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# EFFECT OF TOOL GEOMETRICAL PARAMETERS ON FRICTION STIR WELDING JOINT PROPERTIES OF ALUMINIUM ALLOY AA6061

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## ABSTRACT

Friction stir welding (FSW) process is a solid state joining process in which a non-consumable tool is used to generate frictional heat in the abutting surfaces. The welding parameter such as welding speed, tool rotational speed, and tool profile plays a major role in deciding the weld joint strength. In this investigation, effect of welding parameters and tool pin profile on Mechanical properties in AA6061 aluminium alloy was studied. Friction stir welding of aluminium alloy plates with a thickness of 6 mm are used to perform Friction Stir Weld joints. Tapered cylindrical, and square pin profiles have been used to fabricate the joints at three different rotational speeds i.e. 1500, 2000 and 2500 rpm with two traverse speeds of 20 and 40 mm/min. The mechanical properties (tensile strength, hardness) of the joints have been evaluated and analysed. It has been observed that the design of tool pin profile has considerable effect on tensile properties. Square pin profile tool produces the best tensile properties compared to tapered cylindrical tool pin profiles.

**Keywords:** friction stir welding, mechanical properties, rotating speed, tool geometry.

## INTRODUCTION

Aluminium alloys are considered as one of the most promising materials for their excellent mechanical properties such as corrosion resistance, light weight and high strength. The usage of certain aluminium alloys are restrained, because of their poor weldability [1].

However, there is a new welding technique called the Friction Stir Welding (FSW), invented in the Welding Institute, UK in 1991. The FSW is used to join material in solid state. There are very fewer parameters to be controlled in FSW such as tool rotating speed, tool geometry and tool feed speed while for conventional welding, many factors have to be considered such as purge and shield gas, arc voltage, gap and travel speed [2].

As stated, the best joining method for aluminium alloy is solid state is by using FSW. However, there are some constraints using FSW method due to its still new technology and there still some defect and disadvantage where more study need to be conducted. Although, there are only few parameters for FSW process to be controlled, those different parameters highly affected the result on the joint material in term solidification and strength of the materials. Consequently, any defect in the joint will cause problem when it comes to the application. In industry project a high degree of safety and reliability are a very important factor.

The main objectives of this research are as follows:

- To study the effect of tool geometry (square, tapered cylindrical) and welding parameter (rotating speed, traveling speed) on weld quality.
- To study the effect of the tool geometry and welding parameter on the mechanical properties (tensile, hardness).

The proposed study will mainly focus on studying the effect of the tool profile of FSW process on the weld characteristics by studying the mechanical property of the weld joint such as tensile strength, hardness and ductility in term of elongation. Moreover, the effect of tool geometry on tool durability will be investigated. At present, few studies had been carried out to determine the strengths of welded materials using different tool geometry. In this study, three parameters are selected which are rotating speed, welding tool geometry and feed rate.

The tool geometry plays a critical role in material flow and in turn governs the traverse rate at which FSW can be conducted. FSW tool consists of a shoulder and a pin as shown schematically in Figure 1. Each of these parts has their own role in FSW. The purpose of the pin is to form friction between pin and the material to generate plasticized flow around the pin. Then, the shoulder act as ‘stirrer’ by stir the plasticized material to produce the weld lines [4]. Besides that, the shape of the pin playing a key role in FSW welds joint properties. Different tool geometry will give different hardness, tensile strength, and microstructure property. A half grooved tools give a better weld quality than taper threaded tool [5]. However, as researches and development going on, it is found that a frustum shaped pin reduce welding force, improved plasticized flow of the material and increasing in heat generation due to better interface between pin and plasticized material [5].

