

Experimental Investigation of Weld Characteristics during Friction Stir Welding of Aluminum Alloy 6351 Reinforced with AL_2O_3 Particles

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ABSTRACT: Several studies have been performed on friction stir welding of aluminum alloys and aluminum-based composites. The main objective of the present research work is to perform experimental investigation of friction stir welding (FSW) process with different rotational speeds of 1000rpm, 1200rpm, 1400rpm and welding speeds of 10mm/min, 20mm/min, 30mm/min on Al-6351 alloy reinforced with aluminum oxide particles size of 2 microns with reinforcement percentages of 5%, 10%, 15% and investigate the effect of these parameters on tensile properties and micro structure. The experimental design was carried out by using Taguchi L9 orthogonal array design and optimization using ANOVA

KEYWORDS: AL_2O_3 , Aluminum Matrix Composites, ANOVA, Friction Stir Welding, Stir casting, Taguchi Techniques

I. INTRODUCTION

Friction stir welding is an innovative process which is commonly known as solid state welding process. The innovative FSW Technique was invented by W.M.Thomas in December 1991 at The Welding Institute (TWI) Cambridge, U.K. In friction stir welding the joining process is carried out in solid state using a non consumable tool which produces the heat, which leads to a soft region near the FSW tool. Then the tool mechanically inter mixes the metal and forces it down along the two pieces to form a joint. FSW is primarily used on aluminum, and most often on extruded aluminum (non-heat treatable alloys), and on structures which need superior weld strength without a post weld heat treatment.

Advantages of friction stir welding include metallurgical benefits like solid state process with fine microstructure in the absence of cracking of the joint. Environmental benefits include – consumable material savings like rugs, wire or any other shielding gas. Applications of friction stir welding are employed in various industries like shipping and marine industries, aerospace industries, railway industries and in automobile industries.

In the current work friction stir welding is carried out on Al-6351 which is a commercial grade aluminum used in aerospace structures. The base material i.e. Al-6351 is reinforced with aluminum oxide (AL_2O_3) with different percentages so as to form a metal matrix composite. The chemical composition of Al-6351 is shown in table below.

The development of the friction stir welding FSW process and its applications to particles reinforced with aluminum particles have an opportunity for obtaining high quality joints in aluminum matrix composites materials.

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Table 1 Chemical Composition of Al-6351

Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Zn%	Ti%	Al%
0.956	0.204	0.032	0.578	0.685	0.017	0.001	0.017	Rem

Metal Matrix Composites (MMCs) are composed of a metal matrix and a reinforcement, or filler material, which confers excellent mechanical performance, and can be classified according to whether the reinforcement is continuous (monofilament or multifilament) or discontinuous (particle, whisker, short fiber or other). The principal matrix materials for MMCs are aluminum and its alloys. To a lesser extent, magnesium and titanium are also used, and for several specialized applications a copper, zinc or lead matrix may be employed. MMCs with discontinuous reinforcements are usually less expensive to produce than continuous fiber reinforced. Consequently, MMCs are generally accepted as offering the ultimate in terms of mechanical properties and commercial potential.

Aluminum matrix composites belongs main category of metal matrix composites. The aluminum matrix composites materials are widely applied in automotive and aviation industry because their high strength, high electrical and thermal conductivity and good wear resistance

Aluminum oxide, commonly referred to as alumina, possesses strong ionic inter atomic bonding giving rise to its desirable material characteristics. It can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperatures. Its high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for a wide range of application.

II. LITERATURE REVIEW

L.M. MARZOLI et.al.[1] Experimentally studied friction stir welding process parameters for an AA 6061 alloy reinforced with 20% of Al_2O_3 particles with tool $\varnothing 20$ mm shoulder, $\varnothing 8$ mm pin made of ultra hard material and determined thermal stability, micro and macrostructure, micro hardness and concluded 80% for yield strength and 70% for ultimate tensile strength. **L.M. MARZOLI et.al.[3]** Experimentally studied friction stir welding process parameters for an AA 6061 alloy reinforced with 20% of Al_2O_3 particles with tool $\varnothing 20$ mm shoulder, $\varnothing 8$ mm pin made of ultra hard material and determined thermal stability, micro and macrostructure, micro hardness and concluded 80% for yield strength and 70% for ultimate tensile strength.

