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Friction Stir Welding of Metal Matrix Composite using Coated tool

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Abstract

Friction stir welding (FSW) is a solid state joining technique that has expanded rapidly since its development and has found applications in a wide variety of industries. In the present investigation work, friction stir weldabilty of 5% SiC particulate aluminum matrix cast composite using TiAlN coated tool and effect of process parameters such as tool rotation speed, traverse speed, and axial force on ultimate tensile strength were investigated. The result showed that there was no noticeable tool wear, only aluminum particles were deposited on the tool pin. The effect of process parameters were evaluated using Anova and S/N ratio of robust design. It was observed that the axial force exhibits more influence on tensile strength followed by traverse speed and tool rotation speed.

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Keywords : *Friction stir welding; Aluminum matrix composite ; TiAlN coated; Anova*

The nascent metal joining technique named friction stir welding developed to weld aluminum, magnesium and other light weight materials. The technique was invented and patented in 1991 by The Welding Institute (TWI) of United Kingdom. The process was first used successfully by NASA to weld the super light weight external tank for the space shuttle. Furthermore, a noteworthy factor is the technique is used to join structural component of Delta IV, Atlas V and Falcon IX rockets [Tracie prater, 2014].

The solid state process in which the frictional heat is generated by the rotating welding tool and work piece gets softened because of rotating and plunging action of the tool in to the work piece. The tool is moved along the joint line to finish the welding process [Byung –Wook et.al, 2012].

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Metal Matrix Composites are valued by the aerospace industry as potential futuristic material due to increased enhanced mechanical properties [Periyasamy et.al, 2013]. The ceramic particles addition enhanced the strength, wear resistance, and temperature rigidity of the base material without additional increase in weight [Prater et.al, 2013].

However, there is a barrier to the widespread use of metal matrix composites in industrial applications due to the difficulties encountered when joining them to other composites or unreinforced materials [Batalha et.al, 2012]. The problematic aspect of the fusion welding of MMCs is the formation of theta phase due to reaction of molten matrix with reinforced particles which results the degradation of the mechanical properties. For example, joining of Aluminum metal matrix composites by traditional fusion welding processes produces effects such as coarse microstructure; segregation and decomposition of ceramic particles, brittle inter metallic compounds formation [Dinaharan et.al, 2012].

Friction stir welding is being considered as a prospective joining technique to solve the above mentioned problems. However the presence of hard ceramic particles in the AMCs resulted in appreciable tool wear [Liu et.al, 2005]. The more robust means of combating wear potentially lies in the use of harder tool materials than the composites.

The main objectives of the present investigation were to study (a) the weldability of composite materials using TiAlN coated tool and (b) the effect of process parameters on mechanical properties of the welded joints.

1. Experimental Procedure

The parent material was LM 25 Aluminum alloy reinforced with 5% SiC particles fabricated by stir casting technique which is the liquid state processing technique. The Chemical Composition of the LM 25 alloy is given in table 1.

Table 1. Chemical Composition of LM 25 alloy

Material	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Zn	Sn	Al
LM 25	6.5 – 7.5	0.5	0.2	0.3	0.2 – 0.6	0.1	0.1	0.1	0.1	0.05	Remainder

The casted work pieces were milled, surface finished and they were cut to the dimension of 100 X 50 X 6 mm using Wire EDM. Wire EDM was preferred for cutting the finished work pieces because there will be less material wastage and improved dimensional accuracy. Fig.1. shows the casted work piece prepared for welding.

Fig.1. W- EDM machined casted Composite material

Many critical components are involved in FSW and obviously tool is most critical among them to the success of the process. High speed steel was selected as the tool material to prepare the tool and then TiAlN was coated on the tool material to the thickness of 4 microns using Physical Vapour Deposition (PVD) technique. Fig.2. shows the coated tool. The dimensions of the tool are given in the table .2.

The process parameters considered in this study were tool rotation speed, traverse speed and axial force which are mostly contribute to heat input and subsequently influence the mechanical properties of the welded joints. Table.3. shows the process parameters and their levels.

Fig. 2. TiAlN coated tool

Table.2. Details of the tool

Description	Dimension
Tool Length	120mm
Shoulder Diameter	19.5mm
Pin Diameter	Smaller dia – 4mm, Larger dia - 6 mm. (taper pin)
Pin length	5.7mm
Coating material	TiAlN
Coating Thickness	4 Microns

Table.3. Process parameters and their levels

S.NO	Parameter	Unit	Notation	Level 1	Level 2	Level 3
1	Tool rotation Speed	Rpm	A	1200	1500	1800
2	Travers speed	mm/min	B	20	40	60
3	Axial force	KN	C	6	7	8

Square butt joint configuration was prepared using computer controlled friction stir welding machine available in metal joining lab, Department of metallurgy, IIT Chennai. Totally nine experiments were conducted as per L9 orthogonal array for the selected process parameters.Fig.3. shows the sample welded work piece.

Fig.3. Welded work piece

Fig.4. Shape of tool pin after welding

2. Results and Discussion

There was no tangible wear in the tool, only the deposition of aluminum on the tool pin profile which is shown in the fig. 4. Dog – bone – shaped tensile specimens were prepared as per the dimensions given by ASTM E8- 04 standards. From the 9 welded work pieces, totally 27 samples were machined 3 from each and tested in Universal Testing Machine. . Tensile specimen samples are shown in the fig.5.

