International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 12 (2015) pp. 30277-30285

http://www.ripublication.com

# Effect of FSW Process Parameters on Dry Sliding Wear Behavior of Friction Stir Welded Dissimilar Aluminum Alloy AA6061 T6 and AA5083 O

**Sabitha Jannet**
*Asstprofessor, karunyauniversity, Coimbatore*
*P. Koshy Mathews*
*Dean, Kalaivani college of technology,coimbatore*

## Abstract

Joining of dissimilar aluminum alloy using fusion welding has been a challenging task.Friction stir welding (FSW) is arelatively new solid state welding which overcomes all the setbacks of fusion welding.An attempt has been done to FSW dissimilar aluminum alloys and analyse the effect of the process parameters such as tool pin profile, tool rotational speed, traverse speed and axial force on the wear rate and wear resistance of the joints. A central composite design with four factors and five levels were run to reduce experiments.

**Keywords:** FSW, Wear resistance, wear rate

## Introduction

The major FSW process parameters which influence the joint strength and microstructure are tool rotational speed, welding speed, axial force and tool tilt angle [1]. The dimensions and especially shape of the tool play a crucial role to obtain sound joints. Rai et al reported that the tool design significantly alters material flow and consolidation of plasticized material during welding [2].Jayaraman inferred that the rotation of the tool results in stirring and mixing of material around the rotating pin. The rotational speed (N) is a significant process variable since it tends to influence the transitional velocity. Higher tool rotation speed generates higher temperature because of high frictional heating which results in more intense stirring and mixing of material [3]. The rate of stirring of plasticized material determines the formation of defects. Excessive stirring of plasticized material will result in tunnel defects. Lack of stirring will result in lack of bonding. Azimzadegan and Serajzadeh (2010) observed an increase in the width of stir zone with increased tool rotational speed [4]. Karthikeyan reported that tool rotational speed influences the temperature in the stir zone and subsequent grain growth [5].An excessive axial force results in higher amount of flash leading to defects.The magnitude of axial force decides the coefficient of friction between the tool and the workpieces [6]. Zhang and Zhag investigated the effect of axial pressure in FS welding of AA6061 aluminum alloy and reported that the maximum temperature and plastic deformation could be increased with an increase in the axial pressure. The axial force applied through the rotating tool causes the plasticized metal to extrude around the tool pin in the vertical direction and get consolidated in the back side when the tool moves forward. Both the stirring and extrusion cause the elongated grains to into smaller grains nd fracture the strengthening precipitates into very fine particles [7].Oyuang and Kovacevicobserved that the axial force wasdirectly responsible for the plunge depth of the tool pin into the work piece and load characteristics associated with linear FS weld. When the axial force was relatively low, there was a tunnel found at the bottom. While with higher axial force, the weld was observed to be sound with full penetration. It showed that sufficient axial force was required to form good weld. It was due to the temperature during FS welding defining the amount of plasticized metal, and the temperature was greatly dependent on the axial force [8].FSW eliminates fusion welding defects. But FSW can induce other serious defects such as pin hole, worm hole, kissing bond, tunnel and voids [10][11].The primary function of the non-consumable rotating tool pin is to stir the plasticized metal and move the same behind it to have good joint. Tool design plays a critical role in FSW process. Tool design influences the material flow and in turn governs the traverse rate at which FSW can be carried out. The factors attributed to tool design are tool material, tilt angle, shoulder diameter and pin length, pin diameter and pin profile.

## Experimental Details

### Finding the Limits of Control Variable

In order to find the working range of process parameter viz., the tool rotational speed, welding speed and axial force, trial runs were conducted using all the five different tools to find the upper and lower limit of process parameters for AA6061-T6 and AA5083 aluminum alloy, by varying one of the parameters and keeping the rest of them at constant values. The limits of the FS welding parameter were identified based on the visual inspection for the smooth appearance without any visual defects such as cracks undercut etc. The crown appearances of good quality of FS welds are shown in Figure 4.3. The upper limit of the parameter is coded as +2 and lower limit as -2. The intermediate coded values are calculated from the following relationship.

$$X_i = 2\,[2X - (X_{max} + X_{min})] / (X_{max} - X_{min})$$

Where

$X_i$ is the required coded value of a variable X

X is any value of the variable from $X_{min}$ to $X_{max}$.

