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Process Design and Optimization of end Milling Parameters of Al 7075 Metal Matrix Composite

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ABSTRACT

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This paper investigates the machinability characteristics of end milling operation to yield minimum tool wear with the maximum material removal rate using RSM. Twenty-seven experimental runs based on Box-Behnken Design of Response Surface Methodology (RSM) were performed by varying the parameters of spindle speed, feed and depth of cut in different weight percentage of reinforcements such as Silicon Carbide (SiC-5%, 10%,15%) and Alumina (Al2O3-5%) in alluminium 7075 metal matrix. Grey relational analysis was used to solve the multi-response optimization problem by changing the weightages for different responses as per the process requirements of quality or productivity. Optimal parameter settings obtained were verified through confirmatory experiments. Analysis of variance was performed to obtain the contribution of each parameter on the machinability characteristics. The result shows that spindle speed and weight percentage of SiC are the most significant factors which affect the machinability characteristics of hybrid composites. An appropriate selection of the input parameters such as spindle speed of 1000 rpm, feed of 0.02 mm/rev, depth of cut of 1 mm and 5% of SiC produce best tool wear outcome and a spindle speed of 1838 rpm, feed of 0.04 mm/rev, depth of cut of 1.81 mm and 6.81 % of SiC for material removal rate.

Keywords : Response Surface Methodology, Box Behnken, Material Removal Rate, Tool Wear, Minitab.

I. INTRODUCTION

In milling operation of Al 7075, one of the main output parameter of the process is tool wear, so we tried to minimise the tool wear by varying the inputs such as speed, depth of cut and feed by varying the composition of sic in Al 7075 as another input . We wanted to experiment on minimizing tool wear and alternatively tried to maximize MRR. ASHOK KUMAR.U [1] The Present work deals with the effects of various milling parameters such as spindle speed, feed rate, and depth of cut on the surface roughness of finished components. The experiments were conducted on AISI 304 S.S plate material on vertical milling machine using carbide inserts and by using Taguchi's technique including L9 orthogonal array. The analysis of mean and variance technique is employed to study the significance of each machining parameter on the surface roughness. Richardson [11] Had developed a model of cutting induced work piece temperatures during dry milling. A large number of experimental works have to be carried out when the number of the process parameters increases. Therefore, to reduce the number of experiments and to obtain good quality of investigation the term named Design of experiments (DOE) is getting familiar in all over the world.

II. MATERIAL SPECIFICATION

Material = Al 7075 alloy with constant percentage weights of Al_2O_3 (5%) & variable percentage weights of Sic (5%); Sic (10%) and Sic (15%)

1. Al7075 and 5% Al_2O_3 + 5% Sic
2. Al7075 and 5% Al_2O_3 + 10% Sic
3. Al7075 and 5% Al_2O_3 + 15% Sic

Dimensions of workpiece:
Work Piece Size: 130 mm X 100 mm X 50 mm (3 plates)

III. EXPERIMENTAL METHODOLOGY

Response Surface Methodology (RSM)

The response surface methodology (RSM) is a widely used mathematical and statistical method for modeling and analyzing a process in which the response of interest is affected by various variables and the objective of this method is to optimize the response. The parameters that affect the process are called dependent variables, while the responses are called dependent variables.

It can be expressed as the dependent variable y is a function of X1 and X2.

$$Y=f(X1)+f(X2)+e$$

where Y is the response (dependent variable), X1 and X2 are independent variables and e is the experimental error. Response surface is a method based on surface placement. Therefore, the main goals of an RSM study are to understand the topography of the response surface including the local maximum, local, minimum and ridge lines and find the region where the most appropriate response occurs.

CNC MILLING MACHINE

CNC milling, or computer numerical control milling, is a machining process which employs computerized controls and rotating multi-point cutting tools to progressively remove material from the workpiece and produce a custom-designed part or product. This process is suitable for machining a wide range of materials, such as metal, plastic, glass, and wood, and producing a variety of custom-designed parts and products.

Fig 1: End milling operations were carried out in a BHARAT FRITZ WERNER BF-1 universal milling machine with 2.2 kW motor capacity.