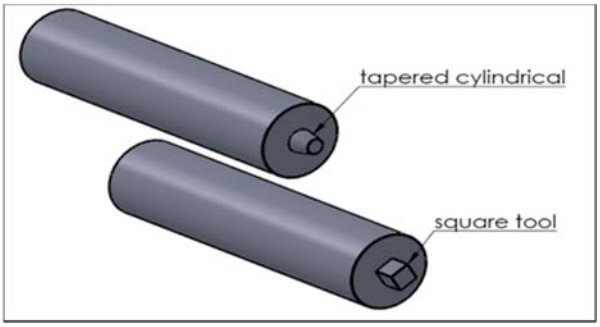


**Figure-1.** Schematic drawing of FSW tool.

Elangovan and Balasubramanian studied welding of 6061 aluminum alloy using several friction stir welding tool pins like straight cylindrical, cylindrical taper, threaded cylindrical, square, and triangular with different shoulder pin diameters viz., 15, 18, and 21-mm. In their investigation, square pins provided superior tensile properties with least number of defects [6]. The effect of tool pin profiles on mechanical and metallurgical properties of dissimilar 6351-5083 H111 aluminum alloy welds have been reported by Panaivel *et al.* Tool pin profiles such as straight cylindrical, threaded cylindrical, square, tapered square, and tapered octagon were used for the purpose and the square straight tool provided the best result [7].Vijay and Murugan investigated the effects of FSW tool pin profiles such as square, hexagon, and octagon, and concentric circular grooved shoulders on stir cast Al-10 wt-% TiB2 metal matrix composite welds and reported that the tapered pin produced narrower stir zones with coarser grains compared to that of the straight pin tools [8].

## Mechanical properties

Aluminium alloys show similar yield strength and fracture behavior [9-11]. Throughout these tests, it is shown that fracture will possibly occur at retreating side of the weld as the tensile strain restricted in the heat affected zone (HAZ) on both sides of the nuggets. Hence, it can be said that, mechanical behavior of the friction stir weld exhibits the importance of this localization region [9-11]. In another study, it is concluded that, hardness and tensile strength influence by the tool rotation speed. It is shown that, hardness within the weld was higher on the advancing side than on the retreating side [12]. This was supported by another study by Lee *et al* [13] of aluminium alloy 6005, the tensile strength and hardness increase as welding speed increases.

Extensive literature of friction stir welding of Al alloys does indicate that there are few areas particularly on the relationship between welding parameters and change in the mechanical properties of weldment. This study focuses on finding the optimal speed (rpm) and feed rate (mm/s) with respect to mechanical properties such as hardness number and tensile strength.

## EXPERIMENTAL PROCEDURE

The aluminium alloy AA6061 is used due to its high strength, ease of formability, corrosion resistance and heat-treatable. The tool material is tool steel K110 type. FSW performed on the samples according to factorial experimentation. ‘Dog bone’ samples are made by wire cut technique to undergo tensile strength testing. A normal rectangular piece from weld joint is tested with Rockwell Hardness scale B (HRB) test.

**Table-1.** Parameters selected for experiments.

| Parameters | 1 | 2 | 3 |
|---|---|---|---|
| Tool Geometry | Square (A1) | Tapered cylindrical (A2) | - |
| Feed rate (mm/min) | 20 (B1) | 40 (B2) | - |
| Rotating speed (rpm) | 1500 (C1) | 2000 (C2) | 2500 (C3) |

## Tool design

The mechanical properties of FSW joint are influenced by tool geometry. The tool stirs base material provides in-situ heating, and thus creates weld. There has been variety of tool shapes used in previous studies with different geometry in term of shoulder diameter, pin diameter; pin length and pin angle [17-18]. In this study the two tools used are square and tapered cylindrical with 20 mm shoulder diameter and 5mm pin length as shown in Figure-2.

