International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 12 (2018) pp. 10365-10371


# Experimental Investigation of Friction Stir Welding on AA 5052 H32

**Anant Kumar Gupta*** **and Sunil Kumar Yadav****

** PG student, Mechanical Engineering Department, M.M.M.U.T., Gorakhpur, U.P. India.*
*** Assistant professor, Mechanical Engineering Department, M.M.M.U.T., Gorakhpur, U.P., India.*

**Abstract**

Friction stir welding (FSW) is an effective mean of solid-state joining. It can weld thin plates with good weld joint that's why it is gradually replacing the riveting technique. In recent years, the application of Aluminium alloys gained a good attention because of its advanced mechanical, physical and tribological properties. Aluminium alloy 5052 H32 has very good corrosion resistance, weldability, high fatigue strength and moderate strength. In this paper, FSW of 2 mm thick AA5052 H32 plates were performed .The weld joint was tested for ultimate tensile strength (UTS) and Brinell harness number (BHN). Taguchi method was used to obtain the optimum process parameters and then ANOVA test was carried out to find the contribution and most significant process parameter effecting the ultimate tensile strength and Brinell hardness number.

**Keywords:** Friction stir welding, AA5052, ANOVA analysis, Ultimate tensile strength, BHN

## INTRODUCTION

Friction stir welding is relatively new solid state welding process. FSW was initially invented by the 'The Welding Institute (TWI)' in December 1991 in the United Kingdom. The patents of the FSW process are also held by the TWI, UK [1]. This welding technique can weld a wide range of materials and as it needs almost negligible pre welding preparations, thus automation of this technique can reach to a high degree.

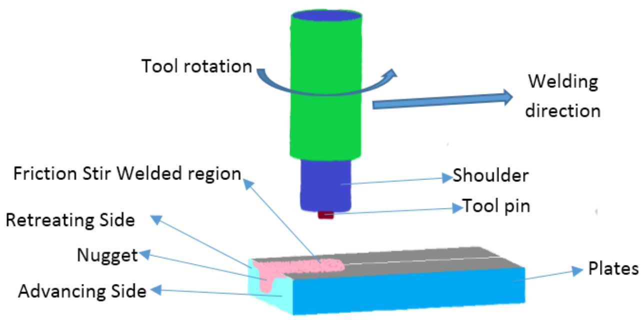



**Figure 1.** Systematic diagram of Friction stir welding

FSW uses a non-consumable tool for joining the two plates or faces without melting the material of the work piece. The heat in FSW is mainly generated due to the friction between the rotating tool and work piece material which ultimately soften the stirred region and welding take place [2]. In FSW, parameters can be classified on the basis of welding parameters, tool design and joint configuration. The welding parameters consist of tool rotation speed, welding speed, and axial forces. Former two parameters are more significant than the last one. The properties of base material is also effect the weld quality. The tool design is very important because welding parameters are dependent on the design of tool. The parameters involve in tool design are pin diameter, shoulder diameter, profile of pin and shoulder, plunge depth, and tilt angle. Each of these parameters are significant and affect the quality of weld. The design of joint is also important and it involves like parallelness of edges and smoothness of edges of plates to be joined [3].

## LITERATURE REVIEW

Rao C.M. et al [4] had investigated the microstructure and hardness of the AA6061 joints obtained by the FSW. They found the average gain size in order as follows: HAZ >TMAZ>NZ. The minimum hardness value was 80.2 HV in HAZ and maximum value was 106.32 in base metal (BM). The tensile strength of weld zone were less than that of BM. Rhodes C.G. et al. [5] had studied the microstructural changes occur in AA7075-T6 due to FSW. They found that there were recrystallization of the grains in the weld nugget and the dislocation density in nugget was lower than the base metal. Kimapong K. et al. [6] had investigated the effect of tool geometries on AA 6061-T1.They found that left and right screw pin profiles were producing good joints compared to cylindrical and conical tool. The maximum tensile strength was 168 MPa at 2000 rpm and 125mm/min welding speed. Trimble D. et al. [7] had studied the effect of FSW on 4.8mm thick AA2024-T3 plates. They found that triflute pin was most effective shape for higher welding speeds and scroll shoulder design was better than concave shoulder design. Kwon Y. et al. [8] had done FSW of 2 mm thick AA5052-O at various rotational speed and found that the grain size was smaller in stir zone (SZ) than the base material, and it was decreases with the increase of tool rotation speed. Roudini G. et al. [9] had investigated the effect of tool design at various welding and tool rotation speeds on AA5052. They found Stir zone was dynamically recrystallized and tensile strength was either equal or greater than base material because of grain growth and less welding defects. Kumbhar N.T. et al. [10] had investigated the effect of FSW on AA5052 and they found that Advancing Side (AS) has shear and grain fragmentation, and nugget region had equiaxed grains.

