EFFECT OF TOOL PIN GEOMETRIES ON FRICTION STIR WELDED AA 6061

Suthagar S¹ and Kelvinajan P²

¹Assistant Professor(SG), Department of Manufacturing Engineering, Anna University, CEG, Chennai.
²M.E CIM Student, Department of Manufacturing Engineering, Anna University, CEG, Chennai.

Abstract-The 3 mm thick aluminium alloy (AA) 6061-T6 was Friction Stir Welding (FSW) with three different tool pin geometries namely cylindrical, taper and bobbin at rotational speed of 1400rpm. FSW process was carried out under the welding speed of 40mm/min for cylindrical and taper tool pin whereas for bobbin tool pin FSW process was carried out under the welding speed of 80mm/min. The effect of welding speed on microstructure and mechanical properties of the joints was investigated. On comparing the results the welds carried out using bobbin tool pin shows the best mechanical properties. When the rotational speed increases, the tensile strength and maximum load of the welds also increases which shows that FSW weld at high rotational speed will be effective to weld AA6061. Hardness of the material increases with the increase of the speed. Due to the tensile strength and load of ability obtained, microstructure images for FSW welded plates using bobbin tool, taper tool at 1400 rpm was taken to investigate the grain orientation. Fine grains can be seen in the microstructure of bobbin tool FSW plates compared to the microstructure of cylindrical and taper tool FSW plates.

Keywords- Friction Stir welding, bobbin tool, mechanical properties, tool geometries

I. INTRODUCTION

As the problems associated with the fusion welding of aluminium (Al) alloys includes porosity, cracking, a high level of residual stresses, the significant reduction of baseline mechanical properties, and the need for multi-pass welding in thick sections. At this point the friction stir welding invented by Thomas and co-workers at TWI of the UK in 1991 as an alternative technology for fusion welding. In FSW process, the tool is rotated against the workpieces to a desired plunge depth which produces heat due to friction between the tool shoulder and pin, and the material of workpieces. The frictional heat and surrounding temperature causes the stirred materials to be softened and mixed [1]. Since the materials are not melted, it is considered as solid state welding. The tool has two important functional consequences: (1) to heat the workpiece and (2) contain and direct the plasticized workpiece material. The process variables such as the rotation speed, welding speed, tool geometry have obvious influence on the material flow and thermal cycle [2].

Aluminium alloy 6061 is selected for the study because of Aluminium alloy 6061 is a structural alloy; medium strength alloy with excellent corrosion resistance. High speed steel is selected as a tool material. Rolled plates of 3mm in thickness were cut into the required size (100mmx50mm) as samples. In the present study, the FSW was employed to weld AA6061-T6 of 3mm thick plate using three different tool geometries. The effects of tool pin geometries in the mechanical properties such as tensile strength, micro structure and microhardness of the welded joints have been studied.

II. EXPERIMENTATION

A 3mm thick AA 6061-T6 plate was used to carry out FSW using three different tool pin geometries. The dimension of workpiece is of 100mm length and 50mm width. H13 material was
selected as the welding tool material. The taper tool produces a single sided FSW joints whereas the bobbin tool produces the double sided FSW joints by the use of both upper and lower shoulders.

### Table 1. FSW Process Parameters

| Tool geometry   | Rotational speed | Welding speed |
|-----------------|------------------|---------------|
| Cylindrical pin | 1400 rpm         | 40 mm/min     |
| Taper pin       | 1400 rpm         | 40 mm/min     |
| Bobbin pin      | 1400 rpm         | 80 mm/min     |

### III. RESULTS AND DISCUSSIONS

#### 3.1 Tensile strength

The average of three tensile test specimens were recorded. The tensile strength of the welded joint using cylindrical pin and taper pin was 56% and 58.3% of the parent material respectively. The degree of stirring is highly affected by the welding speed and the tool rotational speed \([3,4]\). The heat input is directly proportional to the tool rotational speed and axial force and indirectly proportional to the welding speed. Quality of weldments is based on the optimum heat input generated.