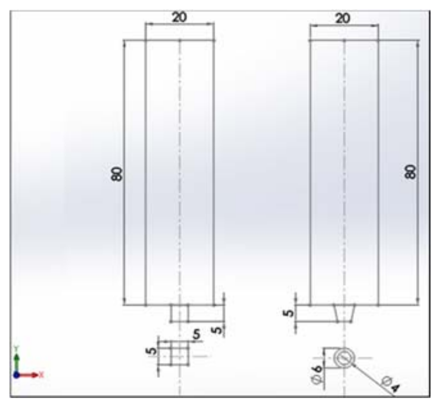

**Figure-2.** Dimensions of FSW tools.

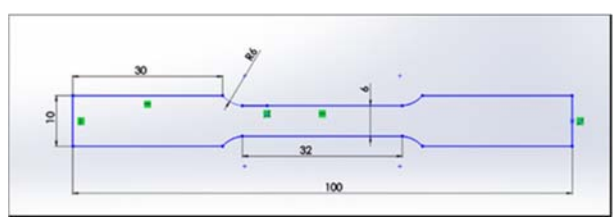

**Figure-3.** Dimensions of tensile test specimen (mm).

The rolled plates of 6 mm thickness, AA6061 aluminium alloy, have been cut into the required size (100mm × 50mm × 6mm). Square butt joint was formed

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by FSW in a single pass welding procedure. Non-consumable tools made of steel k110 have been used to make the joints. The chemical composition of tool material (steel k 110) are given in Table 2.The chemical composition of work piece material (AA6061) is presented in Table 3.

**Table 2.** Chemical composition (weight %) of the tool material (steel k110).

| **Chemical composition steel k110** (wt %) | | | | | |
|---|---|---|---|---|---|
| **C** | **Si** | **Mn** | **Cr** | **Mo** | **V** |
| 1.55 | 0.30 | 0.30 | 11.30 | 0.75 | 0.75 |

**Table 3.** Chemical composition (weight %) of AA-6061 aluminum alloy.

| **Chemical composition AA 6061 aluminium alloy** (wt %) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Mg** | **Si** | **Fe** | **Cu** | **Zn** | **Ti** | **Mn** | **Cr** | **Other** | **Al** |
| 0.8-1.2 | 0.4-0.8 | .7 | 0.15-0.4 | .25 | .15 | .15 | 0.04-0.35 | 0.05 | 98.7 |

The welded joints are cut using wire cutting machine to the required dimensions to prepare tensile specimens as shown in Figure-3.

American Society for Testing of Materials (ASTM E8M-04) guidelines is followed for preparing the test specimens. The specimen is loaded at the strain rate of 2mm/min as per ASTM specifications and extensometer is attached to specimen, so that tensile specimen undergoes deformation. Rockwell hardness is measured across the joint and perpendicular to the joint with 100 kg load according to the ASTM (E18-08b) standard. The hardness have been evaluated for Taper cylindrical and square tool pin.

## RESULTS AND DISCUSSIONS

### Tensile test

The result obtained from the tensile tests is presented in the Figures 4-7 below. It has been observed from the Figure-4 and Figure-5 that the feed rate influences the joint strength.

