International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
Online International Journal Available at http://www.cibtech.org/jet.htm
2020 Vol. 10, pp. 267-274/Pradeep et al.
***Research Article** (Open Access)*

PREDICTING THE MECHANICAL PROPERTIES OF AA6061 AND AA7075 ALLOY JOINTS USING FRICTION STIR WELDING

***M. Pradeep, M. Sureshkumar, V. Aathavan, R. Ramamurthy**
Department of Mechanical Engineering,
St.Joseph's College of Engineering Thanjavur.

ABSTRACT
The main theme of this investigation is to calibrate the effect of welding parameters on the micro structural and mechanical properties of friction stir (FS) welded butt joints of dissimilar aluminum alloy AA6061 and AA7075. Friction stir welding (FSW) is a relatively new solid-state joining process. This joining technique is energy efficient, environment friendly, and versatile. This will be used to join aerospace aluminum alloys and other metallic alloys that are hard to weld by conventional fusion welding. In this process, two metal pieces, AA6061 and AA7075, 100 x 50 x 6mm thick, are welded under different welding parameters like tool rotation speed and transverse feed. The effects of welding parameters were evaluated by studying the resulting mechanical properties such as hardness distribution and tensile properties for axial welded zone.

***Keywords**: Aluminum Alloy AA6061, AA7075, Friction Stir Welding, conventional fusion welding, Hardness and microstructure*

INTRODUCTION
Aluminum is the second abundant metal on earth. Good material characteristics with unique qualities of aluminum and its alloys such as low density, high specific strength, physical and mechanical properties and corrosion resistances, greatly grew the production and use of this metal and its alloys. For example, in many commercial applications, specific strength of material plays an important role in material selection, aluminum and its alloys are proper candidates for these types of applications. . It is extensively used in the aerospace applications because it has good formability, weldability, machinabilty, corrosion resistance and good strength compared to other aluminum alloys. When using the conventional arc welding techniques, long butt or lap joints between AA 6061 and other aluminum alloys are particularly difficult to make without distortion because of high thermal conductivity and special welding procedures and high levels of welder skill are generally required.
AA 7075 aluminum alloy is an aluminum alloy, with zinc as the primary alloying element. It is strong, with strength comparable to many steels, and has good fatigue strength and average the first AA 7075 was developed in secret by a Japanese company, Sumitomo Metal, in 1943.
Friction Stir Welding (FSW) is a solid state welding process developed and patented by The Welding Institute (TWI) in 1991. It is emerged as a novel welding technique to be used in high strength alloys that were difficult to join with conventional welding techniques Friction Stir Welding (FSW) is a relatively new joining process that has exhibited many advantages over traditional arc welding processes, including greatly reducing distortion and eliminating solidification. The present work aims to determine the feasibility to weld two pieces of aluminum plate (150 x 50 x 8 mm) by friction stir welding process and study the effect on the mechanical properties of welding joints.
In recent years, demands for light-weight and/or high strength sheet metals such as aluminum alloys have steadily increased in aerospace, aircraft, and automotive applications because of their excellent strength to weight ratio, good ductility, corrosion resistance and cracking resistance in adverse environments
Several research works has been done on aluminum alloys by considering various weight percentage of low order composite materials, design of various process parameters (FSP) but very few literatures are available on higher order aluminum alloys relating the surface layer composite.

