.
By using straight cylinder tool pin profile, higher mechanical properties obtained due to geometrical configuration of the tool pin profile in which there is no any sharp edge and provides also smooth and perfect welding. Whereas other samples of square and taper hexagon tool pin profile having sharp edge. From those configuration no efficient and smooth welding is achieved, that lead to reduction in mechanical properties.

From the above result, by calculation it is also understood that,

\[
\frac{(196.16 - 140.21)/140.21}{} = 40\%
\]

around 40% improvement in tensile Strength and by the same way

\[
\frac{(174.13 - 124.53)/124.53}{} = 39\%
\]

improvement in yield stress also obtained by using straight cylinder profile.

2.3 Micro Hardness

In Micro hardness test we used three major area of parameter weld, heat affected zone and base metal. The concept proof shows that welding area is welded properly in all the area of parameter.

Table 4. Hardness of six different plates

| Area                  | Weld   | Heat Affected Zone | Base metal |
|-----------------------|--------|--------------------|------------|
| Square                | 158.2  | 132.2              | 85.7       |
| Square                | 134.9  | 119.2              | 78.9       |
| Cylinder              | 156.4  | 129.4              | 89.2       |
| Cylinder              | 148.2  | 129.2              | 89.0       |
| Hexagon               | 152.2  | 132.2              | 104.2      |
| Hexagon               | 144.2  | 130.2              | 120.3      |

The hardness properties for 6 sample plates are listed in table 4 for three different zones. It is quite, the hardness of welded zone and heat affected zone are not much varied for all different plates [9]. Straight square tool pin profile has hardness values of 138.98 HV in welded zone and 121.57 HV in heat affected zone at Al7075 on receding side and Al6061 on advancing side.
Figure 11 Graph for comparison values of the micro hardness between three different tool pin profiles on various zones.

Figure 11 represents the enhancement of six different samples micro hardness. The optimum hardness reflects in the straight square sample 1 due to contact area of tool pin profile is wider comparing to hexagon and cylinder samples.

Figure 12. Graph for cylindrical tool pin profile and Al6061 on receding side and Al7075 on advancing side.
Figure 13. Graph for cylindrical tool pin profile and Al7075 on receding side and Al6061 on advancing side.

Figure 14. Graph for square tool pin profile and Al6061 on receding side and Al7075 on advancing side.
Figure 15. Graph for square tool pin profile and Al7075 on receding side and Al6061 on advancing side.

Figure 16. Graph for hexagonal tool pin profile and Al6061 on receding side and Al7075 on advancing side.
Figure 17. Graph for hexagonal tool pin profile and Al7075 on receding side and Al6061 on advancing side

2.4 Tensile Studies
ASTM-E8 standard is used to prepare specimen to conduct tensile test [11]. The computerized UTM is used to evaluate the following.
1. Tensile strength
2. Yield stress
3. Elongation percentage
The graph shows the yield stress and tensile strength of plates with three different tool pin profile. From the graph it shows the straight cylinder for sample 2 gives better yield stress and tensile strength but for the same tool pin profile it is noted that Al6061 on retreating side is lowest among other welded plates.

**Figure 18.** Graph for comparison values of the mechanical properties between three different tool pin profiles and material placement.
Figure 19. Graph for comparison values of the % of elongation between three different tool pin profiles and material placement.

The graph shows the percentage of elongation for all six positions of plates with three different tool pin profile. From the graph it shows the straight square for sample 4 gives better elongation. At the same time values for Al6061 on retreating side is second last. The elongation for this particular position is 9.2%.

3. Application
Welding of Al7075 and Al6061 can give better rapid solidifying therefore, we can use it in Marine Engineering. Due its higher value of Reinforcement, making of civil Structure is easier when compared to other aluminum alloy. By comparing the properties of these two metals Al7075 is harder than Al6061, so it is advisable to use the Al7075 on flooring for railway compartments followed by Al6061 on the body of the compartment in order to give lesser weight on whole structure.

4. Conclusion
- Chosen different aluminium alloy plate can be welded without any defect by FSW method.
- Tool pin profile plays important role on mechanical properties such as tensile stress, yield stress & elongation.
- Straight cylinder tool pin profile an added advantages over other profiles.
- To gain better hardness, Straightness Square tool can be employed by positioning Al7075 on receding side.

5. Reference
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