IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 15, Issue 3 Ver. I (May. - June. 2018), PP 51-57
www.iosrjournals.org

Optimization of Process Parameters in Friction Stir Processing Using Analysis of Variance (ANOVA)

Gaurav Makkar[1], Sonal Khurana[2], Surabhi Lata[3]
[1,2,3]*(Mechanical Engineering Department, Maharaja Agrasen Institute of Technology, Delhi, India)*
Corresponding Author: Gaurav Makkar

Abstract : *With every industry being replete with ùse of MMC's, due to the superior mechanical properties they offer, their fabrication has attracted lot of research in recent years. One technique following the footsteps of friction stir welding is friction stir processing which can be used to modify the properties of material locally and the properties of bulk of material remain unchanged. In the present work, an Al6082 composite is formed with 400 mesh size graphite powder as a reinforcement using FSP. The processing is carried out at 4 different rotational speeds and traverse speeds. The processed samples are then compared for their mechanical properties (Utimate strength and Rockwell hardness) with the sample processed without reinforcement. Finally an optimization approach using ANOVA is presented optimized set of process parameters.*

Keywords: *Al6082, ANOVA, MMC, tool pin profile*

Date of Submission: 26-04-2018 Date of acceptance: 14-05-2018

I. Introduction

Friction stir processing (FSP) is a novel process of fabrication of metal matrix composites which is based on the principle of Friction stir welding (FSW), that locally changes and manipulates the microstructure near the surface layers of processed metallic compounds by adding high energy in metal in solid state to alter the mechanical properties. Also, it has emerged as a tool to produce composites by embedding second phase particle in the matrix [1]. The solid state process offers several advantages by removing problems which are generally associated with liquid phase. Since the process takes below melting point, the distortion and number of defects associated with the process is very low. FSP is a cleaner process due to absence of need of any filler material and gases. It thus produces no harmful emissions. The energy requirements are also meagre as compared to other welding and fabricating processes.

Friction stir processing utilizes the same equipments and techniques as FSW. This process also involves severe plastic deformation and is mostly used to join light alloys and ferrous alloys. The heat, combined with deformation by the stirring action of tool pin and pressure due to tool shoulder, produces a defect-free, recrystallized, fine-grained microstructure. FSP is an effective method for producing fine-grained structure and surface composite, modifying the microstructure of materials, and synthesizing composites and intermetallic compounds [2].

A lot of literature is available about the effect of FSP on the properties of base metal. L. Kartikeyan et.al studied the relationship between process parameters and mechanical properties of Friction Stir Processed Aluminium alloy. Lower axial forces produced material with lower tensile strength and lower ductility. Tool rotational speeds between 1200 and 1400 rpm yielded good results [3]. K.Elangovan et.al investigation on the effect of Welding speed on FSP zone formation in AA2219 Aluminum alloy. In the experiment, rolled plates of 6mm thickness AA2219 aluminum alloy cut into 300 x 150 mm were prepared in butt joint configuration. With constant rotational speed of 1600 rpm, higher welding speed resulted in lower heat input per unit length of the weld causing lack of stirring in the friction stir processing zone. Lower weld speed resulted in higher temperature and slower cooling rate in the weld zone causing grain growth and severing clustering of carbide precipitates. Another important observation available in literature is related to percentage elongation. The percentage elongation almost doubles as a result of FSP which suggests grain boundary sliding in all conditions [4]. Al6082 is the alloy with highest strength in the Al6000 series. Owing to its low cost, high strength to weight ratio, good formability and excellent corrosion resistance, it is used in marine, automobile, and aircraft industries. Also, due to high strength it is gradually replacing the Al6061. Since an exhaustive research has not gone in studying this alloy with reinforcements. In the present work Al6082 and graphite composite is tested for its mechanical properties. The composite is formed using Friction Stir processing. The composites are formed using cylindrical pin profile, as it is most easy to produce. The processing is done at four rotational speeds and four traverse speeds. These different traverse speeds and rotational speeds are the most common operation speeds used during Friction stir welding processes.