EXPERIMENTAL PROCEDURE

The Friction stir welds between AA7075-T651 and AA6061-T651 aluminum alloys were produced using FSW machine with hydraulic power pack motor of 2.2Kw /440V with 3000 rpm maximum rotational speed; 5000 mm/min as X axis rapid traverse speed and maximum axial thrust as 50kN. The thicknesses of both plates were 8 mm. The plates were in a butt joint configuration and the welding process was carried out normal to the rolling direction of the plate. The dimensions of the aluminum alloy plates are 150 mm length and 50 mm width. The welding process was accomplished at three rotational speeds, 710, 1000 and 1400 rpm, the axial feed is, 14, 20 and 28 mm/sec keeping axial load 12 kN and tilt angle 0º as constant. Simple Square (SS) tools used were machined from high speed tool steel and were hardened to 55HRC

Figure 1: Work piece of AA6061 & AA7075

In order to find tool rotational and transverse speed which results in best powder distribution, all combinations of transverse speeds 60 and 120 mm/min and various rotational speeds were used for experiments. To survey effect of increase in number of FSW passes and shift of tool rotational direction different passes on welding joints. A pin on disc test machine was employed for evaluating friction and wear properties of specimen.

METHODOLOGY

Taguchi Design of Experiments

Taguchi method is a powerful tool in quality Optimization makes use of a special design of orthogonal array (OA) to examine. Number of experiments used to design the orthogonal array for 2 parameters and 3 levels of welding parameters.

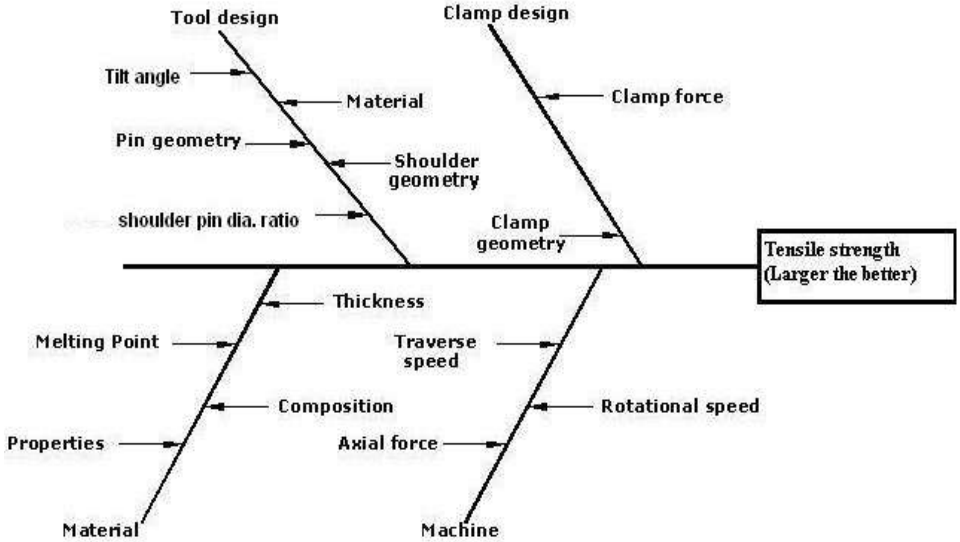


Figure 1: Cause and effect diagram of factors influencing friction stir welded (FSW) joint strength.

Determination of Working Limits of Parameters

A large number of trial runs were carried out using cast plates of AA7075 & AA6061 alloy (8 mm thick) to find out feasible working limits of FSW process parameters. Chemical composition of AA6061 alloy is as follows: Si-5.9; Cu-3.4; Fe-0.8; Mn-0.31; Zn-0.40; Mg-0.12; Ti-0.13; Al -88.94 % (wt basis). Working range of each parameter was decided upon by inspecting macrostructure (cross section of weld region) for a smooth appearance without any visible defects (tunnel defect, pinhole, crack, etc.). From above inspection, following observations have been made: I)

Work piece	*Spindle speed(rpm)*	*Feed (mm/sec)*
1	*710*	*14*
2	*710*	*20*
3	*710*	*28*
4	*1000*	*14*
5	*1000*	*20*
6	*1000*	*28*
7	*1400*	*18*
8	*1800*	*20*
9	*2000*	*27*

Table – 1: Friction stir Welding Parameters.