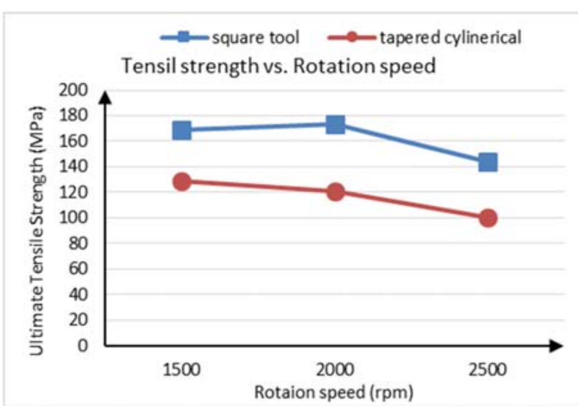


**Figure-4.** Effect of rotational speed and tool pin profile on tensile strength for feed rate (20 mm/min).

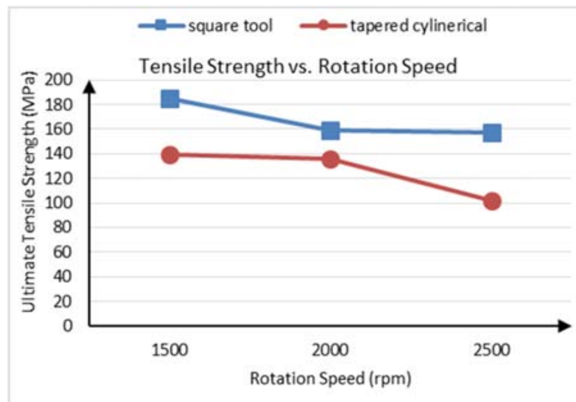


**Figure-5.** Effect of rotational speed and tool pin profile on tensile strength for feed rate (40 mm/min).

From the result obtained it can be inferred that the tool pin profile and rotational speed are having influence on tensile properties of the FSW joints. Of the twelve (12) joints, the joints fabricated by square tool profile exhibited better tensile properties compared to tapered cylindrical pin profile irrespective of rotational speed or feed rate.

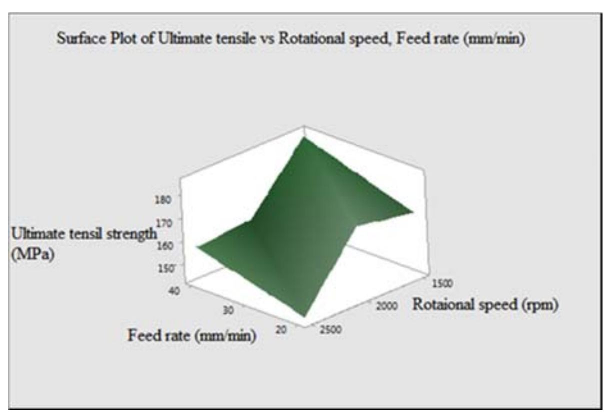


**Figure-6.** Response surface graphs of tool rotational speed and welding speed on UTS for the square tool.

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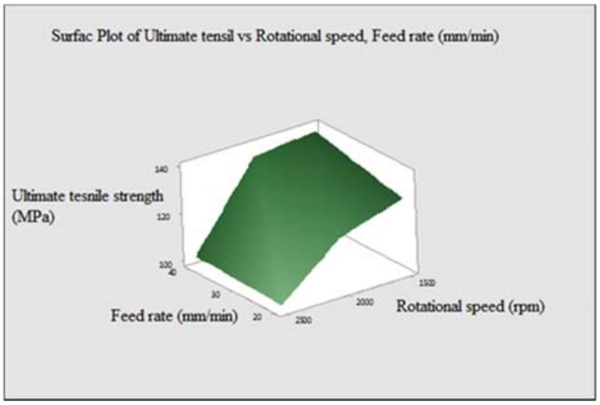


**Figure-7.** Response surface graphs of tool rotational speed and welding speed on UTS for the tapered cylindrical tool.

For the square tool profile, the joints made at a speed of 2500 rpm have shown lower tensile strength compared to the joints made at a rotational speed of 1500 rpm and 2000 rpm for both feed rate 20 and 40 (mm/min). The higher tool rotational speed leads to higher heat generation and this result in to the excessive release of stirred material to the upper surface. This phenomenon produced micro voids in the stir zone. Presence of micro voids affects the tensile properties of the joint fabricated at a rotational speed of 2500 rpm and hence this joints has low strength compared to joints made at a speed of 1500 rpm and 200 rpm. Similarly, for the tapered cylindrical tool profile the joints fabricated at a rotational speed of 2500 rpm have also shown lower tensile strength compared to the joints made at a rotational speed of 1500 rpm and 2000 rpm.

For the square tool the speed of 2000 rpm give the best result for the tensile properties with both feed rate compare to other speeds. For the tapered cylindrical tool the tensile property decrease with the increase of the rotational speed with both feed rate.

