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*Research Article*

# Experimental Comparison of Two Different Pin Contour in Friction Stir Welding of AL 6063 Alloy

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***Abstract***

*AA 6063 has gathered wide acceptance in the fabrication of the light structures required to high strength. Compared to the fusion welding processes that are used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. In my investigation, tool rotation and traverse speeds are kept constant i.e. 2000 rpm and 20 mm/min. The variables are shape of the tool and having passes one sided and both sided. Cylindrical tool pin profile exhibited superior tensile properties compared to other joints, irrespective of tool rotational speed in double pass. The joints fabricated by single pass have shown lower tensile strength and also percentage of elongation compared to the joints fabricated by double pass and this trend is common for all the tool profiles.*

***Keywords****: AL alloy, Friction Welding, tool geometry, Vertical milling m/c.*

## Introduction

Friction stir welding (FSW) is a relatively new solid state welding process which is used for butt joints. FSW was invented by The Welding Institute, Cambridge, UK in 1991 (W.M. Thomas *et al*, 2011) and has emerged as a new process for welding of aluminum alloys. This process has made possible to weld a number of aluminum alloys that were previously not recommended (2000 series & copper containing 7000 series aluminium alloys) for welding. Because the material subjected to FSW does not melt and re-solidify, the resultant weld metal is free of porosity with lower distortion. An added advantage is that it is an environmentally friendly process. FSW is a solid state, localized thermo mechanical, joining process. In FSW, a non-consumable rotating shouldered-pin-tool is plunged into the interface between two plates being welded, until the shoulder touches the surface of the base material, and then tool is transverse along the weld line. In FSW, frictional heat is generated by rubbing of tool shoulder and base material surface. During traversing, softened material from the leading edge moves to the trailing edge due to the tool rotation and the transverse movement of the tool, and this transferred material is consolidated in the trailing edge of the tool by the application of an axial force. FSW parameters are tool geometry, axial force, rotational speed, transverse speed and tool tilt angle. General convention is, where the direction of the velocity vector of the tool and traverse direction are same that side is called the advancing side of the weld, and when the direction of the velocity vector opposite to the traverse direction, it is called the retreating side.

Many attempts have been made on FSW on aluminium alloys Liu *et al*. (2003) discussed on the different parameter of the FSW .In this paper analyzed the joint characteristics of similar and different materials used in fabrication industries which are difficult to join by other technique. The analysis was completed with the help of ANSYS software computationally & same was experimentally verified.

The basic principles covered include terminology, material flow, joint configurations, tool design, materials, and defects. Methods of evaluating weld quality are surveyed as well. The modern applications are discussed, with an prominence on recent advances in aerospace, automotive, and ship building. Kovacevic *et. al* (2003).

Mumin Sahin *et al (2003)* this paper highlights the role of tool geometry, because tool geometry plays a major role in FSW. Proper selection of a tool material and shape of the pin reduces number of trials and tooling cost. In addition this study also highpoints the wear effect due to friction between sliding surfaces.

Huseyin Uzun *et al*. (2004) investigated that the joining of dissimilar Al 6013-T4 alloy and X5CrNi18-10 stainless steel was carried out using friction stir welding (FSR) technique. The microstructure, hardness and fatigue properties of fiction stir welded 6013

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aluminium alloy to stainless steel have been investigated. Optical microscopy was used to characterize the microstructures of the weld nugget, the heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) and the base materials. The research normally lies on characteristics of FSW tool pin's profile on FSW joint. In Present work will be carried out using different tool pin profile like tapper cylindrical, square, tapper hexagonal, and threaded cylindrical. Test specimen will be prepared from acquire results and various tests (tensile and bending test) will be carried out to prove its optimal joints. On the basis of these results and parameters used during experiment the effect of tool pin profile will be understood.