Fig.5. UTM specimens

The main quality characteristics considered in the present investigation was tensile strength which describes the quality of the FSW joints. In order to access the influence of welding parameters on the output response S/N ratio for each control factor were calculated. The S/N ratio was used to analysis the test run results because it represents both the average (mean) and variation (scatter) of the experimental results. The number of S/N ratios are available such as smaller the best, larger the best, nominal the best. Based on the previous knowledge, expertise and understanding of the process the appropriate S/N ratio was chosen.

In this investigation, maximum tensile strength was the objective function, so that larger the best S/N ratio was chosen. It is clear that a larger S/N ratio corresponds to better quality characteristics. Therefore the optimal level of process parameters is the level of highest S/N ratio.

The S/N ratio can be computed using the following equation (1).

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum\frac{1}{Y^2}\right) \quad (1)$$

Where S/N is the signal to noise ratio, n is the number of measurements taken in the test and Y is the individual measured response value (experimental results). The table.4 shows the experimental results and corresponding S/N ratio values. Fig.6. shows the main effects plot for S/N ratio indicating that the tensile strength is maximum when spindle speed, traverse feed, and axial load are at the level of 1, 2, 3 i.e. 1200 rpm, 40 mm/min, 8KN respectively.

Table .4 Experimental Results

S.No	Process Parameters			Mean Ultimate tensile strength [Mpa]	Mean S/N Ratio
	Rotation Speed (RPM)	Traverse Speed (mm/min)	Axial Force (kN)		
1	1200	20	6	95.14	39.16
2	1200	40	7	63.85	36.10
3	1200	60	8	58.16	34.46
4	1500	20	7	39.27	31.41
5	1500	40	8	81.56	38.22
6	1500	60	6	50.53	34.06
7	1800	20	8	85.08	37.36
8	1800	40	6	68.73	35.95
9	1800	60	7	46.17	33.26

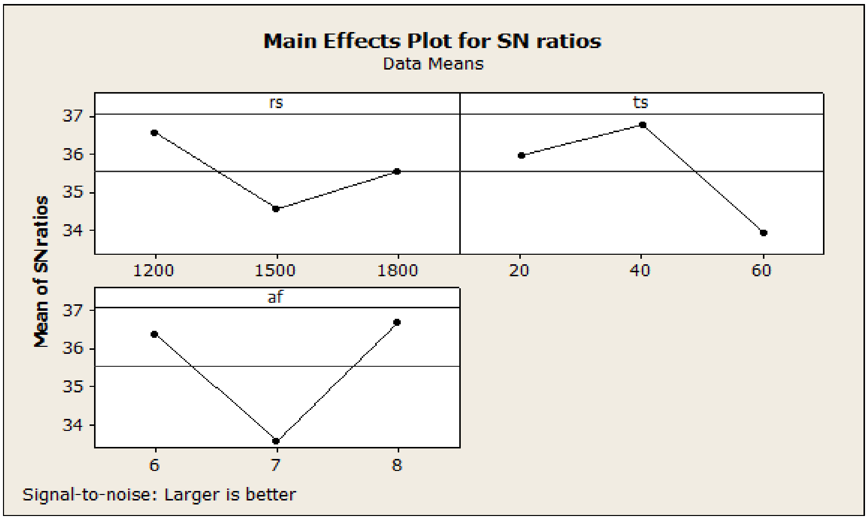

Fig. 6. Main Effects Plots for S/N Ratio

2.1. Anova : Analysis of Variance

The Analysis of Variance popularly known as the ANOVA can be used to identify the process parameters that are statistically significant which affect the tensile strength of the welded joints produced by FSW. ANOVA was performed using Minitab 16 statistical software. The results of ANOVA are summarized in the table 5.

Table.5. Anova table for tensile strength

Source Of Variation	D.o.F	Sum Of Squares	Mean Sum Of Squares	F	P	Percentage Of Contribution
RS	2	6.07	3.03	0.45	0.687	12.2
TS	2	12.8	6.41	0.96	0.510	25.8
AF	2	17.48	8.74	1.31	0.433	35.16
ERRORS	2	13.33	6.67			26.85
TOTAL	8	49.69				

In addition, the F –test named after Fisher can also be used to determine which process parameter has a significant effect on the tensile strength. Usually the process parameters have a significant effect on the quality characteristics when F is large.

The results of ANOVA indicate that the considered process parameters are highly significant factors affecting the tensile strength of FSW joints in the order of axial force, traverse speed and tool rotation speed. The percentage of contribution is the portion of the total variation observed in the experiment attributed to each significant factors and/or interaction which is reflected. The percentage of contribution is a function of the sum of squares for each significant item it indicates the relative power of a factor to reduce the variation. If the factor levels are controlled precisely, then the total variation could be reduced by the amount indicated by the percentage of contribution

3. Conclusion

The butt joint configuration of aluminum matrix composites was successfully welded using TiAlN coated tool using friction stir welding. The samples were characterized for tensile strength of welded joints. ANOVA was performed to investigate the significance of the process parameters and following conclusions were made.

- Aluminum particles were deposited over the tool pin and no physical wear observed after welding.
- The optimal FSW process parameter combinations were spindle speed at 1200 rpm, traverse speed at 40 mm/ min and axial load at 8 KN.
- The percentage of contribution of FSW process parameters was calculated. It was found that the axial force had the maximum contribution of 35% followed by traverse speed and spindle speed of 25% and 12% respectively.

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