II. Experimental Procedure And Observations

Since FSP is a thermo-mechanical process the temperature at the interacting surface reaches solidus temperature of the base metal, hence selection of tool which does not loses its dimensional stability is important. The material for tool was chosen to be D-2 steel which is a high carbon, high chromium steel. Also, D2 shows little distortion on hardening. Processes involving friction stirring utilize the frictional force produced between shoulder and workpiece. The pin design is primarily responsible for the depth the tool can achieve which determines the shear force generated during the movement and stirring action. The tools are made with cylindrical profiles since those are easy to manufacture, though they produce composites whose mechanical properties are not at par with composites formed from triangular or square profile which produce more stirring in the processed region, but the stirring can be improved by providing threads on the cylindrical profile. The tool is shown in Fig-1. The dimensions of the tool are given in Table 1

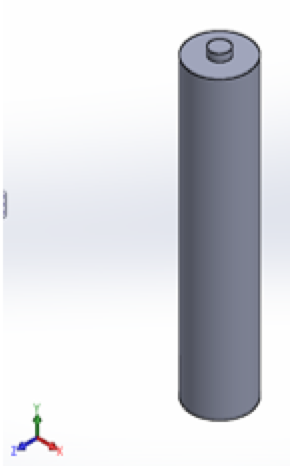

Figure 1-Tool profiles used- cylindrical threaded

Table 1- Tool dimensions

S.no	**Tool Attributes**	**Dimensions (mm)**
1	Shoulder diameter	16
2	Pin depth	2.5
3	Diameter of pin of circular cross section	5
4	Pitch of threads	1.5 threads per mm

Commercially available Al plates of 6 mm thickness were used, length and width being 100mm and 50mm respectively. The composition of Al6082 is shown in table 2. A slot of 1 mm thickness was made in the plates and filled with graphite powder of 400 mesh size. Friction Stir processing was carried out on a vertical milling machine and single pass was used for all cases. The process was carried out at 4 rotational speeds of 800, 1000, 1200 and 1400 rpm and 4 traverse speeds of 0.8, 1.0, 1.2, 1.4 mm/s. Two different diameter of tool profiles were used but these don't have profound effect on the properties of the composite produced and hence it is not optimized. The input parameter values are given in table 3. Hence a total of 32 (4x4x2) experiments were carried out. After all the samples were processed, specimen for strength and hardness testing were removed from the processed samples. Dogbone specimens were used for tensile strength testing as per ASTM standards. The test were carried out on a digital UTM. For hardness testing, class B Rockwell hardness testing is used which uses a shell type indenter with diameter of 0.0625 inches, major load of 100kgf and minor load of 10kgf.

Table 2-Al6082 composition

Element	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Ti**	**Cr**	**Al**
% present	0.7-1.3	0.0-0.5	0.0-0.1	0.4-1.0	0.6-1.2	0.0-0.2	0.0-0.1	0.0-0.25	Balance

Table 3- Input parameters

Input Parameters					
Rotational Speed (rpm)		**Traverse Speed (mm/s)**		**Tool diameter (mm)***	
R1	800	**T1**	0.6	**D1**	5.0
R2	1000	**T2**	0.8		
R3	1200	**T3**	1.0	**D2**	5.5
R4	1400	**T4**	1.2		

The value of ultimate strength and Rockwell hardness (Scale B) was recorded for all the samples. The values are tabulated in table 4. These parameters are then optimized using one way and two way ANOVA techniques to find the combination of parameter values which would yield best set of Mechanical properties. These experiments are carried out with two tool diameters of 5.0 mm and 5.5 mm. These values are used only to see if variation in tool diameter leads to huge variation in mechanical properties. These combination of parameters form a total of 32 experiments. To check the strength of base metal after processing without any addition of composite, a plate was processed without addition graphite. The UTM value for the plate was recorded to be 136 MPa.

