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Experimental Investigation and Prediction of Mechanical Properties of Friction Stir Welded Aluminium Metal Matrix Composite Plates

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Friction stir welding (FSW) is a relatively contemporary solid state welding process and has been employed in aerospace, railway, automotive and marine industries for joining of aluminum, magnesium, zinc, titanium, copper alloys, dissimilar metals and thermoplastics. The FSW process parameters such as tool rotation speed, tool traverse speed and tilt angle play an important role in deciding the joining quality. The present study defines the effect of FSW process on the tensile properties of the AA2124/SiC/25p metal matrix composite (MMC) plates. Obtained results showed that the joint efficiency decreases by increasing the tool traverse speed while tool rotation speed was kept constant. Second contribution of this study is the application of decision tree technique to predict the tensile properties of friction stir welded MMC plates. It is seen that methodology can be applied with great accuracy.
Keywords: friction stir welding, metal matrix composite, decision tree technique, tensile properties.

1. INTRODUCTION

Aluminum metal matrix composites (MMCs) reinforced with SiC particles are considered as advanced materials of great interest for structural applications [1]. They have been found in a wide range of applications in automotive and aerospace industries because of their lightweight, high stiffness and strength, high thermal stability and their superior wear resistance, compared to the unreinforced aluminum alloys. The fabrication of durable and usable aluminum-based MMCs is challenging in several aspects. With respect to the joining techniques, it is hard to obtain defect-free welds by using conventional fusion welding methods. It has been observed in the fusion zone, that deleterious reactions between the reinforcement particles and the liquid metal and an irregular redistribution of reinforcement particles frequently occurred, which greatly limits the weldability of aluminum-based MMCs [2]. However, the major difficulty with fusion welding for MMCs is that prolonged contact between a molten-metal matrix and particulate reinforcements can lead to undesirable chemical reactions [3].

The development of the FSW process and its application to particles reinforced composites [4] open a new opportunity for obtaining high quality joints in these materials [5]. Therefore, many component shapes, such as long, large cross section, one-off, box sections and spars, which normally would not be practical, or cost effective, to extrude or cast, can now be fabricated by FSW process [6]. In this process, a rotating tool with a specially designed tool rotating probe travels down the length of contacting metal plates, and produces a highly plastically deformed zone through the associated stirring action. The localized thermo mechanical affected zone is produced by friction between the tool shoulder and the plate top surface, as well as plastic deformation of the material in contact with the tool. The probe is typically slightly shorter than the thickness of the work piece [7 – 8]. There is no liquid state for the weld pool during FSW. For this reason the potential defect types within the weld, such as tunnel defect, "lazy S" and "kissing-bond", are quite different from conventional welding flaws [9]. Since FSW involves large plastic flow at elevated temperatures, the MMCs must be capable of sustaining such flow without suffering damage to the reinforcements. This requirement is difficult to satisfy with fiber reinforced MMCs, but is feasible with particulate MMCs. These considerations led to selection of AA2124 containing 25 vol.% of SiC particles MMCs. Bozkurt et.al have studied on this material considering wear of FSW tool [10] and mechanical properties of FSWed joint for a certain condition [11].

To obtain the desired strength, it is essential to have a complete control over the relevant process parameters to maximize the tensile strength on which the quality of a weldment is based. Therefore, it is very important to select and control the welding process parameters for obtaining the maximum strength. It has been proved by several researchers [12 – 15] that efficient use of statistical design of experimental techniques, allows development of an empirical methodology, to incorporate a scientific approach in the fusion welding procedure. Various prediction methods can be applied to define the desired output variables through developing mathematical models to specify the relationship between the input parameters and output variables [16 – 19].

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Even though sufficient literature is available on friction stir welding of aluminum alloys, no systematic study has been reported so far to correlate the process parameters and tensile properties of friction stir welded aluminum alloy and metal matrix composite joints. The first aim of this work is to enhance the previous studies [3, 7] and to evaluate the mechanical properties under different tool rotation speeds of the AA2124/SiC/25p-T4 metal matrix composite plates. The second aim is to model the obtained results by using decision tree technique and to evaluate the accuracy of the model.