**Table-4.** Rockwell hardness (HRB) values on either side of the weld region from path of the weld.

| Tool Profile | Feed rate (mm/min) | Rotation speed (rpm) | Retreating side at 10 mm distance HRB | At weld centre HRB | Advance side at 10 mm distance HRB |
|---|---|---|---|---|---|
| Square tool | 20 | 1500 | 38 | 34.2 | 35.8 |
| Square tool | 20 | 2000 | 44 | 41.4 | 42 |
| Square tool | 20 | 2500 | 39.6 | 37.3 | 38.5 |
| Square tool | 40 | 1500 | 41.1 | 38.5 | 39.6 |
| Square tool | 40 | 2000 | 46.2 | 43 | 45 |
| Square tool | 40 | 2500 | 44.6 | 41.3 | 42.5 |
| Tapered cylindrical | 20 | 1500 | 36.5 | 34.5 | 35.2 |
| Tapered cylindrical | 20 | 2000 | 39.2 | 36.4 | 37.9 |
| Tapered cylindrical | 20 | 2500 | 37 | 33 | 34.5 |
| Tapered cylindrical | 40 | 1500 | 38 | 35.4 | 36.4 |
| Tapered cylindrical | 40 | 2000 | 45.3 | 40 | 43.2 |
| Tapered cylindrical | 40 | 2500 | 40.3 | 36.9 | 38 |

The best result for tensile strength was obtained from the joint fabricated at a rotational speed of 1500 rpm with feed rate of 40 (mm/min) for the square tool profile[7-8]. However, for the tapered cylindrical tool profiles the best result for tensile strength obtained with lowest speed of 1500 rpm irrespective of feed rate used [7-8].

**Hardness test**

To characterize the hardness of the weld region of the FSW, Rockwell hardness testing machine was used. The Rockwell hardness values on either side of the weld region, from the centre of the weld (nugget region), at different rotational speeds and welding speeds are shown in Table 4 and presented in the figures 8-11 below.

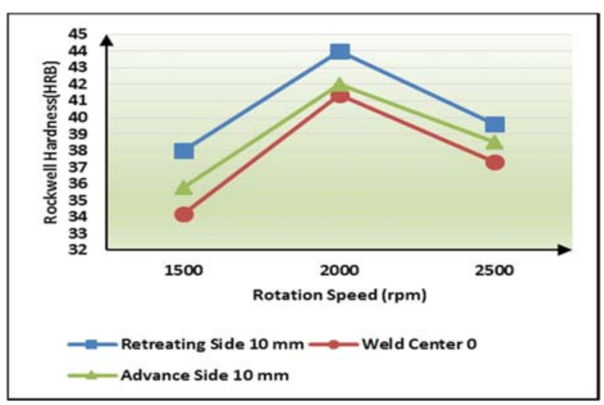


**Figure-8.** Effect of square tool profile and rotational speed on hardness at feed rate (20 mm/min).

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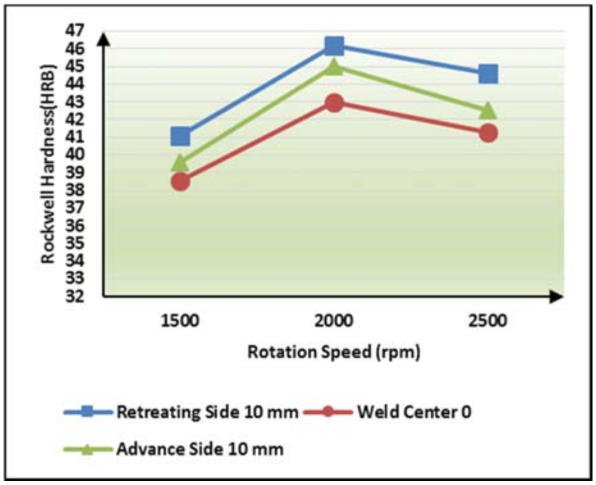