L.CESCHINI et.al.[2] Experimentally studied the effect of friction stir welding over AA 7005 alloy reinforced with 10% Al_2O_3 particles with tool made of $\varnothing 18$ mm shoulder, tool pin profile with $\varnothing 8$ mm, length 6.8mm, left hand pitch 1.25 with material ferro-titanit. the parameters used are axial force 12KN, rotation speed 600RPM, welding speed 300MM/MIN and the microstructure, variation in tensile and low-cycle fatigue behaviour were studied.

G.ASHOK KUMAR et.al.[3] Experimental work on AA6061/8wt% of Al_3Zr composite was produced by the in situ reaction of molten aluminum and in organic salt K_2ZrF_6 through casting process. A double pass friction stir processing was carried out by using tool rotational speed of 1200rpm, travel speed of 50mm/min and axial force of 8kn. A tool made of HCHCR steel with oil hardened to 62 HRC with hexagonal tool profile is used and concluded that using stir casting technique a uniform distribution of Al_3Zr particles in aluminum matrix and also concluded FSP converted needle shape morphology of Al_3Zr particles into spherical shape which results in increase of hardness of the composite.

N.ARUN KUMAR et.al.[4] Investigated process parameters of friction stir welding on AA7075-T651 with 6.35mm thickness. The process is optimized by using ANOVA technique. FSW tool used is made of high carbon high chromium steel with 22mm diameter shoulder, 6mm diameter pin, 6mm length of pin with 1200rpm, 1600rpm, 2000rpm rotational speed for 50mm/min, 62mm/min, 74mm/min welding speeds at 2.0KN, 2.5KN and 3.0KN axial force and concluded that 62mm/min welding speed is favourable to weld with good properties.

M.V. NIRANJAN REDDY et.al.[5] explained Al 6351 has high corrosion resistance and is easily machinable and can have a wide variety of surface finishes along with good electrical and thermal conductivities and is highly reflective to

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heat and light. Due to the superior corrosion resistance, Al 6351 offers extremely low maintenance. In this investigation the tensile strength on circular rod specimen of Al 6351 is finding out by applying the loads on universal testing machine with various dimensions and conclusion derived are 250MPa tensile strength and 20% elongation of Al 6351 is nearer to the required strength for aerospace structures. The Al 6351 is best suited for the aerospace structures and the production rate is highly available at lowest possible cost due to its earlier manufacture for the pressure vessel cylinders.

MANDEEP SINGH SIDHU et.al.[6] Has given an overall view of friction stir welding along with its main process parameters which include rotation speed, tilting angle, welding speed, down force and tool profiles commonly available. Along with the application of FSW in various industries. Explained Current and future scope of FSW, several key matters to be addressed and performed some case studies.

CHENNAKESAVA REDDY et.al.[7] investigated the tensile behaviour of 6063/AL₂O₃ metal matrix composites which is fabricated by the investment casting process. The process is observed with 10%, 20% and 30% volume of alumina. And specimens used for tensile test are done in round double shape through investment casting technique and after the casting process the specimens are heat treated and concluded as the volume of alumina increases the yield strength and fracture strength increases and ductility decreases. The ductile fracture is observed in 10% volume composites and brittle fracture is observed in 20% and 30% volume composites and micrographs of 6063/AL₂O₃ composites indicate the distribution of AL₂O₃ particles in metal matrix composites and also performed EDS analysis which confirms the presence of all compounds in the 6063/AL₂O₃ composites.