IV RESULTS AND DISCUSSION

Hardness

The hardness of the Aluminum 6061 & AA7075 and the surface layer composite were found with the help of Brinnell Hardness testing machine. Figure 2 shows the specimen after FSP. The effect of processing parameter on the surface hardness of plain AA6061 and AA6061/TiN MMC specimens was shown in Table 2.

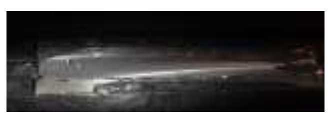
<table>
<tr><th>Material</th><th>Speed</th><th>Specimen</th></tr>
<tr><td rowspan="4">AA6061 & AA7075/TiN</td><td>710</td><td></td></tr>
<tr><td>1000</td><td></td></tr>
<tr><td>1400</td><td></td></tr>
<tr><td>2000</td><td></td></tr>
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Figure 2: Specimen after FSW

Table 2: Effect of Processing Parameters on Hardness

Spindle speed (rpm)	Axial feed (mm/sec)	Rockwell hardness			
		T1	T2	T3	Avg (hrc)
710	14	30	21	36	29.00
710	20	20	38	27	28.33
710	28	24	22	27	24.33
1000	14	28	22	26	25.33
1000	20	27	23	22	24.00
1000	28	23	26	21	23.33
1400	14	21	32	25	26.00
1400	20	21	28	26	25.00
1400	28	28	22	24	24.66

Increased traveling speeds causes' significant increment on the hardness value for all rotational speeds for AA6061/TiN & AA7075 specimens. The hardness of as received Al has an average of 55.80 BHN. The highest hardness value was obtained for change of passes at 1300 rpm and 120 mm/min for AA6061/TiN & AA7075 specimens. Contrary to these, an increase the rotation speed and increase travelling speed causes higher increases of hardness value. As a result, the hardness was enhanced with uniformly TiN additions, which may govern the mechanical properties of stirred zone.

Table 3: Response Table For Signal To Noise Ratio

Level	Spindle speed (rpm)	Axial Feed(mm/sec)
1	28.67	28.54
2	27.68	28.20
3	28.03	27.64
Delta	0.99	0.90
Rank	1	2

From the table value, it is clearly noted that, spindle speed is an influencing parameters for producing higher hardness on dissimilar AA6061 and AA7075 alloy optimized by single noise to ratio.

Wear Properties

The velocity and frictional force in sliding distances of 100mm and wear properties for all specimens for as- received aluminum and composite specimen is displayed in Table 3. Results show that fabrication of composite layer decreases wear rate, therefore improves wear resistance.

Fig .3 Pin on disc arrangement used for the surface wear study

TiN particles in composite layer sustain wearing loads and direct load contact of aluminum matrix. Also hardness enhancement with production of composite layer positively affects wear behavior. The particle in specimens FSPed with TiN powder prevents adhesive wearing and drastic material removal during wear test. Table 3 describes that specimen with two passes of FSP on change in direction has better wear rate. Decreases of grain size, increases the hardness and better dispersion of TiN particles in MMC with passes in opposite direction improves better wear properties.