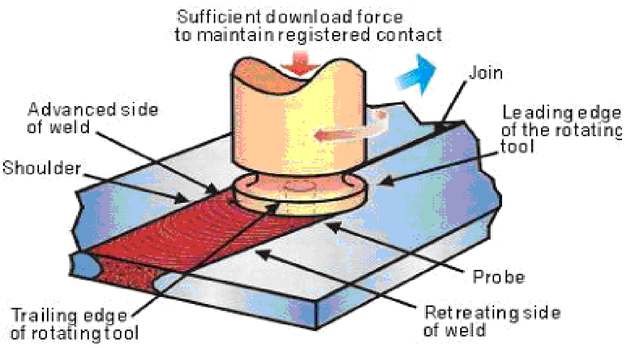


**Fig.1** Schematic representation of FSW

Mariano *et al*. (2012) states that Friction Stir Welding (FSW) is fairly a recent technique that uses a non consumable rotating welding tool to generate frictional heat and plastic deformation at the welding location while the material is in solid state. The principal advantages are low distortion, absence of melt related defects and high joint strength. Tool design and material plays a vital role in addition to the important parameters like tool rotational speed, welding speed and axial force. The paper focuses on optimization of FSW parameters in different conditions of base material and the microstructures of the as-welded condition are compared with the post weld heat treated microstructures welded in annealed and T6 condition.

Single pass friction stir welding is not able to provide better results in case of thick work material plates which is mainly due to the difficulty in finding a suitable backing material. Obviously the thickness of plate that can be joined by FSW can be increased by passing the tool along both sides of the butted plates in sequence. The use of the sequential double pass weld can almost double the plate thickness that can be joined, thereby significantly increasing the industrial utility of the FSW joining process for other materials like steels etc. Considering these facts, the objective of the present study is to investigate the influence of tool shape on the tensile strength of AA 6061 in single and double sided friction stir welds.

**Experimental Set-Up**

The base material used in this study was aluminium alloy AA6063 plates thickness of 6mm. A pair of work pieces of dimension 200mm ×200mm ×5 mm were abutted and clamped rigidly on the backing plate for welding, having chemical composition as shown in table 1:

**Table-1**-Composition of AA-6063

| Element | Al | Si + Fe | Mg | Cu | Cr |
|---|---|---|---|---|---|
| Weight %age | 97.5% | 0.2-0.6% | 0.45-0.9% | 0.1 Max | 0.1 Max |

The base material tensile strength is 130 Mpa with the elongation of 18%. FSW trials were carried out on vertical milling machine with the square butt joint configuration.

The welding tool material is High Speed Steel of hardness 60-63 HRC. Two different profiles are used i.e. cylindrical and square shown in fig 2 a and fig 2 b:

**Fig.2 a)** Circular Tool Profile

**Fig.2 b)** Square Tools profile

The tool material is available in 20 mm diameter rod. Straight Cylindrical tool geometries were processed on central grinding machine according to the dimensions specified. Square tool were processed on milling machine by indexing. Specifications of the tool are given in the table 2:

**Table-2:** Tool specifications

| Specifications | Values |
|---|---|
| Tool Material | High Speed Steel |
| Length of tool | 50 mm |
| Tool shoulder diameter | 18 mm |
| Pin diameter | 7.2mm |
| Pin length for single pass | 5.7mm |
| Pin length for double pass | 3.7mm |

It is worth noting that for the double pass weld, the plates were turned over about an axis along the weld after the first pass was made, so that the two welding passes started at the same position along the joint interface, and the advancing side of the second pass was over the retreating side of the first pass weld. All of the welds were carried out along the rolling direction of the steel plate.

Tool rotation speed, traverse speeds and tool tilt angle were kept constant at 2000 rpm, 20 mm/min and zero angles respectively. The process variables were, shape of the tool and tool passes on single and double sided. In both cases, depth of depression was 0.05 mm. For Friction Stir Welding, single and double pass were adopted:

Single pass FSW

- Tool pin length was 5.7 mm
- Time taken was 10 min for length 200 mm.