The tensile strength 60.6% of the parent material was obtained as high for the bobbin tool welded joint. Also, the maximum load 2.74kN is obtained in the bobbin tool pin on comparison with other tool pins.

### Table 2. Tensile Strength of BM & Welds using various Tool Geomeries

| Tool geometry   | Tensile strength |
|-----------------|------------------|
| Base Material   | 307 MPa          |
| Cylindrical pin | 172 MPa          |
| Taper pin       | 179 MPa          |
| Bobbin pin      | 186 MPa          |

The tensile strength of the BM and welds using various tool geometries (Table 2) are represented in the figure 1. It is also found that the FSW process parameters are significantly influenced by the base material properties like yield strength, hardness and elongation which in turn due to the heat generated during FSW process.

![Figure 1. Tensile Strength of Welded Plates using Various Tool Geometry](image-url)
3.2 Microstructure Analysis

Microstructure of the parent metal AA6061 which is treated T6 solution and precipitation hardened followed by work hardening. The grains are along the direction of forming. The microstructure shows the fine precipitate of Mg2Si and the coarser particles are insoluble Al6 (Fe, Mn) in main matrix of primary alpha Al solid solution.

The microstructures of the specimens was revealed through etching with Keller’s reagent and examined using the optical microscope. Microstructure analysis carried out with the welded plate using bobbin tool pin. In the microstructure analysis, the stir zone in the bobbin FSW has a compressed hourglass shape. The two weld extremities possess the slightly largest diameter than that of the shoulders while the mid surface displays the smallest diameter. This shape is related to the special material flow conditions imposed by the upper and lower shoulders.

![Figure 2](image-url)

*Figure. 2. Microstructure of welded AA6061 using Bobbin Pin Tool - (a) WNZ (b) HAZ (c) TMAZ and (d) Top shoulder*

The material in the advancing side (AS) moves to oppose the plate motion and is exposed to a more shear stress than that in the retreating side (RS). The grains in the nugget zone (NZ) characterized as fine grain structure due to the dynamic recrystallization in contrast to the base material (BM) microstructure [5]. There is no uniform flow pattern found in these zones.
The microstructures image of various zones of FSW plates using taper tool at 1400rpm was investigated. It resulted that the microstructure of WNZ which indicates that fragmented grains of primary and secondary eutectics. The matrix was undergone into the dissolution of Mg$_2$Si and dynamic recrystallization. The HAZ in which grains are coarser compared to the WNZ and it shows the interface between the HAZ and TMAZ the region along the bottom right shows the HAZ and the region TMAZ, elongated grains are found.

### 3.3 Microhardness

Where specific information is required on the hardness of sub-structures within the HAZ zone, it is necessary to carry out micro-hardness testing with loads in the 0.1 to 0.5kgf range.

Hardness Testing Welds and Heat Affected Zones, Vickers Hardness is the predominant measurement technique for welds and HAZs. The diamond indentation can be made using a range of loads from 1 to 100 kg. The higher the load the larger the impression the diamond makes on the surface and the more of an average the hardness reading becomes.

Vickers microhardness test indicated that the hardness increases from the NZ, TMAZ, HAZ. The microhardness varies along the various regions and differences in the microhardness are due to grain size [6]. The grain size variations are due to the increase in the temperature during FSW process. The other reason for the variation of the microhardness of the welded regions and BM, because in AA6061 the main precipitate is Mg$_5$Si$_6$ which is stable at temperature lower than 200°C [7]. Microhardness values are slightly high along the AS compared to the RS.

Rajkumar et al (2011) observed in his study that a linear regression relationship was established between grain size and hardness of the weld nugget zone of FSW joints [8].

The taper pin weldments obtained high level of hardness compared to hardness of other tool pin weldments. The hardness increased from the NZ to HAZ and then to TMAZ in welds of all tool pins with slight fluctuation.

The hardness profile for various zones of bobbin welds at 1400rpm shows hardness increased from the center of the weld towards HAZ and to TMAZ.