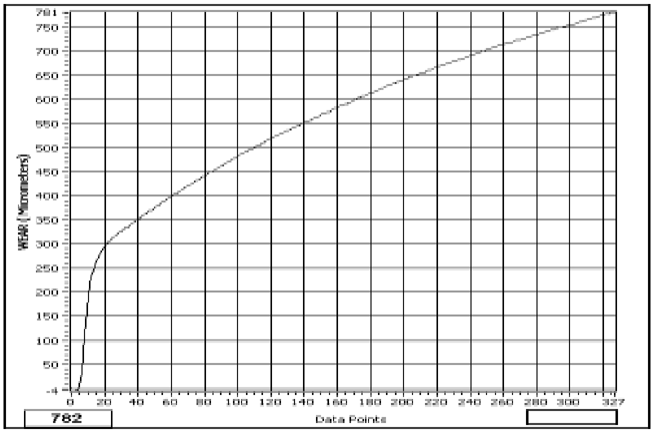

Fig .4 Effect of wear rate on normal Aluminum plate

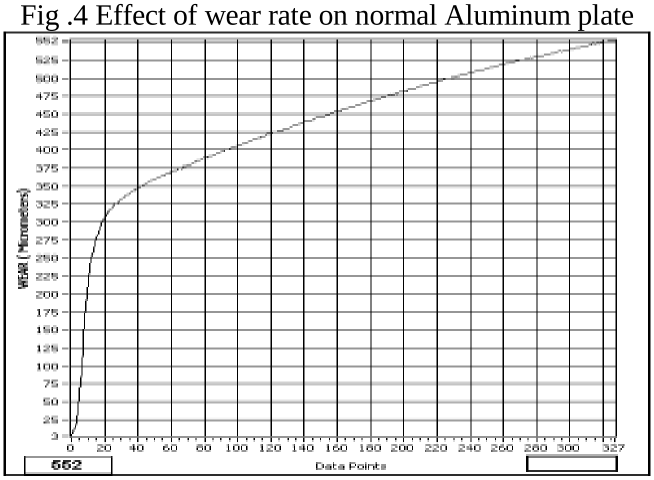

Fig .5 Effect of wear rate on composite layer

Friction Force (N)	Velocity (m/s)	Wear rate (mm3)
10	1	19.52
10	1	13.81
10	1	11.25

		T1	*T2*	*T3*	*Avg (hrc)*

Table 3 Wear Result

From the Table 3 it is observed that higher materials has high wear rate.

1.3 Analysis of Variance (ANOVA)

In order to assess influence of factors on response, means and signal-to-noise ratios (S/N) for each control factor are to be calculated. Signals are indicators of effect on average responses and noises are measures of deviations from experiment output. Appropriate S/N ratio must be chosen using previous knowledge, expertise, and understanding of the process[18]. In this study, S/N ratio was chosen according to criterion, larger-the-better, in order to maximize response. In Taguchi method, S/N ratio is used to determine deviation of quality characteristics from desired value.

Source	*DF*	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Spindle speed	*2*	*14.000*	*14.00*	*7.00*	*5.74*	*0.067*
Feed	*2*	*10.918*	*10.91*	*5.45*	*4.48*	*0.095*
Error	*4*	*4.878*	*4.878*	*1.21*	*--*	*--*
Total	*8*	*29.796*	*--*	*--*	*--*	*--*

Table 4 ANOVA values of friction stir welding process parameters

From Table -4 , it is clearly noted that for various degrees of freedom produces high hardened values for alloys AA6061 compared with the higher end alloys AA7075.

From the graph it is clearly measured for higher end alloys produces high tensile strength with various traverses speed.

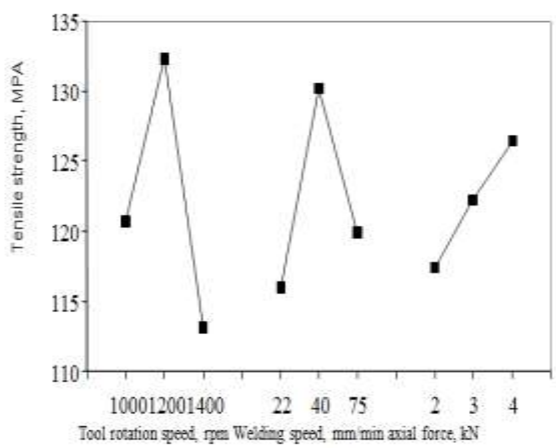

Fig .6 Response graph of tensile strength.

