Optimization of friction stir processing parameters for fabrication of surface hybrid composite (al7075/sic/cr) using full factorial design

Nandakumar N[1], Gopinath K[*]

[1]Assistant Professor, Government College of Technology, Coimbatore.
[*]PG Scholar, Government College of Technology, Coimbatore.
[1]nannthu@yahoo.com,*gopikrish695@gmail.com

Abstract

Friction Stir Processing (FSP) is a promising solid-state technique to develop surface composites. The present investigation is to develop hybrid surface composite of Al7075 reinforced with the mixture of silicon carbide (SiC) and chromium (Cr) particles through FSP route and optimize the FSP parameters to investigate mechanical behaviour and maximize the corrosion resistance. The influence of tool rotational speed, tool traverse speed and number of passes on aluminium alloy (Al 7075) based surface composite was studied for optimizing the FSP parameters to fabricate hybrid composite. The Vickers micro-hardness tests along top surface of the processed samples were evaluated for all the runs. The experimental results revealed that maximum corrosion resistance and hardness was obtained at high rotational speed and number of passes with low traverse speed.

Keywords: Corrosion rate, Friction stir processing, Micro hardness, Surface composite Al7075/SiC/Cr.

1. Introduction

A composite material is a combination of two or more materials that results in better properties than those of the individual components used alone. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. Many fabrication techniques had been identified for fabrication of surface composite, but friction stir processing (FSP) has been identified as one of the most promising techniques. FSP works on the same principle of friction stir welding (FSW) [1]. The limitation such as, formation of intermediate detrimental phase and porosities due to elevated temperature process conditions occur in the Liquid phase processing techniques. To avoid such problems, the process should be carried out at a temperature below the melting point of the substrate as done in solid phase surface modification techniques. As FSP is one of the solid-state surface modification techniques, in which process is carried out at a temperature below the melting point of the substrate, it has been used in the present investigation for fabrication of SC.

Mishra et al.[1] developed the first surface composite through friction stir processing technique. Later many researchers have researched the area of friction stir processing technique. Among them H.G. Rana et.al [2] has investigated the micro hardness and wears properties, the study reveals that there is reducing trend of micro hardness with increase in tool traverse speed and wear resistance increase with reducing tool traverse speed. K. Surekha, et.al [3] have studied the effect of process parameters on the corrosion behaviour of friction stir processed AA2219 aluminium alloy, The study reveals that the corrosion resistance of aluminium alloy increased with the increase in rotation speed and Dissolution of the $CuAl_2$ particles during FSP reduces the number of sites available for galvanic coupling hence amount of dissolution increases with rotation speed and hence the corrosion resistance also increases with rotation speed. K. Surekha et.al[4],have investigated the microstructural characterization and corrosion behaviour of multipass friction stir processed AA2219 aluminium alloy, the investigation reveals that number of passes during FSP has a significant effect on the corrosion resistance. Three pass and two pass FSP alloy showed better corrosion resistance in comparison to the single pass processed alloy.

During FSP, reinforcement particles are wrapped and flow together with plastic metal. Due to difference in the physical properties between SiC and Cr particles and base metal, it is hard for the particles to travel with the trail left by the plastic metal. That's why SiC and Cr particles cannot be easily dispersed and the agglomeration occurs. So, it is necessary to fabricate surface composite by higher number of passes, which ensures better distribution.

In present work, Aluminium 7075 has been used as matrix phase. Silicon Carbide (SiC) and Chromium (Cr) has been used as reinforcement phase. Al 7075/SiC/Cr surface composite has been fabricated using various combination of tool traverse speed (TS), number of passes and tool rotation speed (RS). Investigation of micro hardness and corrosion behaviour had been done for the SC formed. Optimization of process parameters for micro hardness and corrosion behaviour had been done for the formed SC.

2. Experimental details

Experiments have been performed on conventional vertical milling centre. Base plate for manufacturing of surface composite used is 6 mm thick Aluminum alloy 7075 plate with length of 150 mm and width of 100 mm. The chemical composition for the same is mentioned in table 1. For, reinforcement, a groove of 2 (W) × 4 (D) × 100 (L) mm was prepared using shaper machine and same was filled with reinforcements of Silicon carbide (SiC) and Chromium (Cr) powders.