## EXPERIMENTAL PROCEDURE

In this study, thin plates of AA 5052 H32 were used. The dimension of the plates were 200x85x2 mm. The aluminium alloy 5052 H32 sheet was initially cut into the required size from the big sheet by shearing operation. The sheets were then end milled by the vertical milling machine. The milling of the plates brings the accuracy in terms of smoothness and make edges parallel and also milling removes hardness and stresses induced by the shearing at the edges. The plate edges were cleaned by the emery papers to remove burrs and scratch marks formed due to the milling tool cutting edges. This makes the smoother and thus reduces the gap between two edges of plates. The chemical composition of AA5052 H32 is shown in table 1.

**Table 1** Composition of AA 5052 H32 [11]

| Component | Al | Mg | Cr | Si | Fe | Zn |
|---|---|---|---|---|---|---|
| Wt. % | 95.7-97.7 | 2.2-2.8 | 0.15-0.35 | Max 0.25 | Max 0.4 | Max 0.1 |

In my experiment, the tool pin material was H13 die steel having cylindrical shape. The tool has pin diameter of 4 mm, pin length of 1.8 mm and shoulder diameter of 14 mm.

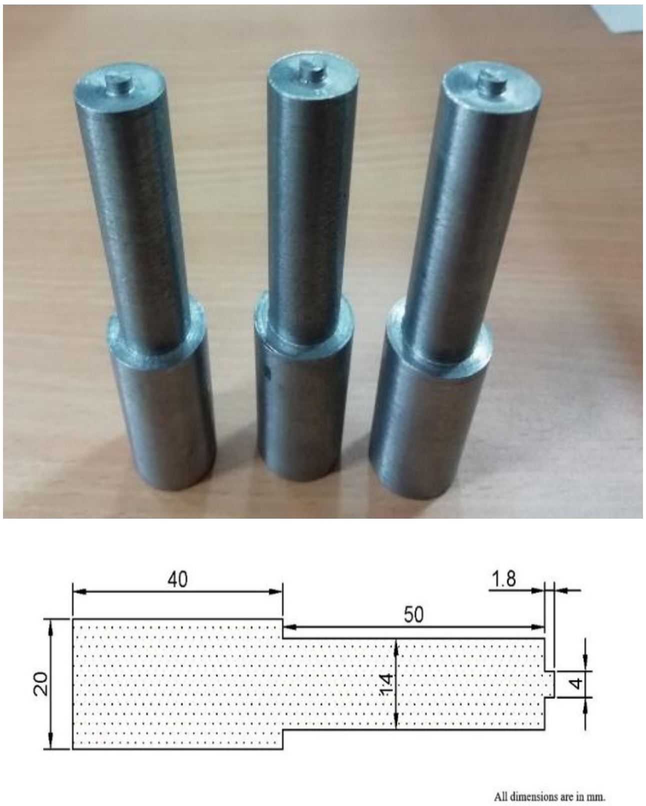



**Figure 2.** Steel tool and their dimensions

The two important parameters i.e. welding speed and rotational speed of tool was considered for the experiment. There were three levels was selected the each parameters.

**Table 2.** Process parameters and their levels

| Parameters | Level 1 | Level 2 | Level 3 |
|---|---|---|---|
| **Welding speed (mm/min)** | 30 | 40 | 50 |
| **Rotational speed of tool (rpm)** | 1300 | 1400 | 1500 |

