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Developing an Empirical Relationship to Predict the Maximum Tensile Strength on Friction Stir Welded Al Based Metal Matrix Composite Joints Produced by Stir Casting Method.

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ABSTRACT

Aluminum based Metal Matrix Composites (MMC) have recently received considerable attention due to their admirable properties such as stiffness, high specific strength, and high wear resistance. These advantages make MMC very attractive materials in wide variety fields of aerospace and automobile industries. Stir casting is cheap and cost effective method for manufacturing of the composites. In this research work, the MMC were produced by stir casting method in order to analyze its friction stir welded joints strength. Friction Stir Welding (FSW) is classified as a solid-state welding process where metallic bonding is produced at temperatures lower than the melting point of the base metals. Rotational speed (N), Transverse speed (V) and Downward force (F) are the most important parameters in the FSW process and these parameters were optimized using Response Surface Methodology (RSM) to develop a proper approximation for the right functional relationship between independent variables and the response variable that may differentiate the nature of the joints. The empirical relationships were developed with the help of ANOVA design matrix to obtain the maximum tensile strength in the joints. The integrity of the joints was evaluated by Optical Microscopy (OM).

KEY WORDS: Friction Stir welding; MMC; RSM; Empirical relationship; Microstructure.

1. INTRODUCTION

Aluminum is mostly available abundant metal in the earth's crust. In 19th century, aluminum has become a tough competitor for steel in the field of aerospace, automobile and other industries. AA6061 Aluminum has wide availability and its desirable properties finds extensive applications. In the past few years the global need for low cost, high performance and good quality materials has caused a shift in research from monolithic to composite materials where the properties of base metal are increased due to the reinforced particles (Selvamani, 2016; Lindroos, 1995). Hamouda (Ibrahim, 1991), Kang (Hamouda, 2007) used particles of SiC, Al_2O_3 in the MMC's and proved that the Mechanical, metallurgical properties are increased compared to the Aluminum Matrix Composites (AMC). However, MMCs are still not as popular as carbon steel in structural applications and a major technical challenge due to superior joining methods to produce high quality welds. Friction stir welding is a continuous, hot shear, autogenous process involving non-consumable rotating tool of harder material than the substrate material (Kang, 2004). Defect free welds with good mechanical properties have been made in a variety of aluminum alloys, even those previously thought to be not weldable. Friction stir welds will not encounter problems like porosity, alloy segregation, hot cracking and welds are produced with good surface finish and thus no post weld cleaning is required (Selvamani, 2015). RSM is a collection of statistical and mathematical model used to develop, improve and optimizing processes and to explore the relationships between several response variables (Palanikumar, 2007). From the above literature review, it had been understood that most of the published information on friction stir welding of aluminum based MMCs were focused on the metallurgical characteristics, tensile properties and hardness variations on trial basis. In this investigation, an attempt was made to develop the empirical relationship to obtain the maximum strength of friction stir welded AA6061+SiC-10% composite using RSM.

2. EXPERIMENTAL WORK

AA 6061 (Cu-0.28%, Mg-0.9%, Fe-0.33%, Si-0.62, Zn-0.02%, Mn-0.12, Cr-0.17% Al-97.6%) grade aluminum alloy is used in this investigation. Stir casting is one of the adopted methods and it is used to fabricate composites owing to its low cost and uniform distribution of the reinforcement in the matrix. AA 6061 alloy with SiC-10% were melted at 6 kW electrical resistance furnaces to a temperature of 650^{0}C. The as-casted MMC rolled in the press to relive its residual stress and the specimens were prepared with the dimension of 150x75x6 mm have been used for preparing single pass welded joints. The process parameters taken to fabricate the joint are rotational speed, downward force and transverse speed. High Speed Steel (HSS) materials of shoulder diameter 18 mm has been indigenously designed and developed for the FSW process. The mechanical properties of the parent metal are given in the Table 1.

Table.1. Mechanical properties of base metal and MMC

Metal	Yield strength (MPa)	Tensile strength (MPa)	Vicker's hardness (Hv)	Elongation (%)
AA6061	200	270	80	10
AA6061+SiC-10% Wrought form	210	295	90	8

(a) Friction stir welding machine

(b) Friction stir welded MMC joints

(c) Tensile test graph

(d) Tensile test specimens

Figure.1.The experimental work

The Fig. 1 (a-d) shows the Friction stir welding machine, fabricated joints and sample tensile specimen respectively. The ASTM E8M-04 deliberating principle was followed in preparing the test specimen. Tensile test was carried out on a 100 KN electromechanical controlled universal testing machine. In order to determine the quality of the joints, the microstructure and macrostructure of the friction stir welding joints are analyzed to correlate it with the optimized joint. The microstructure of the friction stir welded joints are analyzed by using light optical microscope with various magnification (Make: MEJI, Japan; Model: MIL-7100).