$X_{min}$ is the lower limit of the variable

$X_{max}$ is the upper limit of the variable.

The selected process parameters with their limits, units and notations are given in Table 1.

**Table 1:** FSW Process Parameter and Its Level

| Description | Units | Notations | Level | | | | |
|---|---|---|---|---|---|---|---|
| | | | **-2** | **-1** | **0** | **1** | **2** |
| Tool pin profile | - | P | CT | C | SS | TS | TC |
| Tool rotational speed | rpm | N | 600 | 775 | 950 | 1125 | 1300 |
| Welding speed | Mm/min | S | 36 | 49.5 | 63 | 76.5 | 90 |
| Axial force | ton | F | 1 | 1.25 | 1.5 | 1.75 | 2 |

**Friction Stir Welding Set Up**

The experimental set up consists of a special purpose machine specially designed for FS welding process. The machine was designed and fabricated by M/s R.V.Machine tools, Coimbatore, India. The machine incorporates the main components such as rotating spindle, tool head, horizontal control and automated process controls which make the FS welding operation controllable. The spindle speed can be varied over a wide range between 100 rpm and 3000 rpm by using a variable speed motor drive. The spindle speed is accurately displayed in a digital indicator. The tool head exerts an axial downward force along the spindle which can be varied between 2.5 kN and 50 kN which is indicated in a digital indicator. The downward force is responsible for the plunging of the FS welding tool in to the work piece, and to generate the frictional heat between the rotating tool and the work piece. The work table (700 x 350 mm) consists of two axis movement along the horizontal plane. The first movement is along the length of the table (X - axis) and the second is the crosswise movement (Y-axis). The X axis movement can be controlled by using the hydraulic control unit or manually, whereas the Y axis movement is controlled manually. The top of the table is attached with specially designed fixtures to hold the work piece rigidly. The maximum stroke length of the table is 600 mm. The machine can be operated under automated mode using which the FS welding process can be carried out at the accurate preset values of the process parameter viz. tool rotational speed (N), welding speed(S), and axial force (F). Figure 1 shows the FS welding machine which is used for this research work. The aluminum alloy rolled plate of thickness 6 mm were cut into rectangular plates of size 110 x 60 mm. All the four side of the rectangular plates were machined in a milling machine to the required size of 100 x 50 mm. The two work pieces were fixed on the table of FS welding machine using special fixture to form the square butt joint configuration of 100 x 100 mm. The plate AA6061-T6 was fixed with the advancing side and AA5083 0 was fixed with the retreating side of the fixtures of the machine. The FSW line was parallel to the rolling direction of AA5083-O and perpendicular to the rolling direction of AA6061-T6. The tool which is fixed on the spindle is plunged into the work piece to be welded with help of axial force (F) while rotating the tool by tool rotational speed (N) then tool was moved over the work piece along the direction of welding speed(S). The heating is produced due to friction between the tool and the work piece. The localized heating softens the material around the pin and solid state weld is formed behind the tool.