Table 4- Observation table

Exp No.	**Combination of process parameters**	**UTM (MPa)**	**Rockwell Hardness(B)**
1	**R1, T1, D1**	140	64
2	**R1, T2, D1**	138	60
3	**R1, T3, D1**	137	57
4	**R1, T4, D1**	134	50
5	**R1, T1, D2**	141	65
6	**R1, T2, D2**	139	61
7	**R1, T3, D2**	137	57
8	**R1, T4, D2**	135	52
9	**R2, T1, D1**	142	72
10	**R2, T2, D1**	140	70
11	**R2, T3, D1**	139	68
12	**R2, T4, D1**	137	65
13	**R2, T1, D2**	145	73
14	**R2, T2, D2**	145	71
15	**R2, T3, D2**	142	68
16	**R2, T4, D2**	140	65
17	**R3, T1, D1**	151	79
18	**R3, T2, D1**	150	76
19	**R3, T3, D1**	148	72
20	**R3, T4, D1**	146	70
21	**R3, T1, D2**	154	79
22	**R3, T2, D2**	151	76
23	**R3, T3, D2**	150	71
24	**R3, T4, D2**	155	70
25	**R4, T1, D1**	161	84
26	**R4, T2, D1**	157	77
27	**R4, T3, D1**	162	74
28	**R4, T4, D1**	164	72
29	**R4, T1, D2**	163	84
30	**R4, T2, D2**	161	78
31	**R4, T3, D2**	163	74
32	**R4, T4, D2**	167	72

The values are optimized using one way ANOVA and two way ANOVA, which uses principle of Design of Experiments. The procedure is discussed in next section

III. Results And Discussion

Analysis of variance (ANOVA) is used to optimize the process parameters to find the best set of process parameters which can yield the superior combination of strength and hardness. ANOVA is a statistical technique which uses variance in groups to check if the mean of groups is different from each other and it compares influence of one or more factors by comparing means of different sample groups. ANOVA uses two hypothesis - Null hypothesis and Alternate hypothesis. When the mean of all the sample groups is equal or they don’t show a significant difference in means, it can be considered as null hypothesis otherwise Alternate hypothesis. The decision about hypothesis is made by comparing p values with the chosen α value. For our purpose the value of α is considered as 0.05 [5].

3.1 One way ANOVA

A one way ANOVA is used to compare two means of two independent (unrelated) groups using the F-distribution. The null hypothesis for the test implies that means are equal. Therefore, a significant result means that the two means are unequal. Using one way ANOVA we can make a decision about rejecting the Null hypothesis. If the p-value comes less than the α value then Null hypothesis can be rejected which implies that means of all the groups is not same. Thus larger the F- value or smaller the p- value, more different are the means of individual groups.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Rot. Speed	3	2905.1	968.375	127.45	0.000
Error	28	212.7	7.598		
Total	31	3117.9			

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Traverse Speed	3	31.13	10.38	0.09	0.963
Error	28	3086.75	110.24		
Total	31	3117.88			

Figure 2- One way ANOVA results for UTM

As shown in fig- p-value for rotational speed is less than α value, thus null hypothesis can be neglected for Rotational speed as an input parameter. Whereas for Traverse speed p- value is more than 0.05 thus the mean values of UTM with varying traverse speeds remain more or less in the same bracket. But this conclusion is not sufficient to conclude that the effect of traverse speeds is not significant. The interaction between rotational speed and traverse speed needs to be studied which is presented in next section.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Rot. Speed	3	1620.6	540.21	28.37	0.000
Error	28	533.3	19.04		
Total	31	2153.9			

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Traverse Speed	3	491.1	163.71	2.76	0.061
Error	28	1662.8	59.38		
Total	31	2153.9			

Figure 3-one way ANOVA results for Rockwell hardness

For Rockwell hardness, also the effect of rotational speed is more significant as compared to traverse speed. Thus, a preliminary conclusion can be made- rotational speed has a profound effect on the mechanical properties than traverse speed.

3.2 Two Way ANOVA

Two way ANOVA is an extension of One way ANOVA. In one way ANOVA we have one dependent variable controlling the outcome whereas in two way ANOVA, two variables are considered as independent. Two way ANOVA is generally applied to study interaction between the two independent variables. These are represented through interaction plots where it can be judged about which set of parameters produce best results. The main effect in case of Two way ANOVA is similar to One way ANOVA, with interaction plot all the effects are considered at once. There are assumptions which are made while performing Two way ANOVA. Firstly, the observations must be close to bell curve distribution. The population variances must be equal and the sample sizes must be same.

.

Grouping Information Using the Tukey Method and 95% Confidence

Rot. Speed	N	Mean	Grouping
R4	8	162.250	A
R3	8	150.625	B
R2	8	141.250	C
R1	8	137.625	D

Means that do not share a letter are significantly different.