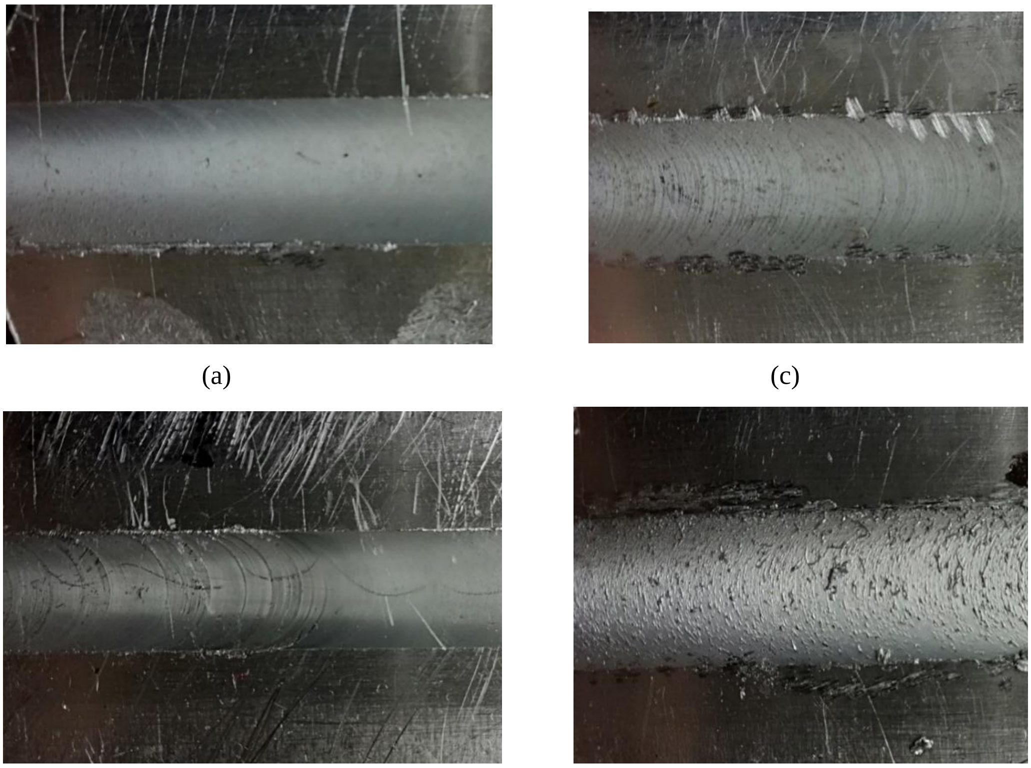
By using the design of experiment (DOE), L9 orthogonal array (OA) was selected for carrying out the experiment is shown in table 3.

**Table 3.** Experimental table based on L9 OA

| Experiment number | Welding speed mm/min | Rotational speed rpm |
|---|---|---|
| 1 | 30 | 1300 |
| 2 | 30 | 1400 |
| 3 | 30 | 1500 |
| 4 | 40 | 1300 |
| 5 | 40 | 1400 |
| 6 | 40 | 1500 |
| 7 | 50 | 1300 |
| 8 | 50 | 1400 |
| 9 | 50 | 1500 |

FSW was performed according to the L9 OA by using computer numerical controlled (CNC) vertical machining centre with power capacity of 3.5kW at the spindle.

**Figure 3.** FSW welded plate



(a) (c)

(b) (d)

**Figure 4.** FSW welded plates at various process parameters (a) 1400 rpm, 40mm/min (b) 1400 rpm,30 mm/min (c) 1500 rpm ,40 mm/min (d) 1300 rpm ,50 mm/min

## RESULTS AND DISCUSSIONS

### Tensile test and hardness test

The tensile test was performed by using the UTM machine [model UTM-60].There were nine specimens were made from the each friction stir welded samples. The specimens were cut perpendicular to the direction of weld.

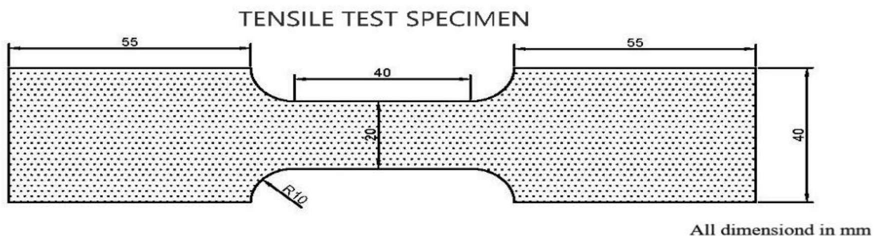



**Figure 5.** Tensile test specimen

**Figure 6.** specimen after tensile test

The data obtained by tensile test is tabulated in table 4. The hardness test was performed on the Brinell hardness testing machine. It was performed at the centre of the stir zone using 100 Kgf load and 10 mm hardened steel ball indenter. The obtained Brinell hardness number is tabulated in table 4.