Levels of Experiment

Parameter Levels	Speed (N) in rpm	Feed (f) in mm/ min.	Depth of Cut(d) in mm	Weight of Sic (%)
Level 1	1000	0.3	1.0	10
Level 2	1500	0.2	1.5	5
Level 3	2000	0.3	1.5	15

The spindle speed, depth of cut, feed rate and weight of Sic are chosen the machining parameters.

Tool used

Cutting Tool: Carbide coated cutting tool inserts (AXMT 0903 PER-EML TT8020, Make: Taegu Tec)

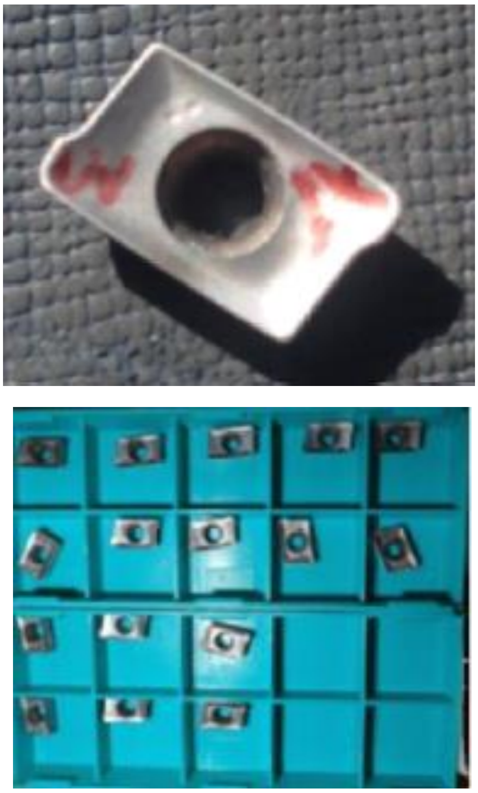


Fig 2 : Tool insert

The tool insert was mounted on a tool holder of designation TE90AX 220-09-L. Length and diameter of tool holder are 170 mm and 20 mm respectively. The end milling operation was done along the direction of width (100 mm) of the specimen.

Fig 3: Cutting Tools

Tool maker's microscope

Holm arc's Tool maker's microscopes are multi-functional measuring instruments which are primarily used for inspection and measurement of miniature mechanical and electronic parts and tools. These microscopes are used to view and measure linear distances, thread pitch, thread angles, tool edges, tool wear surfaces etc.

Fig 4 : Tool Maker's Microscope

Tool wear is measured through METZER tool makers microscope (Model: Metz-1395) was used for measurement of tool flank surface wear on the carbide coated cutting tool insert after end milling operation.

IV. RESULTS AND DISCUSSION

S NO	Spindle Speed, N (rpm)	Feed rate, f (mm/min)	Depth of cut, d (mm)	% Weight of Sic	Material removal rate, MRR (mm3/min)	Tool wear, VB (mm)
1	1000	0.03	1	10	759.49	0.135
2	1500	0.02	1.5	5	805.97	0.188
3	2000	0.03	1.5	15	1258.8	0.401
4	1500	0.03	2	15	812.61	0.395
5	1500	0.03	1	5	756.3	0.184
6	1500	0.03	1.5	10	2148.9	0.249
7	1500	0.03	1.5	10	2148.9	0.249
8	2000	0.03	1	10	956.3	0.347
9	1500	0.04	1	10	1406.3	0.266
10	1000	0.03	1.5	15	834.45	0.231
11	1500	0.03	2	5	1506.3	0.25
12	1500	0.02	1.5	15	805.97	0.249
13	2000	0.03	1.5	5	2111.1	0.288
14	1500	0.03	1.5	10	2148.9	0.249
15	1500	0.02	2	10	1043.5	0.247
16	1500	0.04	1.5	15	1126	0.351
17	1500	0.04	2	10	2201.7	0.298
18	2000	0.02	1.5	10	1303.6	0.316
19	1500	0.03	1	15	762.71	0.289
20	2000	0.03	2	10	1463.4	0.379
21	1500	0.04	1.5	5	2109.4	0.233
22	1000	0.02	1.5	10	698.82	0.136
23	2000	0.04	1.5	10	2160	0.359
24	1000	0.04	1.5	10	925.98	0.199
25	1000	0.03	1.5	5	1088.7	0.116
26	1500	0.02	1	10	734.13	0.202
27	1000	0.03	2	10	812.61	0.188