**Figure-9.** Effect of square tool profile and rotational speed on hardness at feed rate (40 mm/min).

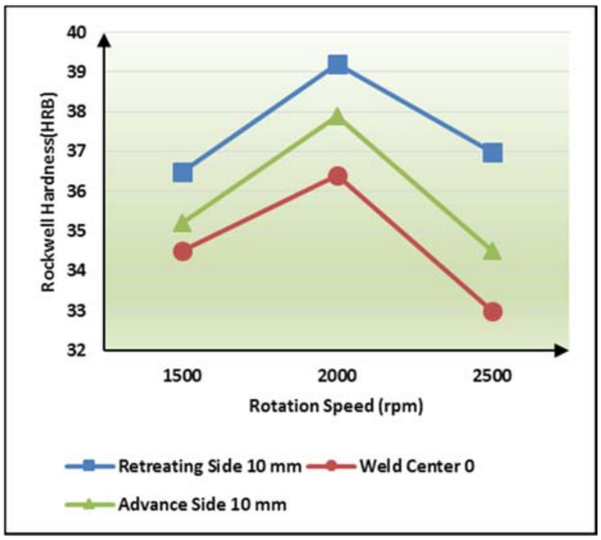


**Figure-10.** Effect of tapered cylindrical tool profile and rotational speed on hardness at feed rate (20 mm/min).

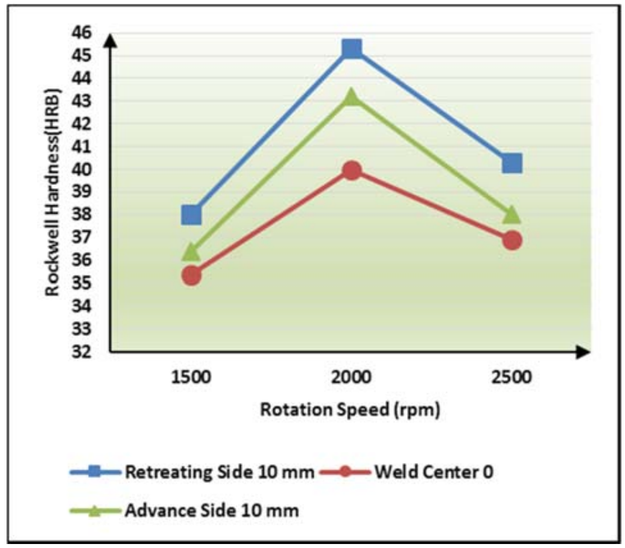


**Figure-11.** Effect of tapered cylindrical tool profile and rotational speed on hardness at feed rate (40 mm/min).

From the result obtained, the hardness values were found to be lower at the nugget zone. Advancing side (AS) show lower hardness values compared to retreating side (RS) irrespective of the tool rotational speed used. This is might be due to the slightly higher shear force and friction force resulting in high temperature in advance side (AS) as compared to retreating side (RS). Similar observations are also reported by other researches [15].

## CONCLUSIONS

In this investigation the effect of welding parameter (rotation speed, feed rate) and tool pin profile on the quality of FSW joints of AA6061 alloy have been studied. From the investigation the following important conclusions are derived:

i. Of the two tool pin profiles used in this investigation to fabricate the joints, square pin profiled tool produced the best tensile properties, irrespective of rotational speeds.

ii. Of the three rotation speed used in this investigation to fabricate the joints, the joints fabricated at a rotational speed of 1500 rpm showed better tensile properties, irrespective of tool pin profiles and feed rate.

iii. For the square tool pin profile the best tensile properties achieved with speed of 1500 rpm and feed rate of 40(mm/min).

iv. For the tapered cylindrical observed that with the increase of rotation speed the tensile properties decrease irrespective of feed rate used. The best tensile properties obtained with speed of 1500 rpm and feed rate of 20 (mm/min).

v. For the hardness it's observed that the retreating side (RS) have lower hardness value compared to the advance side (AS) for the both tools irrespective the weld speed and rotation speed.

vi. For the hardness it's observed that high value obtained for the speed of 2000 rpm irrespective the tool geometry or welding parameter.

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## REFERENCES

[1] MA, Z.Y. 2008. Friction Stir Processing Technology: A Review. Journal of the Minerals, Metals and Materials Society and ASM International, vol. 39A. DOI: 10.1007/s11661-007-9459-0.