3. RESULT AND DISCUSSION

Developing Empirical Relationships: In the present investigation, the RSM has been applied for evolving the mathematical model in the way of multiple regression equations for the quality characteristic of the friction stir welded AA6061 grade aluminum based SiCp reinforced MMC. In utilizing the RSM, the individual variable is observed as a surface to which a mathematical model is tailored. The responses of Tensile Strength (TS) of friction welded joints are the functions of the continuous drive friction welding parameters such as a Rotational speed (N) rpm, Transverse speed (V) mm/sec and Downward force (F) MPa and they are expressed as shown in eq. (1)

$$TS = f\{N, V, F\} \quad (1)$$

The second-order polynomial equation used to represent the response surface TS is shown in eq. (2)

$$TS = b_0 + \Sigma b_i X_i + \Sigma b_{ii} X_i^2 + \Sigma b_{ij} X_i X_j \quad (2)$$

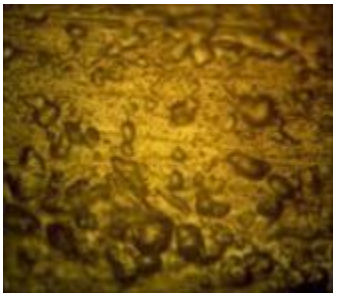
And for three factors, the chosen polynomial could be expressed as shown in eq.(3)

$$TS = b_0 + b_1 (F) + b_2 (V) + b_3 (N) + b_{12} (FV) + b_{13} (FN) + b_{23} (VN) + b_{11} (F^2) + b_{22} (V^2) + b_{33} (N^2) \quad (3)$$

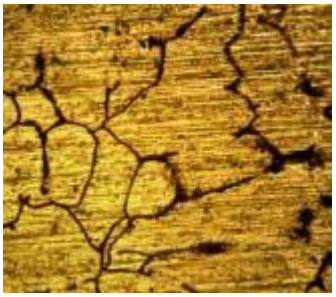
The final empirical relationships are constructed by using significant coefficients and the developed equations are shown in eq. (4)

$$TS = [247.71+1.10 * V+2.16 * F+8.67 * N-2.25 * V * F-6.25 * V * N-1.50 * F * N-25.47* V^2-21.40 * F^2-13.27 * N^2] \text{ MPa} \quad (4)$$

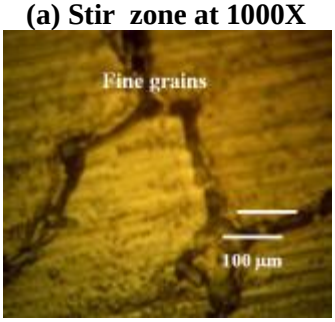
The analysis of variance technique is used to check the adequacy of the developed empirical relationship. The design matrix and the corresponding output response are shown in Table.3. The desired level of confidence is considered to be 95%. The relationship is considered to be adequate, which provides that, the calculated F value of the model developed does not go over the standard tabulated F value and the calculated R value of the developed relationship doesn't exceed the standard tabulated R value for a desired level of confidence w. It is found that, the above model is adequate. In the same way, interaction effect NF, NV, FV has a significant effect. Lack of fit is no significant as it is desired. It reveals that, the residuals are falling on the straight line, which means the errors are distributed normally (Manonmani, 2005). The microstructure view of optimized FSW joint is shown in Fig. 2.



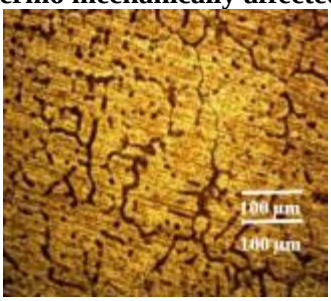
(a) Stir zone at 1000X



(b) Thermo mechanically affected zone



(c) Heat affected zone at 1000X



(d) Base metal at 200X

Figure.2. Micrograph of optimized FSW joint.

Table.2.Feasible working limits of friction stir welding parameters

Parameter	Notation	Unit	Level				
			-1.68	(-1)	(0)	(+1)	+1.68
Rotational speed	N	rpm	731	800	900	1000	1068
Transverse speed	V	mm/sec	0.33	0.50	0.75	1	1.17
Downward force	F	MPa	11	15	20	25	28

Table.3.Design matrix and corresponding output response

Standard order	Run order	Coded value			Tensile strength (MPa)
		N	F	V	
1	12	-1	-1	-1	165
2	2	1	-1	-1	185
3	4	-1	1	-1	177
4	20	1	1	-1	187
5	9	-1	-1	1	198
6	1	1	-1	1	192
7	17	-1	1	1	203
8	6	1	1	1	189
9	7	-1.68	0	0	175
10	13	1.68	0	0	178
11	10	0	-1.68	0	184
12	3	0	1.68	0	192
13	15	0	0	-1.68	196
14	5	0	0	1.68	226
15	19	0	0	0	244
16	11	0	0	0	249
17	18	0	0	0	246
18	8	0	0	0	247
19	14	0	0	0	248
20	16	0	0	0	252

4. CONCLUSION

The outcomes based on the above study, are formulated detailed below:

- The empirical relationships are developed to predict the tensile strength of the friction stir welded AA6061 grade aluminum based SiCp reinforced MMC plates incorporating process parameters at 95% confidence level.
- A maximum tensile strength of 252 MPa could be attained in friction stir welded MMC joints under the welding conditions of Rotational speed (N) of 900 rpm, Transverse speed (V) 0.75 mm/sec and Downward force (F) 20 MPa
- The coarse grains are observed in the HAZ and very finer grains are observed in the fully deformed zone of the friction stir welded AA6061 grade aluminum based SiCp reinforced MMC.

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