1.1 Analysis of variance of material removal rate

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	8623869	615991	7.2	0.001
Linear	4	5033504	1258376	14.71	0
Spindle Speed, N (rpm)	1	1423577	1423577	16.64	0.002
Feed rate, f (mm/min)	1	2189990	2189990	25.6	0
Depth of cut, d (mm)	1	777187	777187	9.09	0.011
% Weight of Sic	1	642751	642751	7.51	0.018
Square	4	2697212	674303	7.88	0.002
Spindle Speed, N (rpm)*Spindle Speed, N (rpm)	1	1267541	1267541	14.82	0.002
Feed rate, f (mm/min)*Feed rate, f (mm/min)	1	465292	465292	5.44	0.038
Depth of cut, d (mm)*Depth of cut, d (mm)	1	1664303	1664303	19.46	0.001
% Weight of Sic*% Weight of Sic	1	1537254	1537254	17.97	0.001
2-Way Interaction	6	893152	148859	1.74	0.195
Spindle Speed, N (rpm)*Feed rate, f (mm/min)	1	98986	98986	1.16	0.303
Spindle Speed, N (rpm)*Depth of cut, d (mm)	1	51524	51524	0.6	0.453
Spindle Speed, N (rpm)*% Weight of Sic	1	89416	89416	1.05	0.327
Feed rate, f (mm/min)*Depth of cut, d (mm)	1	288922	288922	3.38	0.091
Feed rate, f (mm/min)*% Weight of Sic	1	241769	241769	2.83	0.119
Depth of cut, d (mm)*% Weight of Sic	1	122535	122535	1.43	0.254
Error	12	1026519	85543		
Lack-of-Fit	10	1026519	102652	*	*
Pure Error	2	0	0		

Regression equation for material removal rate

Material removal rate(predicted) = -13254 + 5.51*n + 141290*f + 5619*d + 725*p - 0.00195*n*n - 2953679*f*f - 2234*d*d - 21.48*p*p + 31.5*f*n + 0.454*n*d - 0.0598*n*p + 53751*f*d - 4917*f*p - 70*d*p

Where,

n – spindle speed in rpm

f – feed rate in mm/min

d – depth of cut in mm

p – percentage of Sic

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	0.158082	0.011292	40.56	0
Linear	4	0.154654	0.038664	138.89	0
Spindle Speed, N (rpm)	1	0.098102	0.098102	352.4	0
Feed rate, f (mm/min)	1	0.011285	0.011285	40.54	0
Depth of cut, d (mm)	1	0.009296	0.009296	33.39	0
% Weight of Sic	1	0.035971	0.035971	129.21	0
Square	4	0.001962	0.000491	1.76	0.201
Spindle Speed, N (rpm)*Spindle Speed, N (rpm)	1	0.000023	0.000023	0.08	0.778
Feed rate, f (mm/min)*Feed rate, f (mm/min)	1	0.000098	0.000098	0.35	0.564
Depth of cut, d (mm)*Depth of cut, d (mm)	1	0.000861	0.000861	3.09	0.104
% Weight of Sic*% Weight of Sic	1	0.000779	0.000779	2.8	0.12
2-Way Interaction	6	0.001466	0.000244	0.88	0.539
Spindle Speed, N (rpm)*Feed rate, f (mm/min)	1	0.0001	0.0001	0.36	0.56
Spindle Speed, N (rpm)*Depth of cut, d (mm)	1	0.00011	0.00011	0.4	0.541
Spindle Speed, N (rpm)*% Weight of Sic	1	0.000001	0.000001	0	0.953

Regression equation for tool wear:

Tool wear (predicted) = -0.143 + 0.000219*n + 5.27*f - 0.086*d - 0.013*p + 42.9*f*f + 0.0508*d*d + 0.000483*p - 0.001*n*f - 0.000021*n*d - 0.65*f*d + 0.285*f*p + 0.004*d*p