Double pass FSW

- Tool pin length was 3.7 mm
- Time taken was double i.e. 20 min for length 200 mm.

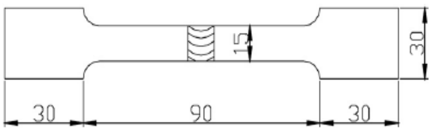


**Fig.3** Dimensions of Tensile Specimen

Tensile test specimens were prepared according to the guidelines of the American Society for Testing of Materials (ASTM) shown in fig 3. Tensile test was carried out on 100 ton Universal Testing Machine at room temperature. The specimen was loaded as per ASTM so that tensile undergoes deformation. Then specimen finally failed after necking and the load v/s displacement was recorded. The ultimate tensile strength, percentage elongation and joint efficiency were evaluated. Specification of the tensile specimen:

- Cross sectional area = 5x15=75 mm$^2$
- Gauge length=50 mm

Micro hardness test was done on Viker's Hardness Tester. Micro hardness tester is based upon indentation method of testing. A diamond pyramid was used to create a permanent deformation in the surface of the test sample and then the hardness of the test sample was determined. The load used in Viker's hardness was 5kgF for 15 seconds.

## Results

*A) Tensile Testing*

Test was carried out in 100 Ton; Universal Testing Machine at a room temperature. The specimen finally failed after necking and the load versus displacement was recorded UTM for t. Table 3 describes the specimen specifications used on the testing.

**Table-3**-Specimen specifications

| Sample | Area (mm$^2$) | Width (mm) | Thickness (mm) | Gauge length (mm) | Final gauge length (mm |
|---|---|---|---|---|---|
| Half square (HS) | 90 | 15 | 6 | 50 | 58.5 |
| Full square (FS) | 90 | 15 | 6 | 50 | 55 |
| Half Cylindrical (HC) | 90 | 15 | 6 | 50 | 60 |
| Full Cylindrical (FC) | 90 | 15 | 6 | 50 | 63 |

Figure 4 shows the welded specimen after tensile testing on the UTM welded with the cylindrical tool profile (single pass).

**Fig.4** Failure of Welded Specimen in Tensile Test (Single pass Cylindrical)

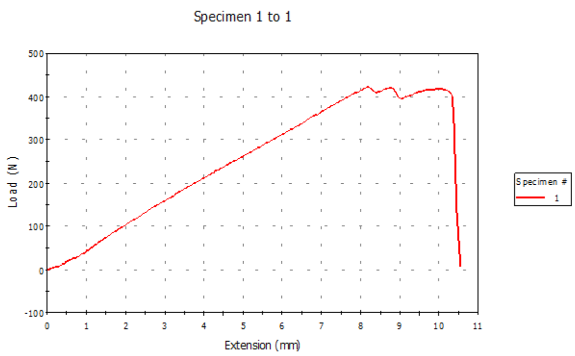


**Fig.5**-load v/s displacement (FC) Single pass

Figure 5 show the graph recorded during the tensile testing of the welded specimen welded by the cylindrical tool profile (Single pass) where the tensile strength of the specimen 0.082KN/mm²at the load of 8.450 KN and the percentage elongation is 82.7%. Figure 6 shows the e welded specimen after tensile testing on the UTM welded with the cylindrical tool profile (double pass).

**Fig.6** Failure of Welded Specimen in Tensile Test (Double pass Cylindrical)

Figure 7 shows the graph recorded during tensile testing of the welded specimen on the UTM welded with the cylindrical tool profile (double pass) where the tensile strength of the specimen is 0.084 KN/mm2 at the load of 8.7KN and the percentage elongation is 84.14%.