2. EXPERIMENTAL PROCEDURE

2.1. Material

The plates used in this study are AA2124-T4 alloy matrix MMC strengthened with 25 vol.% SiC particles (AA2124/SiC/25p). This material was received in the form of billet with the sizes of (400×260×50) mm, which was produced by powder metallurgy and mechanical alloying techniques followed by hot forging and tempering to T4 condition (i. e. solution heat treating at about 505 °C for 1 h. and quenching in 25 % polymer glycol solution followed by room temperature aging for >100 h). The AA2124/SiC/25p MMC plates contain SiC particles with two different particle sizes, i. e. 0.1 µm – 0.5 µm and 1 µm – 5 µm. Ultimate tensile strength of the base AA2124/SiC/25p-T4 MMC is 454 MPa. The chemical composition of the material is given in Table 1.

Table 1. Chemical composition of AA2124/SiC/25p-T4 MMCs plates (mass.%).

Cu	Mg	Mn	Si	Al
3.86	1.52	0.65	0.17	93.8

The MMC plates of (130×50×3) mm sizes were cut from the billet by electro-discharge machining (EDM) technique with a feeding rate of 2 mm/min. The plates have been cut accurately to prevent shoulder from contacting with the surface of the plate. To find out the accuracy of the plates, each plate is measured by micrometer from 6 different locations through welding direction. In case of discrepancies in length, plates are grinded by Taksan TYT-400 surface grinding machine until providing 3 mm thickness.

2.2. Experimental setup

The AA2124/SiC/25p MMC plates were friction stir butt welded using an FSW adapted milling machine as shown in Fig. 1. The FSW tool with a 20 mm diameter shoulder and a pin with a diameter of 6 mm, a length of 2.8 mm and a left-hand screw with a 0.75 pitch, was made of a high wear resistant Aluminum Titanium Nitrate (AlTiN), whose hardness of 62 HRC, coated HSS tool material. Friction stir welding trials were conducted with the tilt angle of 2°, which were chosen according to the optimum results obtained for AA2124/SiC/25p-T4 MMC plates [11].

Different tool rotation speeds of 355 rpm to 1400 rpm and different tool traverse speeds of 40 mm/min. to 100 mm/min. were used.

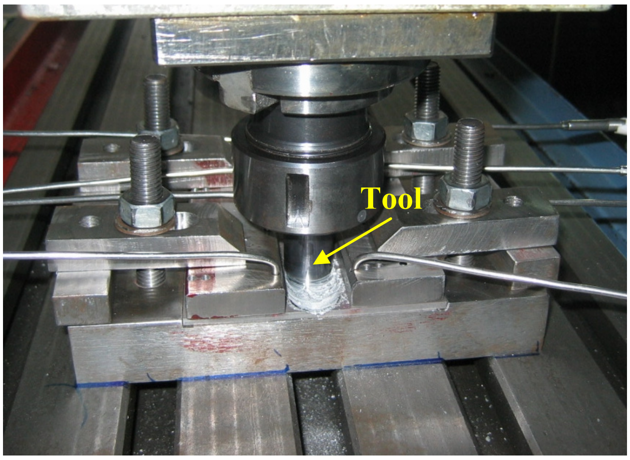

Fig. 1. FSW process of the AA2124/SiC/25p-T4 MMC plates

2.3. Decision tree technique as a prediction tool

A decision tree is a tree-structured plan of a set of attributes to test in order to predict the output. In order to decide which attribute should be tested at first, simply find the one with the highest information grain [20]. In this study, simple C&R tree technique is used. Maximum depth of the built tree model is five. Gini metric is used to measure the impurity of the tree, which is a general impurity measure based on probabilities of category membership for the branch.

3. RESULTS AND DISCUSSION

3.1. Experimental data

The tensile tests were carried out at room temperature, according to ISO / TTA2 specification [21] by a universal type tensile test machine to determine the tensile properties of the joints. The tensile test results for base composite and the FSWed joints (at 355 rpm – 1400 rpm rotation speeds) are given in Table 2. To get reliable data, every test has repeated three times and their average values are used to analysis. It becomes evident that there is no direct relation between tool rotation speed and ultimate tensile strength (UTS). FSWed joint at 1120 rpm has given better UTS values than the other joints. The results have given a clear idea that there is an optimum rotation speed between 355 rpm – 1400 rpm. Also, obtained joint efficiency values (approximately 81 %) are high enough when compared with the previous studies of Marzoli et al. [22] with 70.7 % and Ceschini et al. [5] with approximately 80 % joint efficiency.