AJAY KUMAR et.al [8] Experimental work is focused on the study of behaviour of Aluminum Cast Alloy (6063) with alumina (AL₂O₃) composite produced by the stir casting technique. Different % of alumina powder is used as reinforcement phase in this AMC. The experiment is conducted with 2.5%, 5%, 7.5%, 10% percentage of alumina. Various mechanical tests like tensile test, Hardness Test, Impact test are performed on the samples of AMC to evaluate the mechanical properties of this aluminum based metal matrix composites and concluded that Aluminum matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of AL₂O₃ particles. In the CHARPY V-notch test, with the increase in AL₂O₃% Impact strength increases w.r.t base metal. In Vickers hardness tester machine the hardness increases with increase in AL₂O₃ and in tensile test strength increases with increase in AL₂O₃%.

III. EXPERIMENTAL WORK

The aluminum matrix plates required for the friction stir welding are made by using AA6351-flat with (50mm width x 12mm thick) were melted in a furnace using a graphite crucible. The chemical composition of AA6351-flat was tested by using optical emission spectrometer and composition obtained is listed in table 1. Aluminum oxide with particle size of 2 microns is used to prepare the aluminum metal matrix composite. The temperature of the furnace is maintained at approximately nearer to 650°C. The calculated weight quantity of aluminum oxide is added into the molten aluminum. The molten material was stirred using a mixing stirrer at 750rpm for 15 min. After that slag is removed and the molten material was poured into the die. Castings were obtained with different weight percentage of (5%, 10%, and 15%) of aluminum oxide. Next the casted plates were employed to the rolling process to reduce the porosity of the plates. After rolling the plates are surface finished using milling operations to obtain required dimensions for welding operation. The obtained dimensions after milling are 200 X 100 X 5 mm.

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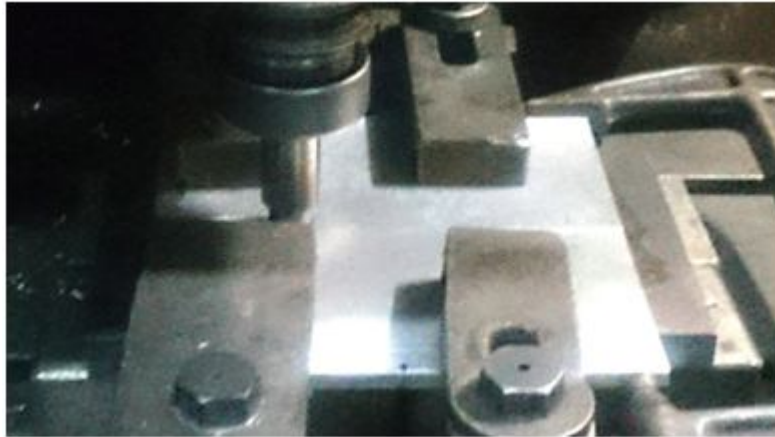


Figure 1 Performing Welding operation.

The friction stir welding process is carried out by using vertical CNC milling machine, maker HADNINGE VMC 800II. Initially one of the two plates to be welded is fixed to a specially designed fixture and its straightness is checked using a plunger gauge. Then the other plate is aligned to it. If the alignment is correct the plates are fixed tightly. After fixing the plates to fixtures a hole is drilled at the starting position of weld process to reduce the load on the machine then friction stir weld is carried out as per the experimental design of TAGUCHI L9 ORTOGONAL array which is showed in below table. The experiment is performed using taper threaded pin profile made of H13 tool steel with oil hardened with 62 HRC

Table 2 Experimental Layout

Rotational speed (Rpm)	Travel speed (Mm/Min)	Reinforcement (Percentage)
1000	10	5
1000	20	10
1000	30	15
1200	10	10
1200	20	15
1200	30	5
1400	10	15
1400	20	5
1400	30	10

IV. RESULTS AND DISCUSSIONS

After welding the micro structures of the specimens were checked using a scanning electron microscope (SEM) by cutting a small square piece with 1 cm dimensions in the weld region. The small square piece is mounted on the holding pin and is subjected to chemical cleaning process. Next the micro structures of the specimens were taken at a magnification of 25000X. The micro structure revealed a pattern of the matrix composite consisting of AL_2O_3 reinforced with aluminum. The percentage of AL_2O_3 in the matrix was confirmed by EDS analysis. The figure below shows the sample microstructures of the specimens.