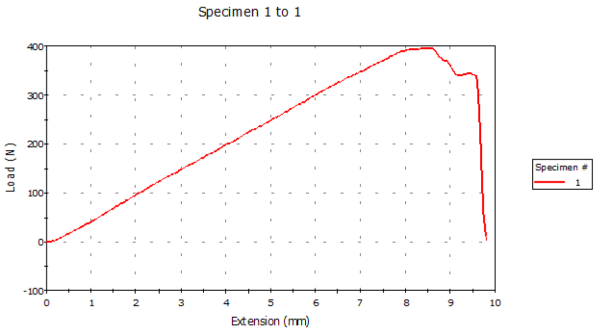


**Fig.7** Load v/s displacement (HC) Double pass

Figure 8 shows the welded specimen after tensile testing on the UTM welded with the Square tool profile (Single pass).

**Fig.8** Failure of Welded Specimen in Tensile Test (Single pass Square)

Figure 9shows the graph recorded during the tensile testing of the welded specimen on the UTM welded with the square tool profile (Single pass) where the tensile strength of the specimen is 0.059KN/mm²at the load of 6.45KN and the percentage elongation is 62.19%

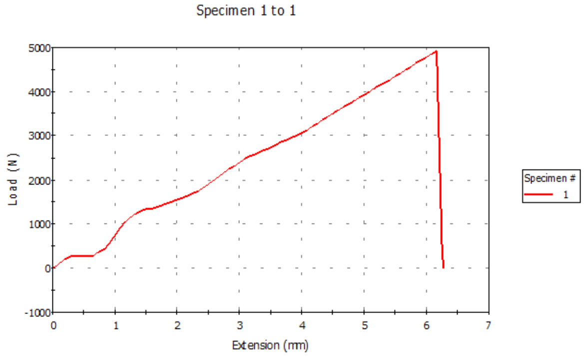


**Fig.9** Load v/s displacement (FS) Single pass

Figure 10 shows the welded specimen after tensile testing on the UTM welded with the square tool profile (Double pass).

**Fig.10** Failure of Welded Specimen in Tensile Test (Double pass Square)

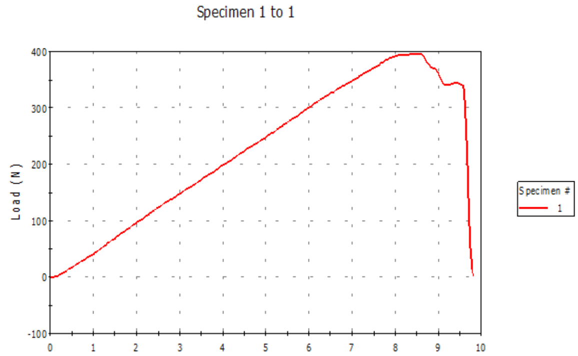


**Fig.11** Load v/s displacement (HS) Double pass

Figure 11 shows the graph recorded during tensile testing of the welded specimen on the UTM welded with the square tool profile (double pass) where the tensile strength of the specimen is 0.0838KN/mm² at the load of 8.65KN and the percentage elongation is 83.65%

Joint efficiency η = joint strength / parent strength

Transverse tensile properties of FSW joints i.e. ultimate strength, percentage elongation and the joint efficiency were evaluated shown in table 4 below.

**Table-4** Ultimate strength, percentage elongation and the joint efficiency

| Specimen No. | Ultimate Tensile Strength | | Percentage Elongation | Joint Efficiency |
|---|---|---|---|---|
| | Load (KN) | Stress (KN/mm²) | % Elongation | |
| Cylindrical (Single pass) | 8.45 | 0.082 | 25 | 82.70% |
| Square (Single pass) | 6.45 | 0.059 | 9 | 62.19% |
| Cylindrical (Double pass) | 8.7 | 0.084 | 20 | 84.14% |
| Square (Double pass) | 8.65 | 0.0838 | 16 | 83.65% |

*B) Micro Hardness*

Vickers micro-hardness profiles of the welded zones were measured on a cross- section perpendicular to the welding direction using a Vickers indenter with a 5kgf load for15 second. The micro hardness of base metal is 44.7 HV. Micro hardness of single pass and double pass is shown in table below. A plot of micro hardness as a function of position from the weld centre line is plotted foe both single and double pass. A plot of micro hardness as function of position from the weld centre line in single pass is shown in figure 12-figure13, where