**Table 4.** UTS and BHN for different process parameters

| Exp. No. | Input parameter | | Response parameter | |
|---|---|---|---|---|
| | Welding speed (mm/min) | Rotational speed (rpm) | Ultimate tensile strength (MPa) | Brinell hardness number |
| 1 | 30 | 1300 | 162.5 | 41 |
| 2 | 30 | 1400 | 175.0 | 43 |
| 3 | 30 | 1500 | 175.0 | 45 |
| 4 | 40 | 1300 | 162.5 | 44 |
| 5 | 40 | 1400 | 187.5 | 48 |
| 6 | 40 | 1500 | 175.0 | 46 |
| 7 | 50 | 1300 | 137.5 | 39 |
| 8 | 50 | 1400 | 162.5 | 43 |
| 9 | 50 | 1500 | 150.0 | 42 |

## Optimization by Taguchi Method and ANOVA test

### A. Ultimate Tensile Strength (UTS)

For obtaining the optimum process parameter, Taguchi method was used to find the signal to noise ratios. The Larger-the-Better criteria was used for UTS. The S/N ratio was calculated by using the given formula:

$$\text{S/N ratio} = -10\log\left(\frac{1}{n}\sum\frac{1}{y2}\right) \qquad \ldots\ldots(1)$$

where n is number of observations and y is observed data. The S/N ratios obtained by using Minitab 18 software is tabulated in table 5.

**Table 5.** Tabulated S/N ratios for UTS

| Welding Speed (mm/min) | Rotational speed (rpm) | Ultimate tensile strength (MPa) | S/N Ratio |
|---|---|---|---|
| 30 | 1300 | 162.5 | 44.21707 |
| 30 | 1400 | 175.0 | 44.86076 |
| 30 | 1500 | 175.0 | 44.86076 |
| 40 | 1300 | 162.5 | 44.21707 |
| 40 | 1400 | 187.5 | 45.46003 |
| 40 | 1500 | 175.0 | 44.86076 |
| 50 | 1300 | 137.5 | 42.76605 |
| 50 | 1400 | 162.5 | 44.21707 |
| 50 | 1500 | 150.0 | 43.52183 |

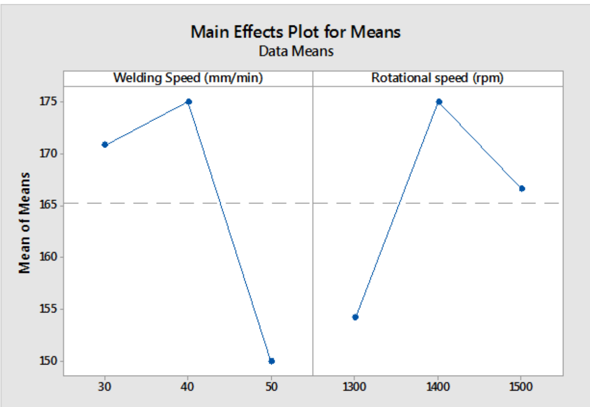



**Figure 7.** S/N Ratio plot for different input parameter

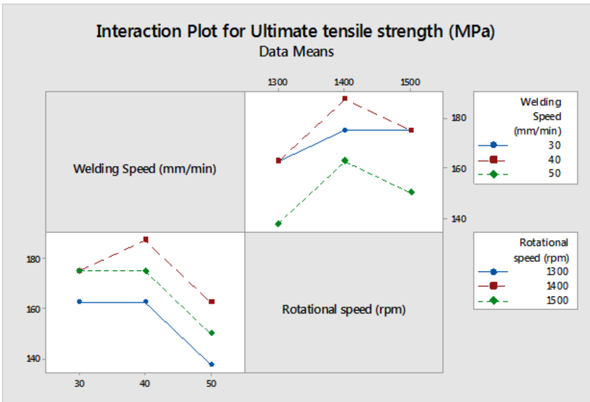



**Figure 8.** Interaction plot for UTS

From fig.7, it is clear that the optimum FSW parameter for UTS is 1400 rpm and 40 mm/min. Now, the optimum response can be predicted by using formula [12]:

$$\varphi = \frac{T}{n} + \left(\gamma_{WS2} - \frac{T}{n}\right) + \left(\gamma_{RS2} - \frac{T}{n}\right) \qquad \ldots\ldots\ldots (2)$$

Where $T/n$ is overall mean of tensile strength, $\gamma_{WS2}$ is avg. tensile strength of 2$^{nd}$ level of welding speed, and $\gamma_{RS2}$ is avg. tensile strength of 2$^{nd}$ level of tool rotational speed .The predicted value for UTS is

$$\varphi = 165.28 + (175 - 165.28) + (175 - 165.28)$$

$$= 184.72 \text{ MPa}$$

The maximum value of UTS obtained in the experiment was 187.5 MPa. Hence, experimental value of UTS is deviated by 1.50% from the predicted value.