A heat-treated pin less tool has been used for capping pass to close the groove cavity. A heat-treated tool having conical profile pin has been used for stirring passes. If FSP directly performed for stirring pass, once the particles are inserted into the groove, extensive loss of powder particles can occur. It can be efficiently reduced by applying a single capping pass on the hole with cylindrical tool without pin profile. Subsequently, powder particles packed in the groove uniformly distributed with cylindrical tool with conical pin.

Eight specimens were prepared as per the design of experiment given in the Table 2.2. Samples for the microhardness and corrosion tests are cut perpendicularly to the processed line at the centre of the plate. Investigation of micro hardness using Vickers hardness tester and corrosion test has been carried out for each sample.

3. Results and discussions.

The results of above experiments are analysed for micro hardness across the processed zone and corrosion behaviour.

3.1. *Micro hardness*

Micro hardness has been recorded for all samples using Vickers hardness tester at 300 gm load and 10 seconds of dwell time using ESEWAY Vickers Hardness Tester. The core hardness was measured by the indentation made at 1 -1.5 mm beneath the top surface in horizontal direction. For which the cross section was cut from the prepared sample. Microhardness recorded for each sample are tabulated in the table no. 3.1

Table 3.1 Microhardness for various samples

Run order	Tool Rotation Speed(rpm)	Tool Traverse speed ((mm/min)	No of passes	Micro hardness (HV)		
				Trial 1	Trial 2	Average
1	900	30	1	172.8	173.2	173
2	1200	30	1	173.4	175.1	174.2
3	900	20	2	179.5	181.4	180.5
4	900	30	2	176.3	177.1	176.7
5	1200	20	2	185.4	187.6	186.5
6	1200	30	2	182.3	181.7	182.0
7	1200	20	1	174.7	176.5	175.6
8	900	20	1	175.2	177.3	176.2

3.1.1 *Optimization for micro hardness*

The response obtained from micro hardness test is optimized with respect to the process parameters rotational speed, traverse speed and number of passes with each factor having two levels namely low and high.

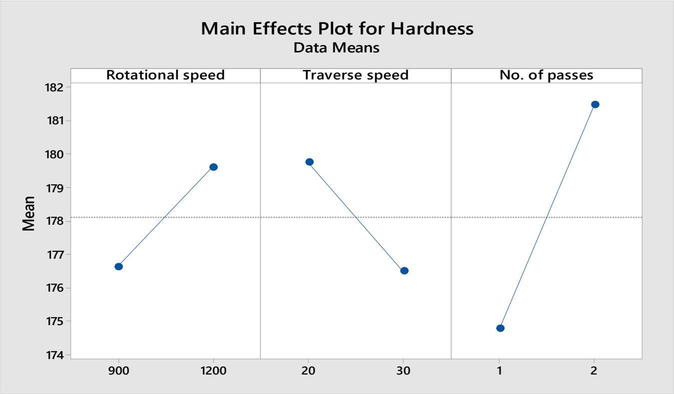

Figure 3.1 Main Effect Plot for Hardness

The figure 3.1 shows the main effects of factors on the response hardness. The optimum value of hardness is considered to be the highest. It can be clearly seen from the graphs that the optimum value of wear occurs at 1200 rpm rotational speed, 20mm/min traverse speed[1] and for 2 number of passes.

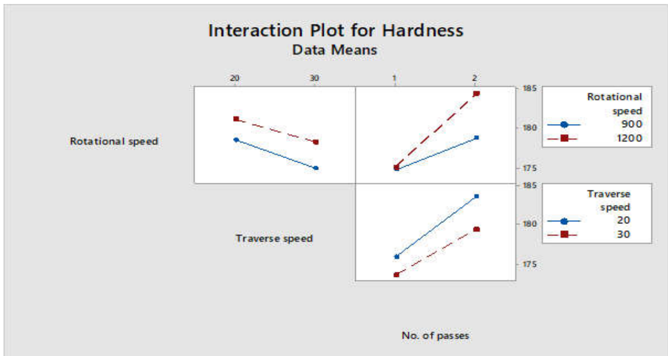

Figure 3.2 Interaction Plot for Hardness

The figure 3.2 shows the interaction of factors on the response. It is seen from the graph that the curves that do not intersect, which implies there is no significant interaction between the factors.