3.2. Predicted data

The experimental data is used in prediction. Table 3 shows the predicted data in partitions. 70 % of data is used to train the model and remaining ones is used to test and evaluated the model. It is seen that decision tree has enough accuracy in prediction of tensile strength of FSW joined plates with 83.1 % correlation (Table 4). This close relation has also shown in Fig. 2. Considering the effect of variables (tool rotation and tool traverse speeds) in prediction, it is carried out that they have approximately same effect whereas tool rotation speed is slightly more effective than tool traverse speed as shown in Figure 3. Obtained model is given in Fig. 4. It is a simplified form of the model. Predicted UTS values are calculated by the rules defining the intervals in terms of tool traverse speed and tool rotation speed values.

Table 2. Tensile test results of the FSWed joints

Experiment No	Tool rotation speed (rpm)	Tool traverse speed (mm/min)	UTS (MPa)
1	355	40	299.78
2	355	50	298.60
3	355	80	281.66
4	355	100	277.97
5	560	40	361.48
6	560	50	343.56
7	560	80	326.03
8	560	100	311.70
9	900	40	357.12
10	900	50	338.97
11	900	80	318.52
12	900	100	262.93
13	1120	40	366.20
14	1120	50	363.35
15	1120	80	362.43
16	1120	100	345.36
17	1400	40	330.75
18	1400	50	286.61
19	1400	80	282.01
20	1400	100	269.01

From the test results, it can be observed that the predicted values are very close and follow almost the same trend as the experimental values. The maximum absolute error for training patterns was found to be 0.6 % and the minimum was found 0 % and for 86 % of the cases the predicted values were same with experimental ones. Prediction accuracy is 100 % for training. The maximum absolute error for testing patterns was found to be 13.6 % and the minimum was found 0.4 % and for half of the cases error was less than 4.6 %. Prediction accuracy is 83.1 % for the testing. Training part has much more accurate prediction as it is expected from the results where value of error and its deviation is much greater for testing part. To change the percentages of partitions and the data selected as testing can improve the results and more accurate results can be gained for testing part.

Importance of the factor is calculated by using factor prioritization: that is, which factor (input variable) leads to the greatest reduction in the variance of the output. The method employed found that tool rotation speed is the most important factor with 52.43 % affecting ultimate tensile strength. Whereas there is only 5 % difference with second factor, tool traverse speed.

Table 3. Predicted tensile strengths of the FSWed joints

Experiment No	UTS (MPa)	Predicted UTS (MPa)	Partition
1	299.78	298.60	Testing
2	298.6	298.60	Training
3	281.66	281.66	Training
4	277.97	277.97	Training
5	361.48	359.30	Training
6	343.56	343.56	Training
7	326.03	281.66	Testing
8	311.7	277.97	Testing
9	357.12	359.30	Training
10	338.97	343.56	Testing
11	318.52	318.52	Training
12	262.93	262.93	Training
13	366.2	366.20	Training
14	363.35	363.35	Training
15	362.43	345.36	Testing
16	345.36	345.36	Training
17	330.75	330.75	Training
18	286.61	286.61	Training
19	282.01	269.01	Testing
20	269.01	269.01	Training

Table 4. Statistical values of data mining model

Partition	Training	Testing
Minimum Error	0	1.18
Maximum Error	2.18	44.37
Standard Deviation	0.855	18.762
Linear Correlation	1.0	0.831

It is quite clear from figures that ultimate tensile strength predicted by the C&R Tree model matches well with the training data as well as the test data. The model developed can be used as an effective tool for predicting the tensile strength value in friction stir welding of metal matrix composite plates.

4. CONCLUSIONS

This study investigated the effect of the FSW process on the mechanical properties of the AA2124/SiC/25p MMC plates and to evaluate the tensile strength under different rotation speeds (355 rpm – 1400 rpm). The AA2124/SiC/25p MMC plates are successfully friction stir butt welded and high joint efficiency are acquired at each welding parameters. But, it is noticed that there is an optimum welding parameter to recover better mechanical properties (1120 rpm and 40 mm/min for our experimental setup). Besides, in this study was investigated the applicability of a data mining tool to prediction of mechanical properties of FSW joined MMC plates. Decision tree is chosen, as no application is found in

