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PREDICTION OF TENSILE STRENGTH BEHAVIOR OF AA2024 REINFORCED WITH CNT IN THE COMBINATION OF FSW+FSP

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Abstract:
Friction stir welding (FSW) is a solid-state welding procedure that is fast becoming the standard within the manufacturing industry. It is a process that can produce welds of utmost quality and durability in hard-to-weld materials such as alloys of Aluminum and Copper. It has potential applications in some of the most demanding and varied industries, such as aerospace, the military, robotics as well as trains, and ever computer hardware. FSW also has the extraordinary advantages of being one of the very few fabricators that can weld a wide range of materials with sufficient strength at an economical cost. These welds also offer an unmatched, environmentally harmless solution to tackle these problems faced by the traditional and outdated industry. Friction stir processing (FSP) is on the FastTrack to becoming the industry's most dependable and widely used methods of fabrication. Over the past 10-15 years many researchers have subsequently studied this process and made various changes and alterations in the material used for reinforcement as well as the quantity of material used. FSP also has the added precedence of severely decreasing distortion and also defects in materials. FSP was combined with FSW due to its ability to achieve a better Ultimate Tensile Strength (UTS) and superior hardness in the weld area. This process has been used time and again to weld Aluminum alloys because of its superior and less distorted welds with excellent HAZ properties. The Aluminum 2024 base metal plate was successfully conjoined using the reinforcement material: Multi-Walled Carbon Nano Tubes(MWCNT). During the Tensile tests, the strength was found to be around 476 MPa, without FSW or FSP. After FSW, the optimum joining strength was found to be about 780 MPa, signaling an increase in the strength of the plates. The optimized values for CNT, rotation speed, feed rate, and tilt angle were found to be 2mm depth of the groove, 900 RPM, 60 mm/min, and 1-degree tilt angle.

Key Words- Friction Stir Welding, Friction Stir Processing, Carbon Nanotubes, Aluminium Alloy 2024

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INTRODUCTION

In this day and age, with the fourth phase of the industrial revolution underway, man and machine are becoming more and more intertwined with automation and absolute perfection and accuracy in manufacturing. As a result of which, more traditional and antiquated methods of production have seen a steep decline, especially in the 21st century. This does not mean more primitive methods have become extinct, but they are also continually evolving. The consensus has been that FSW, and by extension, FSP is used in the welding and manufacture of metal matrix composites. The fact is that FSW is a welding process that welds using a localized plastic deformation. When implemented in the right way, this process combines the material without altering the phase and creates a microstructure with fine equiaxed grains. A major advantage of FSW is the absence of a HAZ or heat affected zone, although a narrow HAZ may exist in some cases. 2024 Alumina alloy is the alloy that contains copper as its primary alloying element. It is extensively used in areas that demand high strength to weight ratio, as well as excellent fatigue resistance. It is weldable only through friction welding and has reliable machinability. One of the main objectives of our research work was to get hold of an ideal candidate that would be our dispersion reinforcement material. Carbon nanotubes (CNTs) are cylindrical molecules that consist of rolled-up sheets of single-layer carbon atoms (graphene). They can be single-walled (SWCNT) with a diameter of less than 1 nanometer (nm) or multiwalled (MWCNT), consisting of several concentrically interlinked nanotubes, with diameters reaching more than 100 nm. CNTs also have unique thermal and mechanical properties that make them intriguing for the development of new materials, namely, their mechanical tensile strength can be 400 times that of steel and that they are very light-weight. This was to be done by the dissipation of multi-walled carbon nanotubes into the base alloy using the FSP technique. The rotational tool speed was varied between the values of 600, 900, and 1200 RPM (rotations per minute). The feed rate of the tool was also varied between 40, 60, and 80 mm/min. The mode of addition of the reinforcement material- graphene CNTs, in this case, was performed by making grooves onto the plate edge, and then the depth of cut was varied between 1mm, 1.5mm, and 2mm. The tool tilt angle is an essential factor in the FSW process. It is usually varied between 0 and 3 degrees. A zero value implies that the tool is at a 90-degree angle to the workpiece. The tool tilt angle especially has an essential effect on the formations of defects during welding. The Taguchi method is a method based on "orthogonal array" experiments, which gives much reduced "variance" for the experiment with "optimum settings "of control parameters. The effects of the parameters we have proposed after being optimized using a Taguchi L9 orthogonal array were studied and documented to present an ideal weld. Several research papers carefully detail an augmented FSW process by making slight variations in the dispersing medium or its quantity. In this innovative venture to further improve the strength and microhardness of AA2024 alloy, it was found that a combination of FSW and FSP processes lead to an ideal outcome. Hence, we were able to obtain significantly strengthened samples.