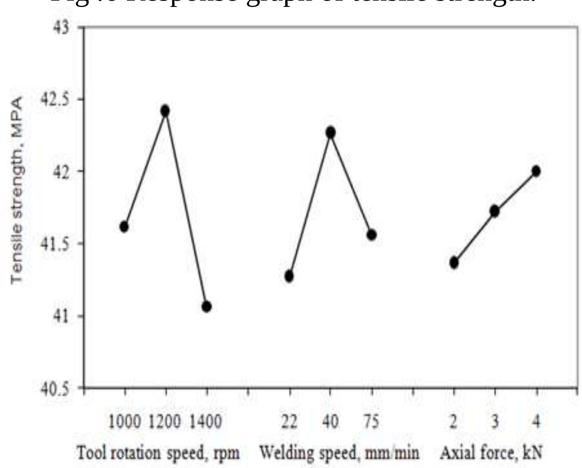

Fig .7 Response graph of (S/N Ratio) tensile strength

1.4 Regression Model

In order to correlate process parameters and TS of welded joints, a nonlinear regression model was developed to predict TS of FSW AA 6061 alloy based on experimentally measured TS. Regression coefficients were calculated using statistical software.

After determining significant coefficients (at 95% confidence level), final model developed. Adequacy of model was tested by using ANOVA. All terms including N, S, F, NS, N2, S2 and F2 were found to be significant at 95% confidence interval. The determination coefficient (R2) indicates goodness of fit for the model. In this case, R2 (0.985953) indicates that only < 1% of total variations are not explained by the model. The value of adjusted determination coefficient (adjusted R2 =0.97331) is also high, which indicates a high significance of the model. Predicted R2 is also made a good agreement with the adjusted R2.

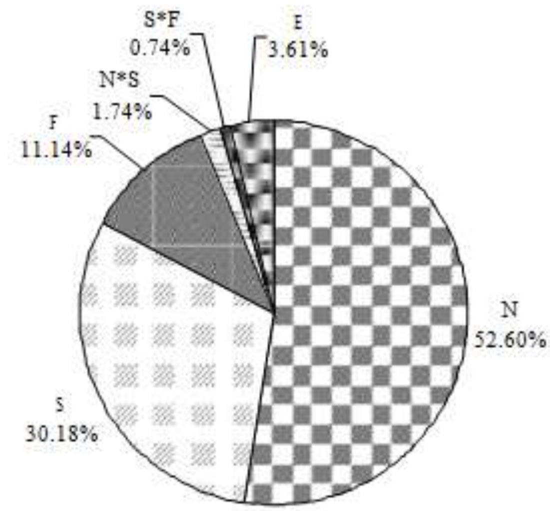

Fig .7 Regression Model of AA7075 Alloy.

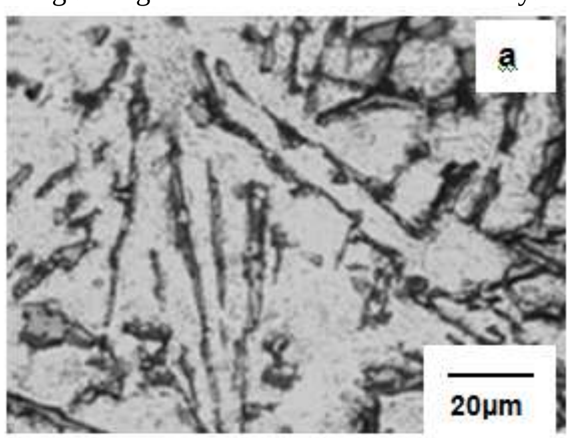

Fig 8 Macrostructure of dissimilar alloy after FSW.

CONCLUSION

In the present experimental work, dissimilar AA6061 and AA7075 alloy joints were made by FSW under different spindle speed and different axial feed. Summarizing the main features of the results, following conclusions can be drawn:

– Dissimilar AA 6061 and AA 7075 alloy joints producing better weldability and higher hardness, during friction stir welding process.
– Spindle speed played an important role for achieving higher hardness in friction stir welding process.
– The optimum parameter of friction stir welding process for producing higher hardness is spindle speed 710 rpm and axial feed 14 mm / sec.

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