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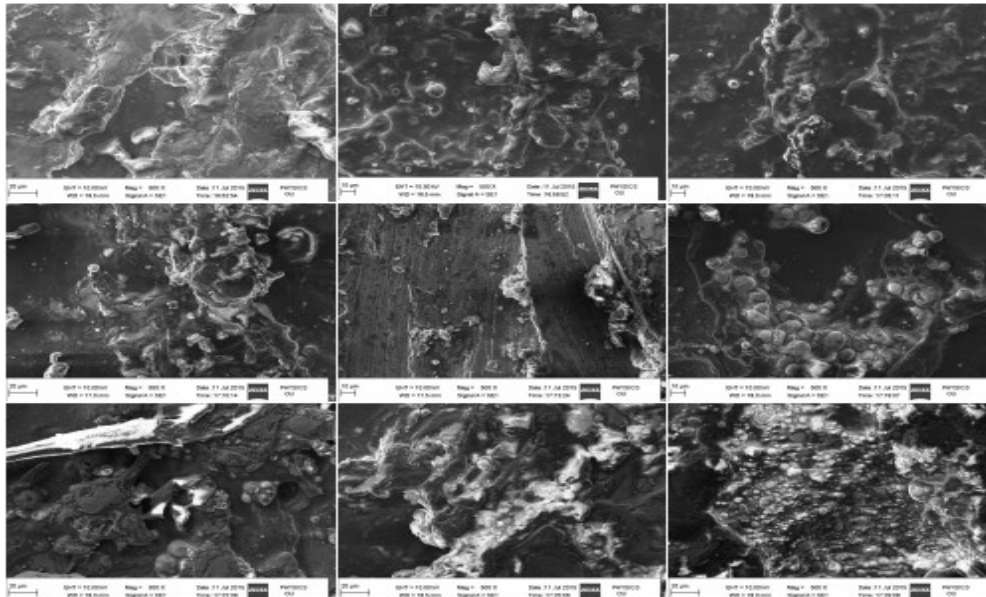


Figure 2 Microstructures of the specimens with 25000X magnification

Now the welded plates are subjected to tensile test cut according to ASTM E8M-04 (figure 3) using a wire EDM machine and the results are noted down as shown in the table below.

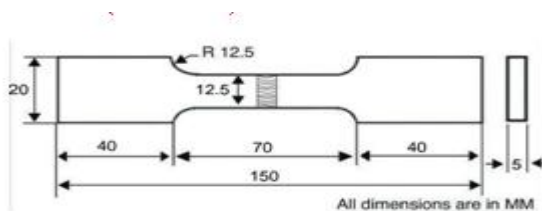


Figure 3 Tensile specimen as per ASTM E8M-04 & Sample weld specimens

Table 3 Experimental Results

Rotational speed (Rpm)	Travel speed (Mm/Min)	Reinforcement (Percentage)	UTS (MPa)
1000	10	5	180.8
1000	20	10	190.9
1000	30	15	197.6
1200	10	10	184.3
1200	20	15	206.8
1200	30	5	168.2
1400	10	15	196.8
1400	20	5	182.3
1400	30	10	169.7

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Finally Analysis Of Variance (ANOVA) was carried out to find out the parameters affecting the response.

Table 4 ANOVA Table

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	1332.31	190.330	471.45	0.035
Linear	3	633.81	211.270	523.32	0.032
Speed	1	37.37	37.367	92.56	0.066
Feed	1	4.11	4.111	10.18	0.193
Reinforcement	1	580.11	580.111	1436.94	0.017
2-Way Interactions	3	100.29	33.432	82.81	0.081
speed*feed	1	96.34	96.340	283.63	0.041
speed* Reinforcement	1	18.82	18.822	46.62	0.093
feed* Reinforcement	1	1.97	1.970	4.88	0.271
3-Way Interactions	1	0.00	0.004	0.01	0.938
Speed*Feed*Reinforcement	1	0.00	0.004	0.01	0.938
Error	1	0.40	0.404		
Total	8	1332.72			