MATERIALS AND METHODS

Aluminum alloy 2024 material is used in this process. The AA2024 plates produced through the casting process are procured in the form of the rectangular slab (Dimension required) with the composition Cu Mn, Mg, and Si. The chemical composition has given in table 1 (observed/tested chemical composition is required). Multi-Walled Carbon Nano Tubes was obtained with a purity of 99% from Ad Nanotechnologies, Bengaluru manufactured by Chemical vapor deposition method with properties given in Table 2 (Properties of CNT is required). Class F fly ash was bought from Neyveli lignite Cooperation Ltd.

The friction stir processing is done using a lathe machine, and the tool used for the machining process is shown in figure 1. The dimension of the device is (dimension and specification of the tool).

Figure. 1. Lathe machine and the tool used for friction stir processing.

The friction stir processing is performed in the AA2024 Plates with the various parameters as given in the below table. The aluminum plates were machined for slots. The Carbon nanotubes were comprised in the slots of the AA2024 plates. The before and welding plates were given below

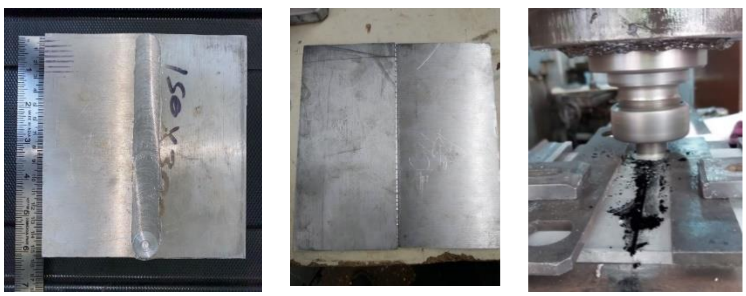

Figure. 2. AA2024 plates before and after the friction stir processing.

After the friction stir processing, the samples were subjected to the tensile test. The sample was cut into ASTM standard testing size using Wire-Cut EDM Machine, which shows in the figure. The average cutting time per sample was around 45 minutes. Three workpieces were cut from each sample. Once the required sample was cut, the sample was attached to the Universal Testing Machine, and the Tensile Stress was calculated. The sample mounted in the machine shown below.

Figure. 3. Tensile specimen prepared using wire-cut EDM and UTS machine arrangement for tensile tests.

Optimization Technique

The friction stir processing is done with the various input parameter, namely revolution of the tool in rpm, the feed rate of the tool in mm/min, Depth of cut in mm, and tilt angle in degree. The numerical values are designed with the Taguchi optimization technique [21]. The experimental values which developed in the L9 orthogonal array using the Taguchi process are given in table 1.

Table. 1 DOE of L_9 Orthogonal Array

Sample No	Revolution	Feed Rate	Depth of Cut	Tilt Angle
1	600	40	1	1
2	600	60	1.5	2
3	600	80	2	3
4	900	40	1.5	1
5	900	60	2	2
6	900	80	1	3
7	1200	40	2	1
8	1200	60	1	2
9	1200	80	1.5	3

RESULTS AND DISCUSSIONS

In this present work, the Friction stir process is carried out to join Aluminum alloy 2024 plates and also the joint reinforced with the carbon nanotubes. The process parameters decided through Taguchi L9 orthogonal array optimization technique. The input values revolution of the tool, feed rate of the tool, Depth of groove and title angle, and output value, which is tensile strength given in table 2.

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The signal to noise ration utilized in this study to determine the fit input. The criteria which carried out to optimize is better because the friction stir processed specimen should show better tensile strength. Hence larger value is utilized [22]. The statistical software named MATLAB is utilized to investigate the best input parameters and its role in improving the mechanical property of the joint

Table 2. Input and output parameter of in FSW process of AA2024 plates.

SAMPLE No	INPUT				OUTPUT	
	Revolution	Feed Rate	Depth of Groove	Tilt Angle	Ultimate Tensile Strength	Average UTS
	(rpm)	(mm/min)	(mm)	(deg)	(Mpa)	(Mpa)
1	600	40	1	1	528	577.3333333
					593	
					585	
2	600	60	1.5	2	543	523
					496	
					511	
3	600	80	2	3	621	600.6666667
					608	
					595	
4	900	40	1.5	3	734	756.6666667
					759	
					763	
5	900	60	2	1	702	783
					811	
					749	
6	900	80	1	2	769	726.6666667
					721	
					698	
7	1200	40	2	2	655	622.4333333
					604	
					617	
8	1200	60	1	3	643	656.3333333
					672	
					651	
9	1200	80	1.5	1	697	676.3333333
					682	
					655	

Table 3. Response table for S/N ratio of input parameters in the FSW process

Level	Tool Rotational Speed (rpm)	Feed rate (mm/min)	Depth of groove (mm)	Tilt angle (deg)
1	55.06	56.23	56.27	56.57
2	57.56	56.20	56.18	55.83
3	56.28	56.47	56.44	56.50
Delta	2.50	0.27	0.26	0.74
Rank	1	3	4	2

Figure 4 and figure 5 given the graphical representation of the behavior of input parameters during the friction stir processing of AA 2024. The graph plotted for the optimum tensile strength of the joined plates according to the input parameters.