Now, applying ANOVA test for understanding the effect of factors on the UTS .The ANOVA test was done by using Minitab 18 software and results for UTS are tabulated in table 6.

From table 6, it is clear both welding speed and rotational speed is significant and percentage contribution shows the relative power of factor to reduce the variance.

## B. Hardness

The larger-the-better criteria is also used for Brinell hardness number and the S/N ratios are tabulated in table 7.

**Table 6.** Analysis of Variance for UTS

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | % contribution |
|---|---|---|---|---|---|---|
| Welding Speed (mm/min) | 2 | 1076.39 | 538.19 | 31.00 | 0.004 | 59.62 |
| Rotational speed (rpm) | 2 | 659.72 | 329.86 | 19.00 | 0.009 | 36.54 |
| Error | 4 | 69.44 | 17.36 | | | 3.84 |
| Total | 8 | 1805.56 | | | | 100 |

**Table 7.** Tabulated S/N ratios for BHN

| Welding Speed (mm/min) | Rotational speed (rpm) | Brinell Hardness Number (BHN) | S/N Ratios |
|---|---|---|---|
| 30 | 1300 | 41 | 32.2557 |
| 30 | 1400 | 43 | 32.6694 |
| 30 | 1500 | 45 | 33.0643 |
| 40 | 1300 | 44 | 32.8691 |
| 40 | 1400 | 48 | 33.6248 |
| 40 | 1500 | 46 | 33.2552 |
| 50 | 1300 | 39 | 31.8213 |
| 50 | 1400 | 43 | 32.6694 |
| 50 | 1500 | 42 | 32.4650 |

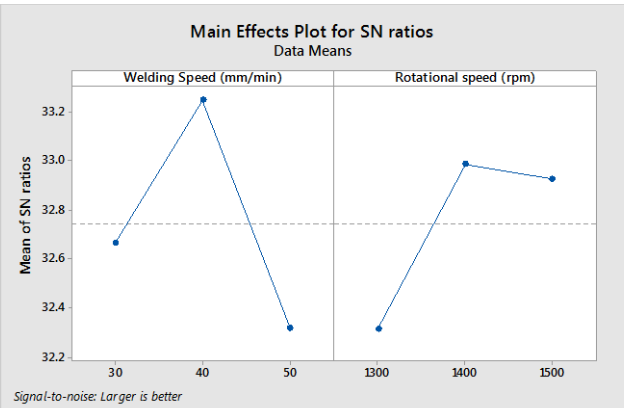



**Figure 9.** S/N Ratio plot for different input parameter

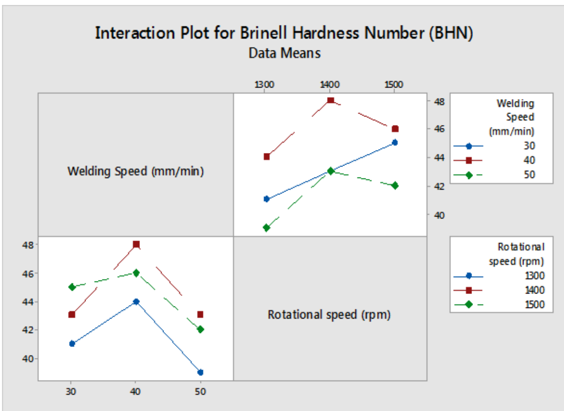



**Figure 10.** Interaction plot for BHN

Form Fig.9, the optimum input parameter for BHN is 1400 rpm and 40 mm/min. Now, the optimum response can be predicted by using formula [12]:

$$\varphi = \frac{B}{n} + \left(\mu_{WS2} - \frac{B}{n}\right) + \left(\mu_{RS2} - \frac{B}{n}\right) \quad \ldots\ldots\ldots\ldots.. (3)$$

Where $B/n$ is overall mean of tensile strength, $\mu_{WS2}$ is avg. brinell hardness number of 2nd level of welding speed, and $\mu_{RS2}$ is avg. brinell hardness number of 2nd level of tool rotational speed .The predicted value for BHN is

$$\varphi = 43.44 + (46 - 43.44) + (44.67 - 43.44)$$

$$= 47.43$$

The maximum value of BHN obtained in the experiment was 48. Hence, experimental value of BHN is deviated by 1.20% from the predicted value. The ANOVA test was done by using Minitab 18 software and results for BHN are tabulated in table 8.