A-Advancing Side
0-centre
R-Retreating Side

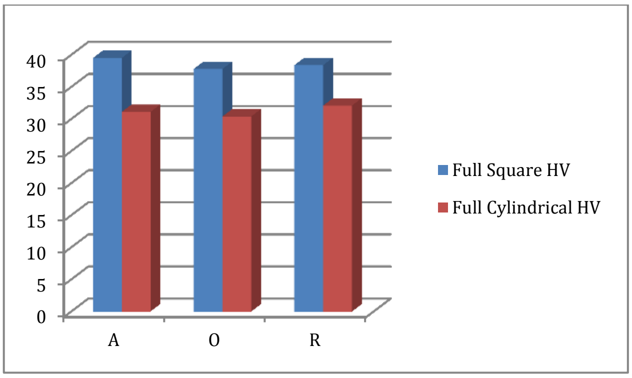


**Fig-12**-Micro hardness of specimen Half Square and Half Cylindrical

**Table-5**-Test Results Micro-hardness

| S.No. | Distance from centre | Half Square HV | Half Cylindrical HV |
|---|---|---|---|
| 1 | A | 32.5 | 32.1 |
| 2 | 0 | 31.9 | 34.8 |
| 3 | R | 32.7 | 33.5 |

Table 5 and table 6 describe the micro- hardness of the specimens done on the Viker's Hardness Testing Machine:

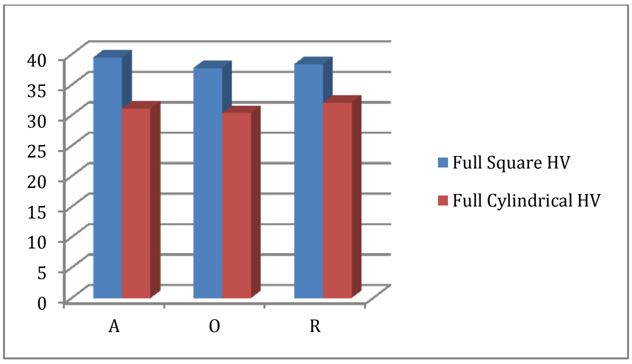


**Fig.13**-Micro hardness of specimen Full Square and Full Cylindrical

**Table-6**-Test results Micro hardness

| S.No. | Distance from centre | Full Square HV | Full Cylindrical HV |
|---|---|---|---|
| 1 | A | 39.5 | 31.1 |
| 2 | 0 | 37.8 | 30.4 |
| 3 | R | 38.4 | 32.1 |

## Conclusion

In this investigation an attempt has been made to study the effect of tool pin profile (straight cylindrical and square) on the formation of friction stir processing zone in a single and sequential double sided friction stir weld in AA6061. From this investigation, the following important conclusions are derived:

(i) Double side weld joint have more joint efficiency as compared to Single side weld by 84.14% of cylindrical (Double sided) pin profile as compared to other pin profiles (82.7% cylindrical single pass, 62.19% Square single pass and 83.65% Square double pass).

(ii) The joints fabricated by double passes have shown higher ultimate tensile strength as compared to the joints fabricated by double pass and this trend is common for all the tool profiles (0.084 KN/mm²Cylindrical double pass, 0.0838 KN/mm² Square double pass, 0.059 KN/mm² Square Single pass, 0.082 KN/mm² Cylindrical single pass).

(iii) Cylindrical tool profile single pass has more percentage elongation (25%) as compared to other tool profiles (9% square tool single pass, 16 % square tool double pass, 20% cylindrical tool double pass.)

(iv) Square tool profile single pass has maximum micro hardness value (39.5) as compared to other tool pin profiles (32.7 Square tool double pass, 34.8 cylindrical tool double pass, 32.1 cylindrical tool single pass)

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