Where,

n – spindle speed in rpm

f – feed rate in mm/min

d – depth of cut in mm

p – percentage of Sic

GRAPHS

Normal probability plot for MRR AND Tool Wear

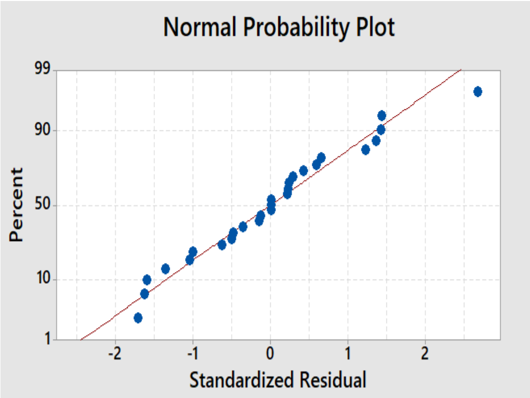


Fig 5: Normal probability plot for MRR

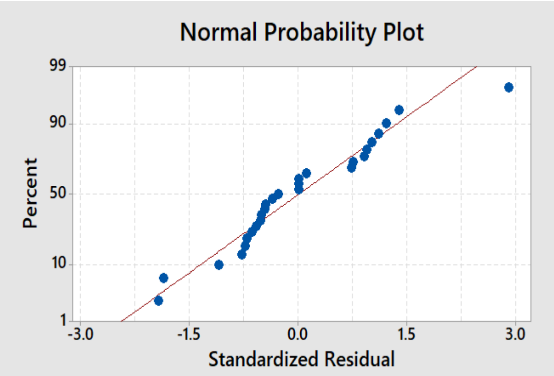


Fig 6: Normal probability plot for Tool Wear

From fig 1 & 2 the above graphs we have obtained a straight line which concludes that the data is normally distributed.

Standardized residual vs Fits plot for MRR and Tool Wear

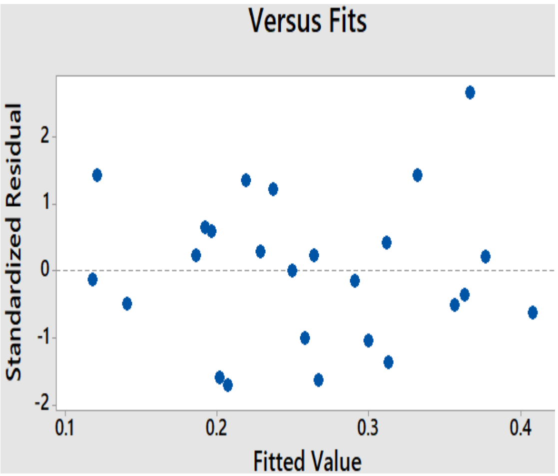


Fig 7: Standardized residual vs Fits plot for

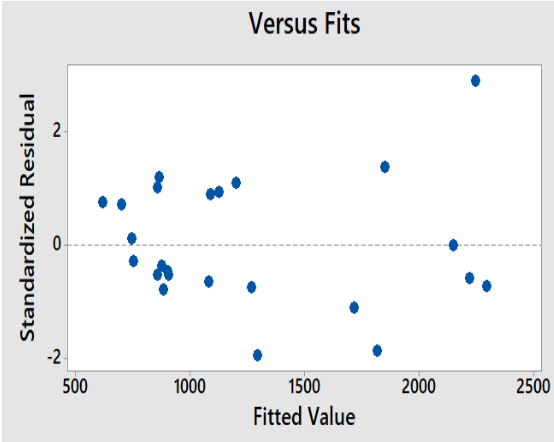


Fig 8: Standardized residual vs Fits plot for Tool wear MRR

From fig 3 & 4 the above graphs we can observe that variability has remained same for all the fitted values, so the variability is equal all the way along. There also doesn't appear to be any curvature or any other indications that there a problem with the model.