**Table 8.** Analysis of Variance for BHN

| Source | DF | Adj SS | Adj MS | F-Value | P-Value | % contribution |
|---|---|---|---|---|---|---|
| **Welding Speed (mm/min)** | 2 | 33.556 | 16.778 | 15.10 | 0.014 | 57.63 |
| **Rotational speed (rpm)** | 2 | 20.222 | 10.111 | 9.10 | 0.032 | 34.73 |
| **Error** | 4 | 4.444 | 1.111 | | | 7.64 |
| **Total** | 8 | 58.222 | | | | 100 |

From table 8, it is clear both welding speed as well as rotational speed is significant for Brinell hardness number.

## CONCLUSIONS

The value obtained through the experiment shows that the ultimate tensile strength and hardness are maximum at 1400 rpm and 40 mm/min, and minimum at 1300 rpm and 50 mm/min. Reddy et al. [13] had also welded the AA5052 H32 plates but of thickness 1.6 mm and 2 mm with tool angle 1.91°. They were achieved the best welding properties at 1400rpm and 63 mm/min, which is close to the results obtained in these experiments.

The maximum value of ultimate tensile strength and Brinell hardness number achieved in the experiment is 187.5 MPa and 48 respectively. Both the factors i.e. welding speed and rotational speed significantly affect the ultimate tensile strength and Brinell hardness number.

## REFERENCES

[1] Mishra, R.S. and Ma, Z.Y., 2005. Friction stir welding and processing. *Materials Science and Engineering: R: Reports*, *50*(1-2), pp.1-78.

[2] Mishra, R.S., De, P.S. and Kumar, N., 2014. *Friction stir welding and processing: science and engineering*. Springer.

[3] Heidarzadeh, A., Barenji, R.V., Esmaily, M. and Ilkhichi, A.R., 2015. Tensile properties of friction stir welds of AA 7020 aluminum alloy. *Transactions of the Indian Institute of Metals*, *68*(5), pp.757-767.

[4] Raoa, C.M. and Raob, K.M., 2017. Evolution of Microstructure and Hardness of Aluminium 6061 after Friction Stir Welding. *International Journal of Theoretical and Applied Mechanics*, *12*(3), pp.405-410.

[5] Rhodes, C.G., Mahoney, M.W., Bingel, W.H., Spurling, R.A. and Bampton, C.C., 1997. Effects of friction stir welding on microstructure of 7075 aluminum. *Scripta materialia*, *36*(1), pp.69-75.

[6] Kimapong, K., Kaewwichit, J., Roybang, W., Poonnayom, P. and Chantasri, S., 2015. Friction Stir Welding Tool Geometries Affecting Tensile Strength of AA6063-T1 Aluminum Alloy Butt Joint. *International journal of advanced smart convergence*, *4*(1), pp.145-153.

[7] Trimble, D., O'Donnell, G.E. and Monaghan, J., 2015. Characterisation of tool shape and rotational speed for increased speed during friction stir welding of AA2024-T3. *Journal of Manufacturing processes*, *17*, pp.141-150.

[8] Yong-Jai, K.W.O.N., Seong-Beom, S. and Dong-Hwan, P.A.R.K., 2009. Friction stir welding of 5052 aluminum alloy plates. *Transactions of Nonferrous Metals Society of China*, *19*, pp.s23-s27.

[9] Roudini, G., Shiri, S.G. and Rahvard, M.M., 2012. Tool design and speed parameters effects on microstructure and tensile strength of friction stir welding (FSW) 5052 Al alloys. *Applied Mechanics and Materials* Vol. 110, pp. 3165-3170.

[10] Kumbhar, N.T., Sahoo, S.K., Samajdar, I., Dey, G.K. and Bhanumurthy, K., 2011. Microstructure and microtextural studies of friction stir welded aluminium alloy 5052. *Materials & Design*, *32*(3), pp.1657-1666.

[11] ASM International, ASM International. Handbook Committee and ASM International. Alloy Phase Diagram Committee, 1990. *Metals Handbook: Properties and selection* (Vol. 2). ASM international.

[12] Salehi, M., Saadatmand, M. and Mohandesi, J.A., 2012. Optimization of process parameters for producing AA6061/SiC nanocomposites by friction stir processing. *Transactions of Nonferrous Metals Society of China*, *22*(5), pp.1055-1063.

[13] Reddy, P.J., Kailas, S.V. and Srivatsan, T.S., 2012. Effect of tool angle on friction stir welding of aluminum alloy 5052: Role of sheet thickness. In *Advanced Materials Research* (Vol. 410, pp. 196-205).