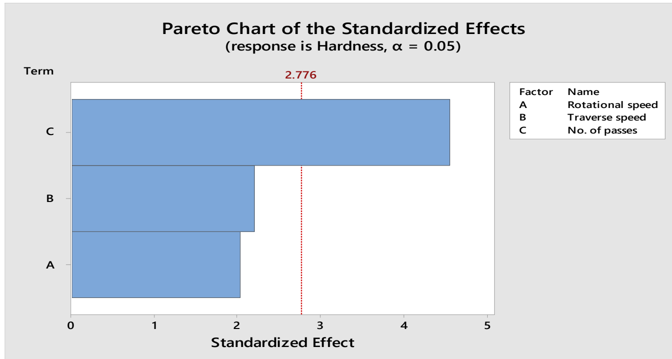

Figure 3.3 Pareto Chart of the standardized Effects

The figure 3.3 shows the Pareto chart of the effects i.e. the contribution of the effects of the main parameters. It is clear from the figure that the factor C: has the highest impact whereas the factor A: rotational speed has the least impact.

3.1.2 *ANOVA for hardness*

The inferences made from the above said graphs can be arrived at mathematically with the help of ANOVA. The confidence limits are taken as 95% for all the factors. Factors with P-value less than 0.05 are considered to be significant. The table 3.2 shows the values obtained for ANOVA test. It is clear from the table that all the inferences made from the figures 5.3 are statistically true.

Table 3.2 ANOVA table for hardness

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Rotational speed	1	17.82	17.820	4.14	0.112
Traverse speed	1	21.06	21.060	4.89	0.091
No. of passes	1	89.38	89.378	20.76	0.010
Error	4	17.22	4.306		
Total	7	145.48			

3.1.3 *Multiple linear regressions for hardness*

The data adequacy and analysis of the model designed in Full Factorial model can be evaluated using multiple linear regression model. The results from regression analysis can be used to cross check the results drawn from the graphs and ANOVA test. Regression test also gives the regression equation which is generalized equation corresponding to the effects of all the parameters on the responses. Substituting the optimum conditions namely 1200 rotational speed, 20mm/min traverse speed and 2 number of passes in the regression equation the optimum value of hardness obtained is 184.58 Hv

Hardness = 165.76 + 0.00995 Rotational speed – 0.325 Traverse speed + 6.69 No. of passes

3.2 *Corrosion Rate*

The rate of corrosion is the speed at which any given metal deteriorates in a specific environment. The rate or speed, is dependent upon environmental conditions as well as the type, and condition, of the metal. Table 3.3 shows corrosion rate for fabricated material.

mpy = 534 x (W / DAT)

Where,

W = weight loss in milligrams
D = metal density in g /cm^3
A = area of sample in cm^2

T = time of exposure of the metal sample in hours

Table no 3.3 Corrosion rate for various samples

Run order	**Area (cm)**	**Density (g/cm^3)**	**Before weight (grams)**	**After weight (grams)**	**Weight loss (grams)**	**Corrosion rate (mpy)**
1	4	2.81	5.352	5.325	0.027	1.781
2	4	2.81	5.402	5.380	0.022	1.451
3	4	2.81	5.345	5.329	0.016	1.055
4	4	2.81	5.332	5.314	0.018	1.187
5	4	2.81	5.365	5.361	0.004	0.263
6	4	2.81	5.400	5.390	0.010	0.659
7	4	2.81	5.322	5.303	0.019	1.253
8	4	2.81	5.335	5.315	0.020	1.319

3.2.1 *Optimization of corrosion rate*

The response obtained from micro hardness test is optimized with respect to the process parameters rotational speed, traverse speed and number of passes with each factor having two levels namely low and high.