S= 0.635383

R-squared= 99.97%

R-squared (adjusted) = 99.76%

R-squared (predicted) = 82.94%

The R-squared is the percentage of response variable variation that is explained by its relationship with one or more process variables. To be simple R-squared is a statistical measure of how close the data are to the fitted regression line. In general, the higher the R-squared, the better the model fits your data. However, this may not be true in all the cases in some cases a lower R-Squared value may also fit your model. The key limitations of R-squared are that every time you add a process variable to a model, the R-squared increases, even if due to chance alone. It never decreases. Consequently, a model with more terms may appear to have a better fit simply because it has more terms the other limitation is that if a model has too many process variables and higher order polynomials, it begins to model the random noise in the data. This condition is known as over fitting the model and it produces misleadingly high R-squared values and a lessened ability to make predictions.

The adjusted R-squared is a modified version of R-squared that has been adjusted for the number of predictors in the model. The adjusted R-squared increases only if the new term improves the model more than would be expected by chance. It decreases when a predictor improves the model by less than expected by chance. The adjusted R-squared can be negative, but it's usually not. It is always lower than the R-squared.

Predicted R- squared determines how well the model predicts responses for new observations. Larger values of predicted R^2 indicate models of greater predictive ability. It is calculated by systematically removing each observation from the data set, estimating the regression equation, and determining how well the model predicts the removed observation. Predicted R^2 ranges between 0 and 100%.

Predicted R^2 can prevent over-fitting the model and can be more useful than adjusted R^2 for comparing models because it is calculated using observations not included in model estimation. Over-fitting refers to models that seem to explain the relationship between the predictor and response variables for the data set used for model calculation but fail to provide valid predictions for new observations.

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Hence in order to find out how well your data fits the model it is necessary to calculate all the three Goodness-of-fit statistics and these three should be as close as possible.

The following plots obtained from analysis are also used to interpret the terms affecting the response. The normal probability plots of the residual; the plots of the residual vs. fitted value and run order and histogram for UTS are shown in Figure 4. A check on the normal probability plot revealed that the residual generally fall on a straight line implying that the error is distributed normally. Also Figures versus v/s fits and versus v/s order revealed that they have no obvious pattern and unusual structure. This implies that the models proposed are adequate and there is no reason to suspect any violation of the constant variance and independence assumption.

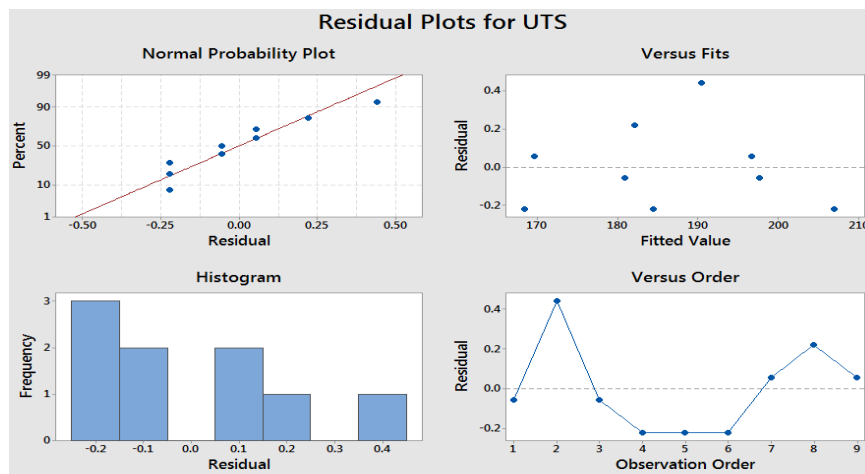


Figure 4 Residual plots for UTS

The P values in the ANOVA table were used to check the significance of each coefficient. The P values less than 0.05 indicates that the model and model terms were statistically significant, this is shown by the pareto chart below. The graph shows that the factor C and the interaction A*B are significant.