Table 4. Response table for means of input parameters in the FSW process

Level	Tool Rotational Speed (rpm)	Feed rate (mm/min)	Depth of groove (mm)	Tilt angle (deg)
1	567.0	652.1	653.4	678.9
2	755.4	654.1	652.0	624.0
3	651.7	667.9	668.7	671.2
Delta	188.4	15.7	16.7	54.9
Rank	1	4	3	2

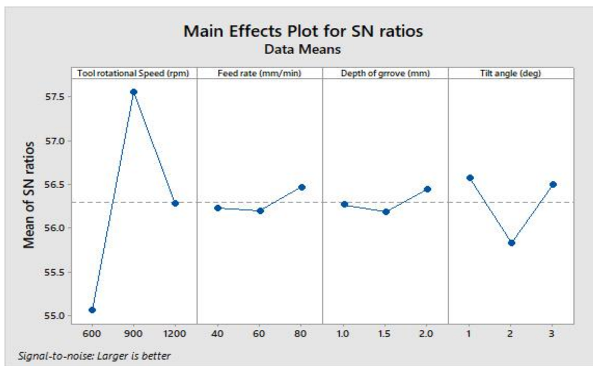

Figure. 4. The main effects plot for S/N Ratio of input parameters in the FSW process

The most significant input parameter is the tool rotation speed of 900rpm with the feed rate of 60mm/min with the Depth of the groove and title angel of 2mm and 1 degree, respectively, with the maximum tensile strength of 780 MPa. By ranking process, the rotational tool speed is the significant parameter of better joining ability, which shown in table 3 and table 4.

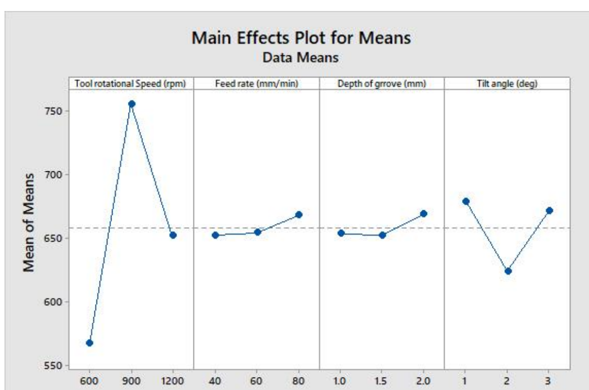

Figure. 5. The main effects plot for means of input parameters in the FSW process

The contribution of each input parameter is analyzed by using the Analysis of variance (ANOVA) carried out by utilizing the MATLAB software. Table 5 shows each input value and its contribution percentage to the output. Figure 6 exhibits the relationship among all input parameters and to ascertain the influencing contribution of the friction stir process of AA2024. The maximal contribution among the input parameters was rotational tool speed (89.5%) followed by tilt angle (8.8%), Depth of cut, and feed rate.

Table 5. Analysis of variance of input parameters and its contribution percentage in the FSW process

Source	DF	Adj SS	Adj MS	Contribution percentage
Tool rotational Speed (rpm)	2	53448.3	26724.2	89.5
Feed rate (mm/min)	2	441.6	220.8	0.7
Depth of groove (mm)	2	513.7	256.9	0.8
Tilt angle (deg)	2	5294.7	2647.4	8.8
Error	0	*	*	
Total	8	59698.3		100

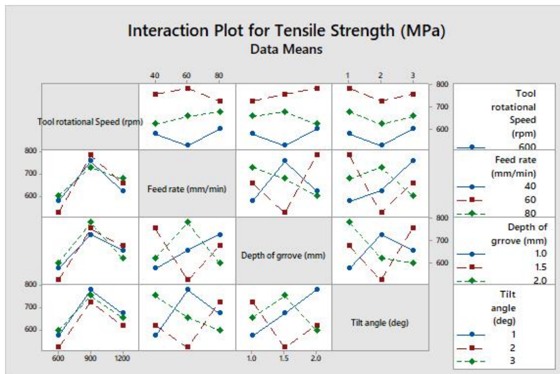

Figure. 11. Interaction plot of input parameters and its contribution percentage in the FSW process

CONCLUSION

The joining of the two AA2024 plates by the FSW process and the continuous reinforcement using multiwall carbon nanotubes was completed. The ultimate tensile strength was estimated and compared according to the ASTM standards. Optimization techniques using Taguchi and ANOVA. The main conclusions are as follows: Through the Taguchi orthogonal array, the rotational speed was found to be a vital process parameter that most affects the weld strength. Before the tests post FSW, the strength was found to be around 476 MPa, without FSW or FSP. After FSW, the optimum joining strength was found to be around 780 Mpa, signaling an increase in the strength of the plates. The operating parameters were found to be 900 rpm, with a feed rate of 60 mm/min as well as 2mm Depth of grove and a tilt angle of 1 degree

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