[2] Rao, M.S.S., Kumar, R. and Hussain, M.M. 2012. Experimental Study of Weld Characteristics during Friction Stir Welding (FSW) OF Aluminum Alloy (AA6061-T6). International Journal of Research in Engineering and Technology, vol. 1(3) from: http://ijret.com/volumes/2012_11_Vol_01_Iss_03/P2 012_01_03_046.pdf

[3] Mishra, R.S. and MA, Z.Y. 2005. Friction Stir Welding and Processing. Journal of Materials Science and Engineering, R 50, 1-78. DOI: 10.1016/j.mser.2005.07.001.

[4] Storjohann, D., Babu, S.S., David, S.A. and Sklad, P. 2003. Friction Stir Welding of Aluminum Metal Matrix Composites from: https://www.aws.org/conferences/abstracts/2003/10c. pdf.

[5] Peel, M., Steuwer, A., Preuss, M. and Withers, P.J. 2003. "Microstructure, Mechanical Properties and Residual Stresses as a Function of Welding Speed in Aluminium AA5083 Friction Stir Welds", Journal of Acta Materialia, 51, 4791-4801. DOI: 10.1016/S1359-6454(03)00319-7. 19

[6] Elangovan, K., and Balasubramanian, V. 2008. "Influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in AA6061 aluminium alloy", Materials and Design 29: 362-373.

[7] Palanivel, R., Mathews, P. K., and Murugan, N. 2010. "Influences of tool pin profile on the mechanical and metallurgical properties of friction stir welding of dissimilar aluminum alloys", Int. Journal of Engg. Science and Technology. 2(6): 2109–2115.

[8] Vijay, S. J., and Murugan, N. 2010. "Influence of tool pin profile on the metallurgical and mechanical properties of friction stir welded Al-10 wt-% TiB2 metal matrix composite", Materials and Design 31: 3585-3589.

[9] Padmanaban, G., and Balasubramanian, V. 2009. "Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy - An experimental approach", Materials and Design 30: 2647-2656.

[10] Peel M, Steuwer A, Preuss M, Withers PJ. 2003. "Microstructure, mechanical properties and residual stresses as a function of welding speed in AA5083 friction stir weld", Acta Mater; 51: 4791-801.

[11] Neto, D.M. and Neto, P. 2012. "Numerical modeling of the friction stir welding process: a literature review", International Journal of Manufacturing Technology, 65:115–126. DOI: 10.1007/s00170-012-4154- 8.

[12] Thomas, W.M., Johnson, K.I. and Wiesner, C.S. (2003). Friction Stir Welding - Recent developments and Process Technologies. Journal of Advance engineering Materials, vol. 5(7). DOI: 10.1002/adem.200300355.

[13] Lee, W.B., Yeon, Y.M., Jung, S.B. 2003. "The improvement of mechanical properties of friction stir welded A 6005 Al alloy", Mater. Sci. Eng. A355 154-159.

[14] Cavaliere, P., Squillace, A., Campanile, G., Panella, F., 2006. Effect of welding parameters on mechanical and microstructural properties of AA6056 joints produced by friction stir welding. J. Mater. Process. Technol. 180, 263-270.

[15] Hassan, A.A., Prangnell, P.B., Norman, A.F., Price, D.A., Williams, S.W., 2003. "Effect of welding parameters on nugget zone microstructure and properties in high strength aluminium alloy friction stir welds", Sci. Technol. Weld. Join. 8, 257-268.

[16] Kim, Y.G. *et al*. 2006. "Effect of welding parameters on microstructure in the stir zone of FSW joints of aluminum die casting alloy", Materials Letters, 60(29-30), pp.3830-3837.

[17] Ericsson M., Sandstrom, R. 2003. Influence of welding speed on the fatigue of friction stir welds, and comparison with MIG and TIG. Int. J. Fatigue 25, 1379-1387.

[18] Srinivasa Rao P, Vimalan *et al*. 2015. Effect of Tool parameters on Mechanical Properties of Friction Stir Welded Aluminum Alloy, Applied Mechanics and Materials Vol. 786, pp. 111-115.