**Figure 1:** FSW Machine

**Wear Testing Set Up**

The dry sliding wear behavior was measured using a pin-on-disc wear apparatus (DUCOM TR20-LE) at room temperature according to ASTM G99-04 standard. Figure 2 shows the experimental setup used for this study. The polished surface of the pin was slid on a hardened chromium steel disc. A computer-aided data acquisition system was used to monitor the loss of height.A square pin of size 6 x 6 x 30 mm was prepared parallel to thewelding speed direction from each welded plate. The direction of extraction of wear specimen from the welded plate is shown in Figure 3 Figure 4 shows the extracted wear specimens from the welded plate. The polished surface of the pin was slid on a hardened chromium steel disc. The test was carried out at a sliding velocity of 1.5 m/s, normal force of 25 N and sliding distance of 2500 m. The wear parameters were selected to yield an appreciable steady state wear based on trial experiments. A computer-aided data acquisition system was used to monitor the loss of height. The volumetric loss of the worn material was computed by multiplying the cross section of the test pin with its loss of height. The wear rate (W) and wear resistance (R) were calculated (Mandal et al 2007) as follows and given as experimental values respectively. The wear rate was calculated by dividing the volumetric loss with sliding distance. Sample test specimens are as shown in figure 3.

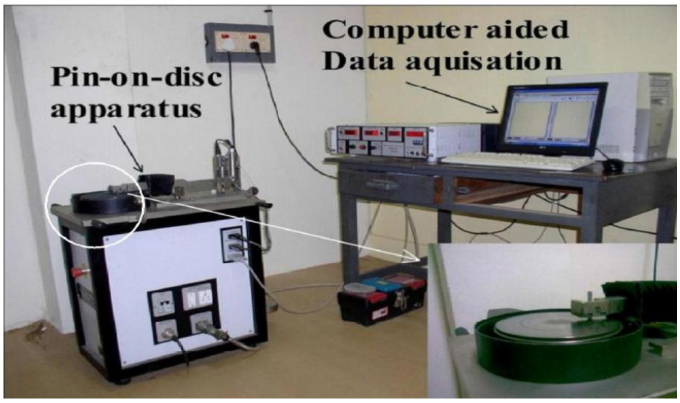


**Figure 2:** Pin on Disc Set Up

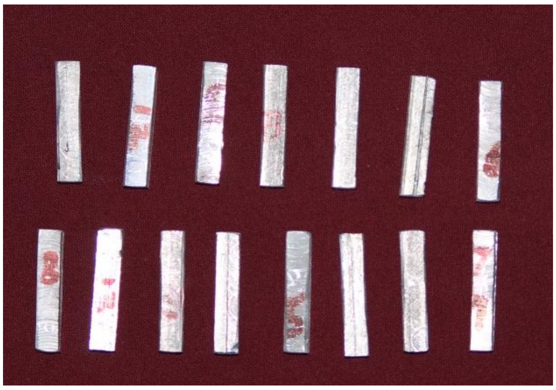

**Figure 3:** Sample Wear Test Specimens

## Results and discussion

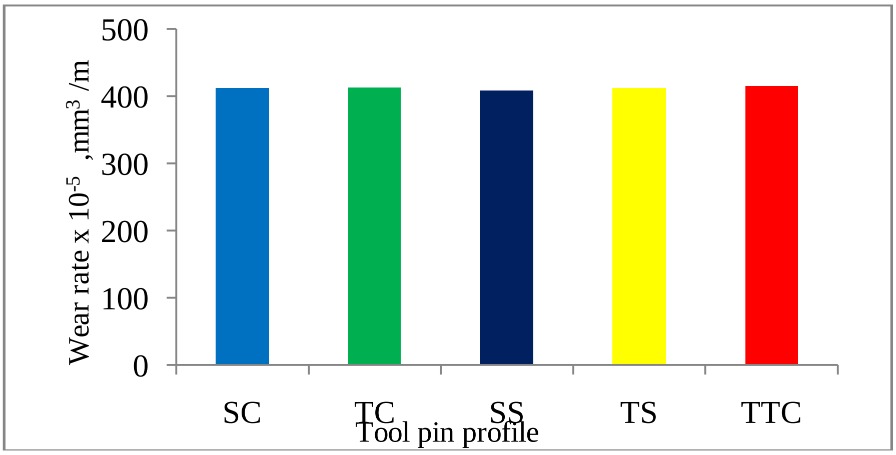


**Figure 5:** Effect of Tool Pin Profile on The Wear Rate

Figure 7 shows the effect of tool rotational speed on dry sliding wear behavior of friction stir welded dissimilar aluminum alloy AA6061and AA5083 O. The wear rate decreases as tool rotational speed increases and reaches minimum at 950 rpm. Further increase in tool rotational speed leads to the increase of wear rate. The wear resistance follows an inverse trend of wear rate. The upper and lower limit of tool rotational speed induced defect while the dissimilar joints welded at 950 rpm had no defect. The tool rotational speed generates frictionalheat as well as stirring and mixing of material around the tool pin. Optimum stirring and sufficient heat generation are required to produce sound joints with fine recrystallized grains.Higher tool rotational speed leads to higher heat generation more than required and releases materials due to excessive stirring. Excessive stirring causes turbulent flow of plasticized material resulting in the creation of micro level voids. The frictional heat generated during welding affects the grain size and Mg2Si precipitates [13].Coarsening of grains and dissolution of Mg2Si precipitates present in this alloy at higher tool rotational speeds. The thermal cycle does not promote nucleation and growth of Mg2Si precipitates[14]. Therefore, coarsening of grains and dissolution of Mg2Si precipitates together with tunnel defect cause increase in wear rate.