In general, increase in the hardness of the welded zones close to the joining areas of the analyzed samples leads to an increase in their tensile strengths. The size and shape of the regions formed as a result of welding depend on the tool pin geometry. It can be concluded that the tool geometry has a significant effect on the mechanical behavior [9,10].

### 3.4 Grain Size

The grain size along the HAZ and TMAZ are higher than the grain size along the BM. Grain size of taper tool pin welded plate is less compared to the welds carried out using cylindrical tool pins.
IV. CONCLUSION

In this study, joining process were carried out by employing the friction stir welding technique. From the samples prepared under this joining technique, the performance of the tool pin geometry was determined with the tensile tests, microstructure and micro hardness characteristics.

From the study, it can be concluded that,

The taper pin tool geometry weld obtained the high tensile strength 185.92 at 1400rpm and maximum load 2.79 than the welds of other tool pins.

Bobbin tool geometry is identified as effective tool pin geometry for FSW of AA6061 because of best mechanical properties is obtained for BFSW joints. In bobbin tool welds, increasing the rotational speed and traverse speed yielded the better tensile strength and maximum load.

Welded joints using bobbin tool yielded high tensile strength with the value of 186 MPa at the load of 2.74kN. It shares 60.6% strength of the parent material.

When the rotational speed increases, the tensile strength and maximum load of the welds also increases which shows that FSW weld at high rotational speed will be effective to weld AA6061.

Microhardness results higher value among the various zones of the welds carried out in Bobbin tool FSW. Hardness of the material increases with the increase of the speed.

Due to the tensile strength and load of ability obtained, microstructure images for FSW welded plates using bobbin tool, taper tool at 1400 rpm was taken to investigate the grain orientation. Fine grains can be seen in the microstructure of bobbin tool FSW plates compared to the microstructure of square and taper tool FSW plates.

REFERENCES

[1] Mishra, Rajiv S., and Z. Y. Ma. "Friction stir welding and processing." Materials Science and Engineering: R: Reports 50.1 (2005): 1-78.
[2] Satao YS, yamashita F, Sugiura y, Park SHC, Kokawa H. FIB-assisted TEM study of an oxide array in the root of a friction stir welded aluminum alloy. Scripta Mater 2004; 50:365-9.
[3] Okamura H, Aota K, Sakamoto M. Behaviour of oxides during friction stir welding of aluminum alloy and their effect on its mechanical properties. Weld Int 2002;16(4):266-75.
[4] Elangovan K, Balasubramanian V. “Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy”[J]. Journal of Material Processing Technology, 2008, 200: 163-175.
[5] Liu, H. J., J. C. Hou, and H. Guo. "Effect of welding speed on microstructure and mechanical properties of self-reacting friction stir welded 6061-T6 aluminium alloy." Materials & Design 50 (2013): 872-878.
[6] Yan Yong, Zhang Da-Tong, Qiu Cheng, Zhang Wen “Dissimilar friction stir welding between 5052 aluminum alloy and AZ31 magnesium alloy” [J]. Transactions of Nonferrous Metals Society of China, 2010, 20(S2): s619-s623.
[7] Bratland D, Grong, Sherclief H, Myhr O. Overview No. 124 “Modelling of precipitation reaction in industrial processing.” [J]. ActaMaterialia, 1997, 45: 1-22.
[8] Rajkumar, V., Venkateshkannan, M., SAdheesh, P., Arivazhagan, N., &DevendranathRamkumar, K. (2014). Procedia Engineering, Vol. 75, pp. 93-97.
[9] Kumbhar, N. T., and K. Bhanumurthy. "Friction stir welding of Al 6061 alloy." Asian J. Exp. Sci 22.2 (2008): 63-74.
[10] Khan AU, Kamadod, ASM, and Bharat Kumar. Fabrication of a butt joint using friction stir welding (FSW) – a non-consumable tool to generate heat. Intenational Jurnalof Research and Scientific Innovation. 2016; 3(12): 53-55.