Grouping Information Using the Tukey Method and 95% Confidence

Traverse Speed	N	Mean	Grouping
T1	8	149.625	A
T2	8	147.625	A B
T3	8	147.250	B
T4	8	147.250	B

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: Rot. Speed*Traverse Speed

Grouping Information Using the Tukey Method and 95% Confidence

Rot. Speed*Traverse Speed	N	Mean	Grouping
R4 T4	2	165.5	A
R4 T3	2	162.5	A B
R4 T1	2	162.0	A B
R4 T2	2	159.0	B
R3 T1	2	152.5	C
R3 T2	2	150.5	C
R3 T4	2	150.5	C
R3 T3	2	149.0	C D
R2 T1	2	143.5	D E
R2 T2	2	142.5	E F
R1 T1	2	140.5	E F G
R2 T3	2	140.5	E F G
R1 T2	2	138.5	E F G
R2 T4	2	138.5	E F G
R1 T3	2	137.0	F G
R1 T4	2	134.5	G

Means that do not share a letter are significantly different.

Figure 4- Two way ANOVA results for UTM

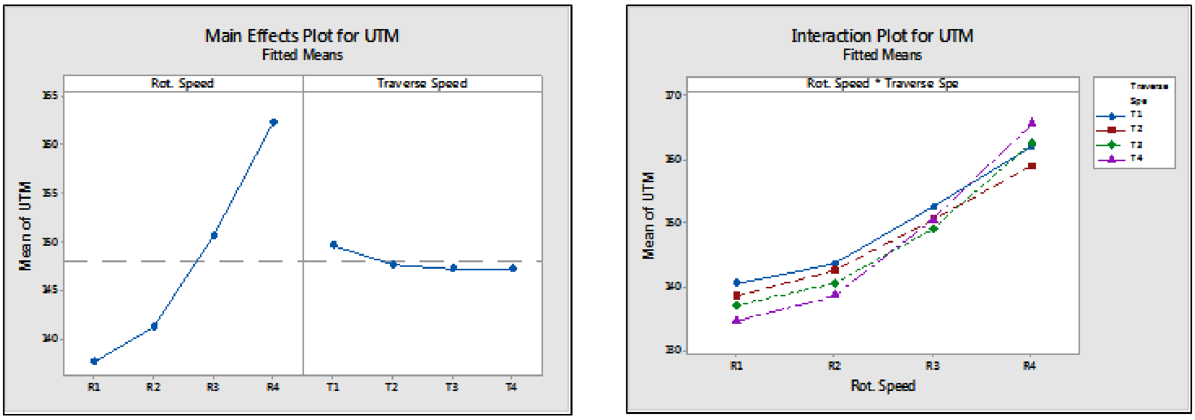

Figure 5- Two way ANOVA plots (a) Main effect plots (b) Interaction plots

As can be evidently seen from the results of Two way ANOVA for UTM, three combination of rotational speed and traverse speed produce highest value of UTM. Thus, traverse speed and rotational speed indeed have an interaction. These results are also presented as graphs in fig-5. These three sets can not be compared with the sets obtained for hardness. The parameter set common to both the screening criteria can be assumed to be the optimum.

Grouping Information Using the Tukey Method and 95% Confidence

Rot. Speed	N	Mean	Grouping
R4	8	76.875	A
R3	8	74.125	B
R2	8	69.000	C
R1	8	58.250	D

Means that do not share a letter are significantly different.

Grouping Information Using the Tukey Method and 95% Confidence

Traverse Speed	N	Mean	Grouping
T1	8	75.000	A
T2	8	71.125	B
T3	8	67.625	C
T4	8	64.500	D

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: Rot. Speed*Traverse Speed

Grouping Information Using the Tukey Method and 95% Confidence

Rot. Speed*Traverse Speed	N	Mean	Grouping
R4 T1	2	84.0	A
R3 T1	2	79.0	B
R4 T2	2	77.5	B C
R3 T2	2	76.0	C
R4 T3	2	74.0	D
R2 T1	2	72.5	D E
R4 T4	2	72.0	E F
R3 T3	2	71.5	E F G
R2 T2	2	70.5	F G
R3 T4	2	70.0	G
R2 T3	2	68.0	H
R2 T4	2	65.0	I
R1 T1	2	64.5	I
R1 T2	2	60.5	J
R1 T3	2	57.0	K
R1 T4	2	51.0	L

Means that do not share a letter are significantly different.

Figure 6- Two way ANOVA results for Rockwell hardness

Similarly, for Rockwell hardness only one combination of the two input process parameter produces superior values and both the input process parameters show interaction. These results are plotted in fig-7.