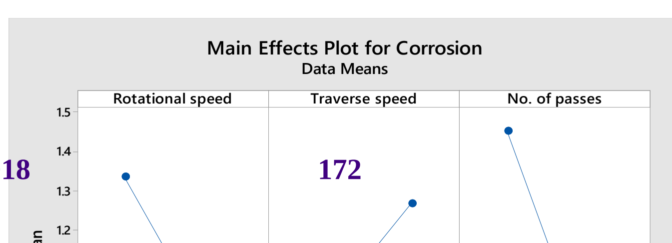

Figure 3.4 Main Effect Plot for corrosion rate

The figure 3.4 shows the main effects of factors on the response corrosion rate. The optimum value of corrosion rate is considered to be the lowest. It can be clearly seen from the graphs that the optimum value of wear occurs at 1200 rpm rotational speed, 20mm/min traverse speed and for 2 number of passes.

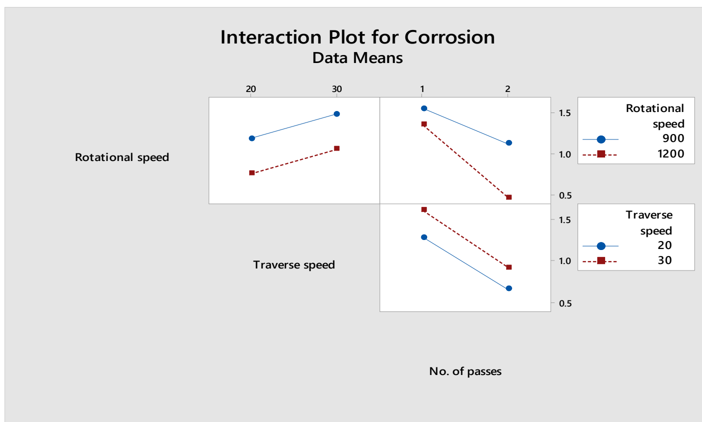

Figure 3.5 Interaction Plot for Corrosion Rate

The figure 3.5 shows the interaction of factors on the response. It is seen from the graph that the curves that do not intersect, which implies there is no significant interaction between the factors.

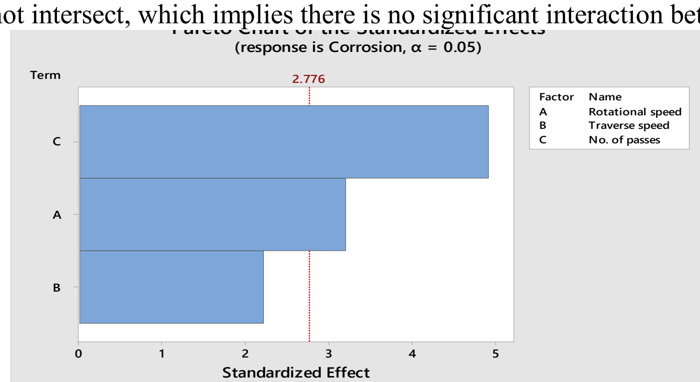

Figure 3.6 Pareto Chart of the Standardized Effects

The figure 3.6 shows the Pareto chart of the effects i.e. the contribution of the effects of the main parameters. It is clear from the figure that the factor C: has the highest impact whereas the factor A: rotational speed has the least impact.

3.2.3 *ANOVA for corrosion rate*

The inferences made from the above said graphs can be arrived at mathematically with the help of ANOVA. The confidence limits are taken as 95% for all the factors. Factors with P-value less than 0.05 are considered to be significant. The table 3.4 shows the values obtained for ANOVA test. It is clear from the table that all the inferences made from the figures 3.6 are statistically true.

Table 3.4 ANOVA table for corrosion rate

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Rotational speed	1	0.3681	23.60%	0.3681	0.36808	10.24	0.033
Traverse speed	1	0.1764	11.31%	0.1764	0.17642	4.91	0.091
No. of passes	1	0.8712	55.87%	0.8712	0.87120	24.24	0.008
Error	4	0.1437	9.22%	0.1437	0.03594		
Total	7	1.5594	100.00%				

3.2.4 Multiple linear regressions for corrosion rate

The data adequacy and analysis of the model designed in Full Factorial model can be evaluated using multiple linear regression model. The results from regression analysis can be used to cross check the results drawn from the graphs and ANOVA test. Regression test also gives the regression equation which is generalized equation corresponding to the effects of all the parameters on the responses. Substituting the optimum conditions namely 1200 rotational speed, 20mm/min traverse speed and 2 number of passes in the regression equation the optimum value of corrosion rate obtained is 0.428 mpy