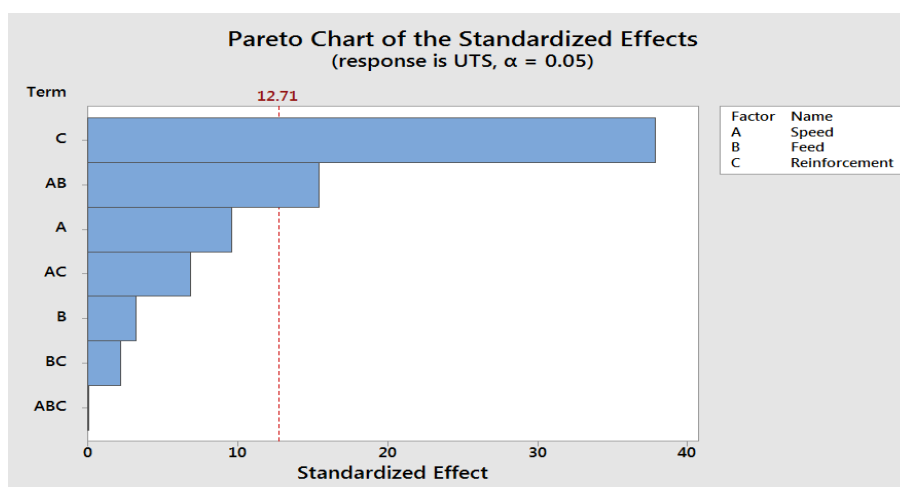


Figure 5 Pareto Chart of Effects.

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V. CONCLUSIONS

This experimental work involves analysis of UTS in Friction Stir Welding of Al-6351 reinforced with Al_2O_3 particles and leads to the following conclusions:

1. The micro structure revealed a pattern of the matrix composite consisting of Al_2O_3 reinforced with aluminium.
2. The factor C and the interaction A*B are significant in effecting the UTS of the Welded specimens.
3. It was found that higher the reinforcement percentage, higher the UTS of the sample specimen.

REFERENCES

- 1) L.M Marzoli, A.V Strombeck, J.F.Dossantos, C.Gambaro and L.M.Volpone. "Friction stir welding of an AA 6061/ $Al_2O_3/20_p$ reinforced alloy". Elsevier, 29 June 2005, pp.363-371.
- 2) L.Ceschini, I.Boromei, G.Minak, A.Morri and F.Tarterini. "Effect of friction stir welding on microstructure, tensile and fatigue properties of the AA 7005/10vol. % Al_2O_3p composites". Elsevier, 17 October 2006, pp. 605-615.
- 3) G. Ashok Kumar, I. Dinaharan, S. J. Vijay and N. Murugan. "Friction stir processing of intermetallic particulate reinforced aluminum matrix composite". Advanced materials letters, 17 October 2012, pp. 230-234.
- 4) Arun kumar, C.Elanchezhian and B.VijayaRamnath. "Investigation of Process Parameters of Friction Stir Welded AA7075 Aluminum Alloys". International Journal of Engineering Research, Volume No.3, pp.148-150.
- 5) M.V. Niranjan Reddy, M. Nikhil Reddy, K. Vijay Kumar and Parthasarathy Garre. "Experimental investigation of tensile strength on al 6351 to the aerospace structural applications". International Journal of Mechanical Engineering and Technology (IJMET), Volume 5, Issue 2, February (2014), pp. 110-114.
- 6) Mandeep Singh Sidhu and Sukhpal Singh Chatha. "Friction Stir Welding – Process and its Variables: A Review". International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 12, December 2012
- 7) Chennakesava Reddy and A.Essa Zitou. "Tensile behavior of 6063/ Al_2O_3 particulate metal matrix composites fabricated by investment casting process". International journal of applied engineering research. Volume 1, no 3, 2010, pp. 542-552
- 8) Ajay Singh, Love Kumar, Mohit Chaudhary, Om Narayan, PallavSharma, Piyush Singh, Bhaskar Chandra Kandpal and Som Ashutosh. "Manufacturing of AMMCS using stir casting process and testing its mechanical properties". International Journal of Advanced Engineering Technology, July-Sept 2013, pp. 26-29.