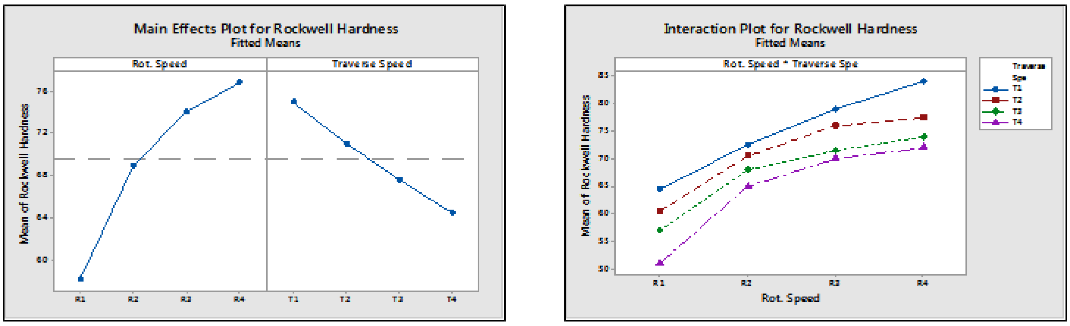

Figure 7- Two way ANOVA plots (a) Main effect plots (b) Interaction plots

The results obtained by optimization are also in line with the literature available about other composites. The addition of reinforcements generally leads to decrease in Tensile strength which can be attributed to change of microstructure in the processed region and increase in hardness which can be attributed to formation of carbides in the composite. Thus, combination of R4 (1400 rpm) and T1 (0.6mm/s) produce the best combination of properties being measured. It is the combination of highest rotational speed and lowest traverse speed, high rotational speeds lead to more heat energy being produced and low traverse speeds help this this heat energy to spread uniformly in the processed region.

IV. Conclusion

The strength of the plate after addition of graphite increases invariably. The amount of increase is a function of rotational speed and traverse speed. Increasing rotational speed leads to increase in UTM which can be attributed to more heat generation in the contact region, thus better fusion. Traverse speed alone does not affect the strength of the composite as long as it provides sufficient time for the metal to melt in the contact region. So UTM decreases with increase in traverse speed but then remains almost constant. But the interaction of both parameter has an effect on strength. Hardness of the material varies with both rotational speed and traverse speed. With increase in rotational speed, the value of hardness decreases and the effect is opposite with traverse speeds. The increase in hardness can be attributed to formation of carbides. Since in case of hardness the input parameters have opposite effects, the interaction study is important. ANOVA is a proficient technique that can be used to optimize the parameters in order to arrive at correct set of parameters, which can help in future experiments. In the set of experiments performed three set of parameters produce highest strength but only one out of these combinations also produces the maximum value of hardness. Thus, this combination of 1400 rpm and 0.6 mm/s produces superior results out of all the parameters sets considered. This can be explained as follows - higher rotational speed leads to more heat generation and lower traverse speed gives it more time for the heat generated to spread uniformly in the processed region. Tool diameter does not have a profound effect on the properties. It can also be used to optimize the parameters to achieve required values of other mechanical properties like ductility and elongation.

References

[1] R.S Mishra, Z.Y Ma, I Charit, Friction stir processing: a novel technique for fabrication of surface composite, *Material Science and Engineering, A 341(2003) 307-310.*

[2] Zahmatkesh B, Enayati MH, Karimzadeh F, Tribological and microstructural evaluation of friction stir processed AL2024 alloy. *Mater Des 2010;31(10):4891-6*

[3] Karthikeyan, L., and VS Senthil Kumar, Relationship between process parameters and mechanical properties of friction stir processed AA6063-T6 aluminum alloy. *Materials & Design32.5 (2011): 3085-3091.*

[4] Elangovan K, V. Balasubramanian V,Influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 aluminium alloy. *Journal of material processing technology 200(2008) 163-175.*

[5] Heiberger R.M., Neuwirth E.,One-Way ANOVA. In: R Through Excel. *Use R.* (Springer, New York, NY, 2009)

Gaurav Makkar. Optimization of Process Parameters In Friction Stir Processing Using Analysis of Variance (ANOVA)." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 15, no. 3, 2018, pp. 51-57