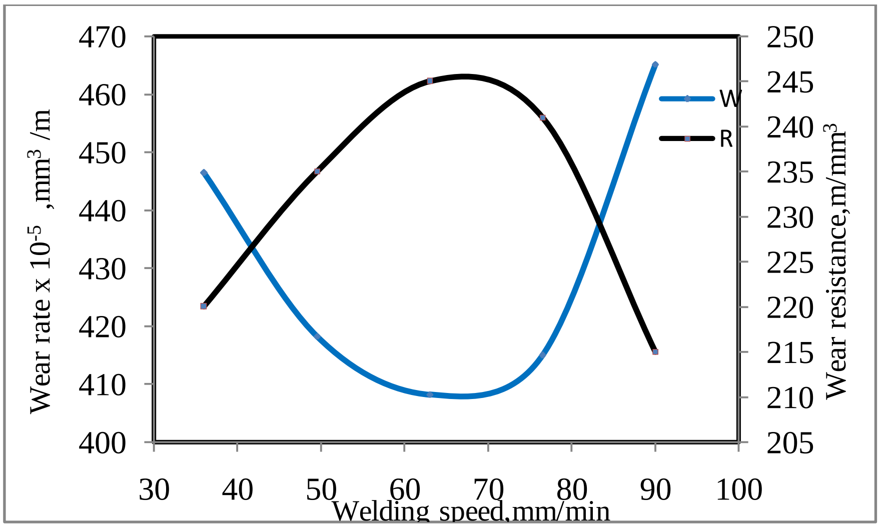


**Figure 7:** Effect of Welding Speed on Wear Behaviour

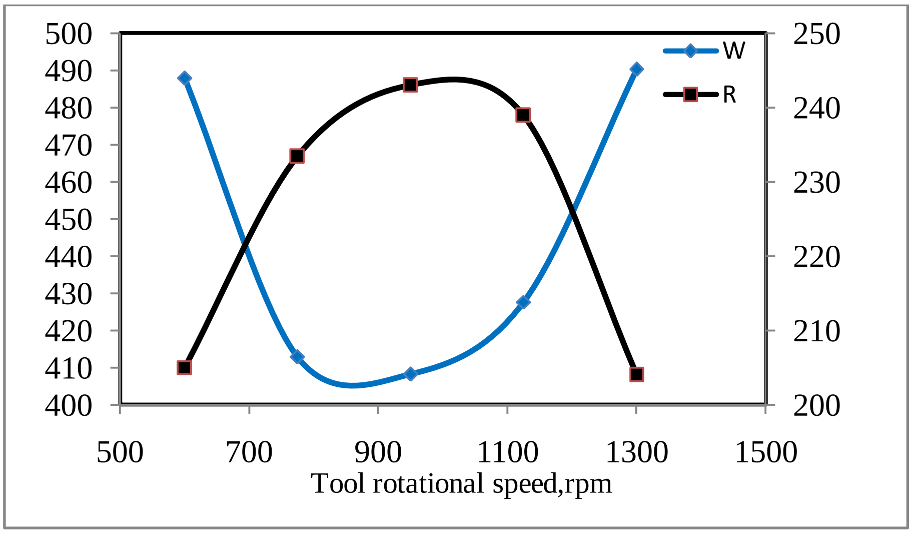


**Figure 8:** Effect of tool rotational speed on wear behaviour

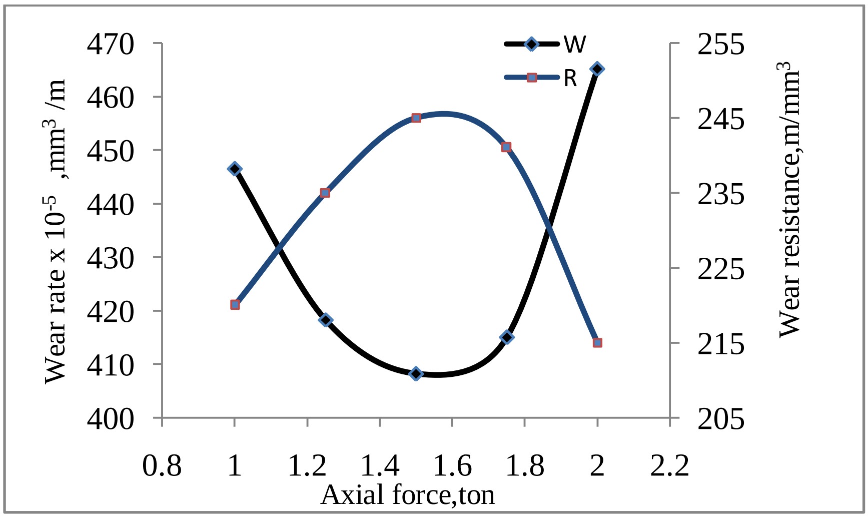


**Figure 9:** Effect of axial force on wear behavior

Figure 9 shows the effect of axial force on dry sliding wear behavior of friction stir welded dissimilar joints AA6061 T6 and AA5083 O. The wear rate decreases as axial force increases and reaches minimum of 1.5 ton. Further increase in axial force leads to the increases of wear rate. The wear resistance follows an inverse trend of wear rate. The upper and lower limit of axial force respectively induced tunnel and worm hole defect while the dissimilar welded at 1.5 ton had no defect.Bonding occurs in FSW when a pair of surfaces is brought in the vicinity of inter atomic forces. Adequate axial force exceeding the flow stress of material is required to obtain defect free joints. Axial force propels the plasticized material in the weld zone for the completion of the extrusion process. Axial force is also responsible for extending the plunge depth of the pin[11].The frictional heat generated between the tool shoulder and the surface of the plates to be welded dependents upon the coefficient of friction which is altered by the axial force. Optimum frictional heat coupled with sufficient extrusion of plasticized material is required to produce sound welds. When this condition is encountered during welding the joint will yield higher UTS and lower wear rate. The joint fabricated at 1.5 ton exhibited higher UTS and wear resistance, lower wear rate.Whenaxial force increases frictional heat generation also increases. Lower heat is generated at lower axial force and cause improper consolidation of material [12]. A tunnel defect appears at lower axial force resulting in reduced UTS and increased wear rate. Higher heat exceeding the desired level is generated at higher axial force. The plunge depth of the tool into the welded plate is higher at higher axial force which causes a worm hole. Further the flash level increases with increased axial force causing local thinning of welded plate leading to reduced UTS and increased wear rate at higher axial forces. The axial force influences the plastic flow of material, change in grain size and formation of defects.