Corrosion rate = 2.870 – 0.001430 Rotational speed + 0.0297 Traverse speed – 0.660 No. of passes

4. Conclusion

This work on optimizing friction stir processing parameters for fabrication of Al7075 surface hybrid metal matrix composite (SHMMC) reinforced with the mixture of SiC + Cr and investigation on mechanical behavior of SHMMC has led to the following conclusions:

- Fabrication of SHMMC was done successfully on the commercially available AA7075 alloy by reinforcing SiC and Cr in 3:1 proportions using friction stir processing technique.
- Micro hardness of friction stir processed Al7075 surface hybrid metal matrix composites has been analysed for different processing conditions such as tool rotational speed, traverse speed and number of passes by following a design of experiments using Full Factorial Design.
- The optimized parameters were obtained using full factorial design and optimum values are, Rotational speed: 1200 rpm, Traverse speed: 20mm/min and number of passes: 2.
- The experimental results revealed that maximum corrosion resistance and hardness was obtained at high rotational speed and number of passes with low traverse speed.

5. Reference

[1]R.S. Mishra et al (1999), High strain rate super plasticity in a friction stir processed 7075 Al alloy, 42 (1999) 163-168

[2] H.G. Rana et.al (2016), Fabrication of Al7075 / B4C surface composite by novel Friction Stir Processing (FSP) and investigation on wear properties.

[3] K. Surekha, et.al (2009), Effect of processing parameters on the corrosion behaviour of friction stir processed AA 2219 aluminum alloy.

[4] K. Surekha, et.al, Microstructural characterization and corrosion behavior of multipass friction stir processed AA2219 aluminium alloy

[5] A. Dolatkhah et.al (2012), Investigating effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing.

[6] R. Abdi Behnagh et.al (2012), Mechanical Properties, Corrosion Resistance, and Microstructural Changes during Friction Stir Processing of 5083 Aluminum Rolled Plates.

[7] Narayana Yuvaraj, Sivanandam Aravindan, Vipin, (2015), Fabrication of Al5083/B_4C surface composite by friction stir processing and its tribological characterization.

[8] Sudhakar.M Srinivasa Rao.CH Meera Saheb.K (2016), Production of Surface Composites by Friction Stir Processing.

[9] D. Amirtharaj, G. Rajamurugan, S. Sivachidambaram and D. Dinesh (2015), Effect of tool geometry on surface modification of aluminium 6065 by friction stir processing.

[10] M. Lotfollahi, M. Shamanian, A. Saatchi (2014), Effect of Friction Stir Processing on Erosion-Corrosion Behavior of Nickel Aluminum Bronze.

[11] Mansour Rahsepar, Hamed Jarahimoghadam (2016), The Influence of Multipass Friction Stir Processing on the Corrosion Behavior and Mechanical Properties of Zircon-Reinforced Al Metal Matrix Composite.

[12] Azeem Dafedar, Rahul Bhandari, Vijayaram T.R (2014) "Processing & Characterization of Titanium Carbide & Titanium Oxide Particulate Reinforced Aluminium Metal Matrix Composite for Aerospace Applications" International Journal of Scientific & Engineering Research, Volume 5, Issue 10, pp1372-1377.

[13] Raghavendra. N, V. S. Ramamurthy "Development and wear characterization of al7075/al2o3/sic hybrid particulate metal matrix composite developed by stir casting" International Journal of Research in Engineering and Technology eISSN: 2319-1163 pISSN: 2321-7308.

[14] A.K.M. Asif Iqbal "Effect of Reinforcement Clustering on Crack Initiation Mechanism in a Cast Hybrid Metal Matrix Composite during Low Cycle Fatigue" Open Journal of Composite Materials, 2013, 3, 97-106.

[15] Mosleh-Shirazi S , Akhlaghi F , Li D.Y (2016) "Effect of graphite content on the wear behavior of Al/2SiC/Gr hybrid nano-composites respectively in the ambient environment and an acidic solution" Tribology International 103 pp620–628