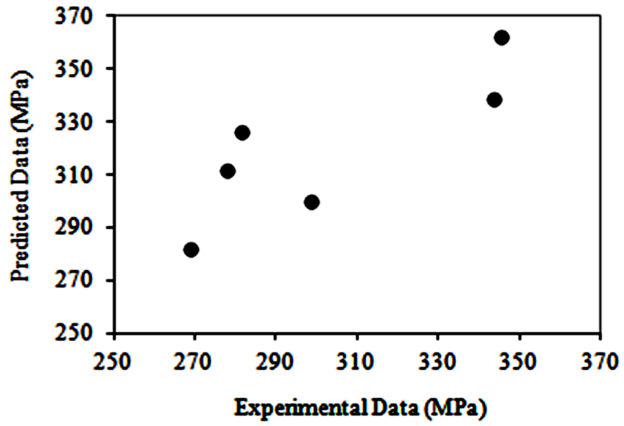

Fig. 2. Predicted values versus experimental values in testing

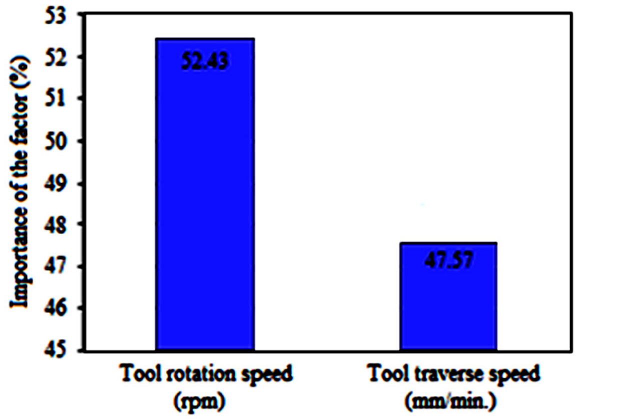

Fig. 3. Importance of factors in determining the predicted values

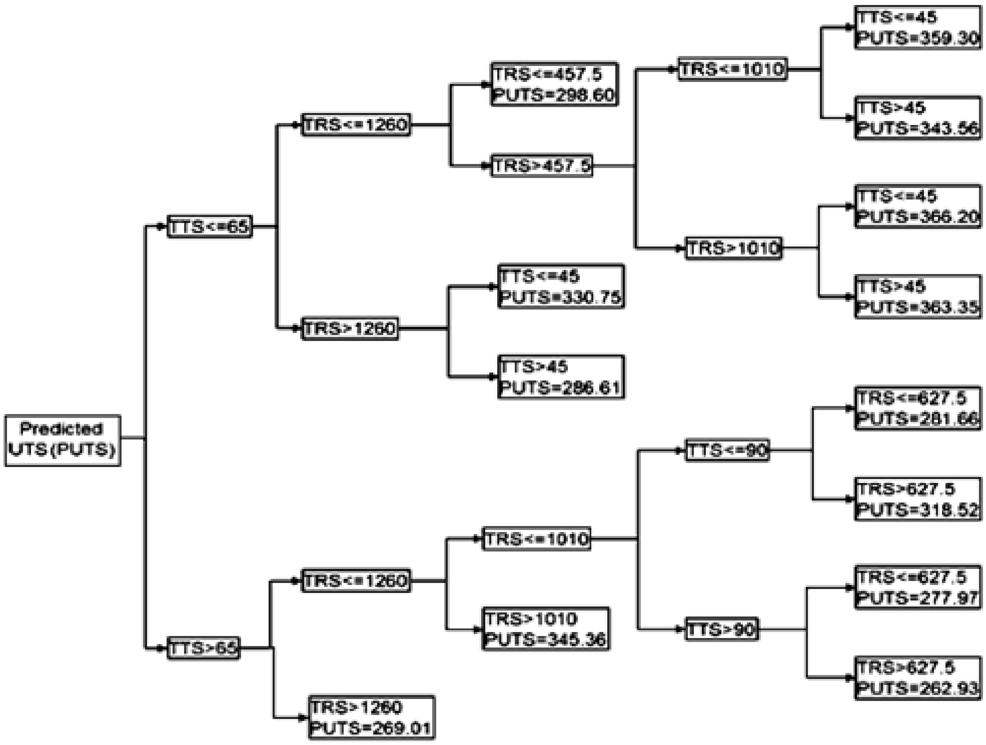

Fig. 4. Schematic view of the model in a simplified form (PUTS: Predicted value of the Ultimate Tensile Strength (MPa), TTS: Tool Traverse Speed ((mm/min.)), TRS: Tool Rotation Speed (rpm))

literature, and successfully applied as a data mining tool. It is revealed that decision tree can be used as a prediction tool as results have great accuracy. Moreover, it can be said that hybridization of decision tree algorithm may lead to a better solution quality than existing and traditional algorithms.

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