## Conclusions

The increase in the tool rotational speed, welding speed and axial force leads to the decrease in the wear rate; and it reaches a minimum value and then increases. The increase in the rotational speed, welding speed and tool axial force leads to the increase in the wear resistance which reaches a maximum value and then decreases.. The FS welded joints produced using straight square pin profiled tool with tool rotational speed of 950 rpm, welding speed of 63 mm/min and axial force of 1.50 ton better wear properties.

## References

[1] Nandan, R., Debroy, T. and Bhadeshia, H.K.D.H. “Recent advances in friction stir welding - process weldment structure and properties”, Prog. Mater. Sci., Vol.53, No.6, pp.980-1023, 2008

[2] Rai, R., De, A., Bhadeshia, H.K.D.H. and DebRoy, T. “Review: friction stir welding tools”, Sci. Technol. Weld Joining., Vol.16, No.4, pp.325-342, 2011

[3] Jayaraman, M., Sivasubramanian, R., Balasubramanian, V. and Lakshmi narayanan, A.K. “Effect of process parameters on tensile strength of friction stir welded cast LM6 aluminium alloy joints”, J. Mater. Sci. Technol., Vol.25, No.5, pp.655-664, 2009b.

[4] Azimzadegan, T. and Serajzadeh, S. “An investigation into microstructures and mechanical properties of AA7075-t6 during friction stir welding at relatively high rotational speeds”, J. Mater. Eng. Perform., Vol.19, No.9, pp.1256-1263, 2010

[5] Karthikeyan, L., Senthilkumar, V.S. and Padmanabhan, K.A. “On the role of process variables in the friction stir processing of cast aluminum A319 alloy”, Mater. Des., Vol.31, No.2, pp.761-771, 2010.

[6] Colligan, J., Konkol, J., Fisher, J., James. J. and Pickens, R. “Friction stir welding demonstrated for combat vehicle construction”, Weld. J., Vol. 82, No.3, pp.1s-6s. 2003

[7] Zhang, Z. and Zhang, H. W. “Numerical studies on effect of axial pressure in friction stir welding”, Sci. Technol. Weld Joining., Vol.12, No.3, pp.226-248, 2007

[8] Ouyang, J.H. and Kovacevic, R. “Malerial flow and microstructure of the friction stir butt welds of the same and dissimilar aluminum alloys”, J. Mater. Eng. Perform, Vol. 11, No.1, pp.51-63. 2002.

[9] Chen, H.B., Yan, K., Lin, T., Chen, S.B., Jiang, C.Y. and Zhao, Y. “The investigation of typical welding defects for 5456 aluminum alloy friction stir welds”, Mater. Sci. Eng., A., Vol.433, No.1-2, pp.64-69, 2006.

[10] Li, B., Shen, Y. and Hu, W. “The study on defects in aluminum 2219- T6 thick butt friction stir welds with the application of multiple nondestructive testing methods”, Mater. Des., Vol.32, No.4, pp.2073-2084,2011

[11] Kumar, K. and Kailas, S.V. “On the role of axial load and the effect of interface position on the tensile strength of a friction stir welded aluminum alloy”, Mater. Des., Vol.29, No.4, pp.791-797, 2008

[12] Elangovan K. and Balasubramanian, V. “Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminum alloy”, J. Mater. Process. Technol., Vol.200, No.1- 3, pp.163-175, 2008

[13] Karthikeyan, L., Senthilkumar, V.S. and Padmanabhan, K.A. “On the role of process variables in the friction stir processing of cast aluminum A319 alloy”, Mater. Des., Vol.31, No.2, pp.761-771, 2010

[14] Azimzadegan, T. and Serajzadeh, S. “An investigation into microstructures and mechanical properties of AA7075-t6 during friction stir welding at relatively high rotational speeds”, J. Mater. Eng. Perform., Vol.19, No.9, pp.1256-1263, 2010