Residuals vs Order plot for MRR and Tool Wear

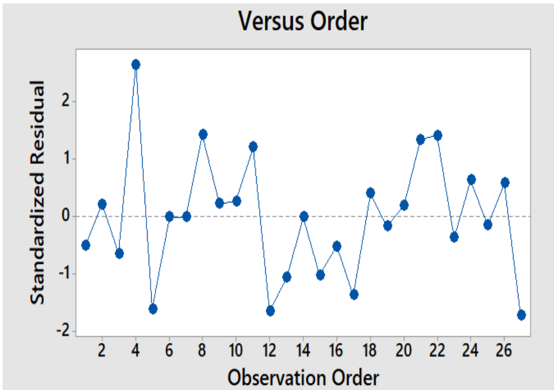


Fig 9: Residuals vs Order plot for MRR

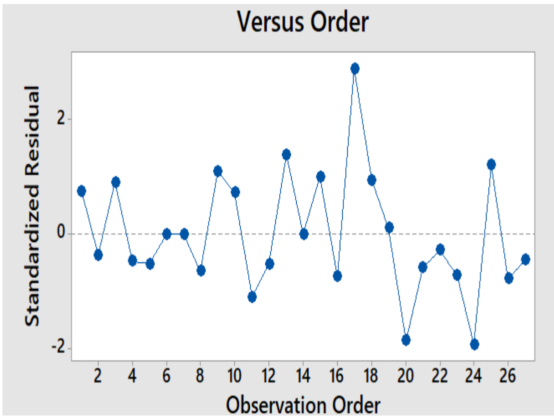


Fig 10: Residuals vs Order plot for Tool Wear

From fig 5 & 6 above graphs connects each experiments error (distance from the zero mean or zero error) with the following experiment and a line plot is obtained.

Pareto Chart of the Standardized effects

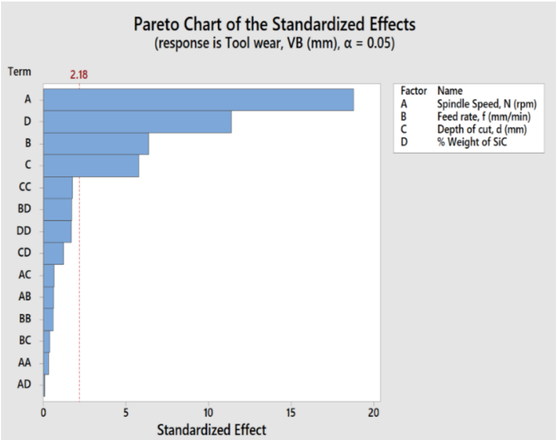


Fig 11: Pareto Chart for Tool Wear

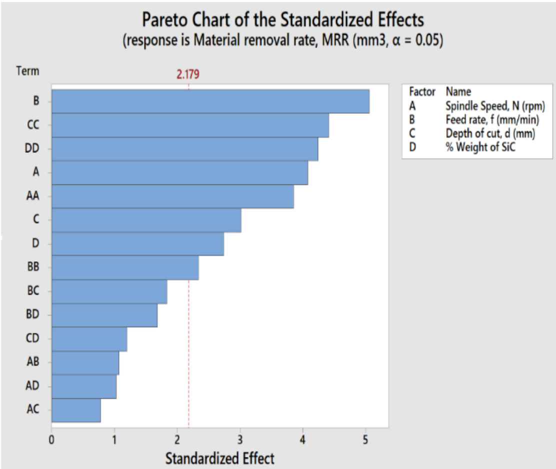


Fig 12: Pareto Chart for MRR

From fig 7 & 8 the above pareto chart it is clear that the terms rightswards to the standardized effect(2.179) are more significant.

Histogram plots for MRR and ToolWear

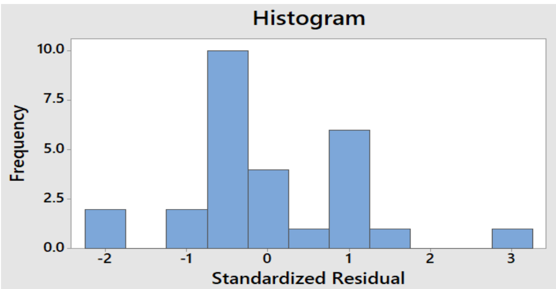


Fig 13: Histogram plots for MRR

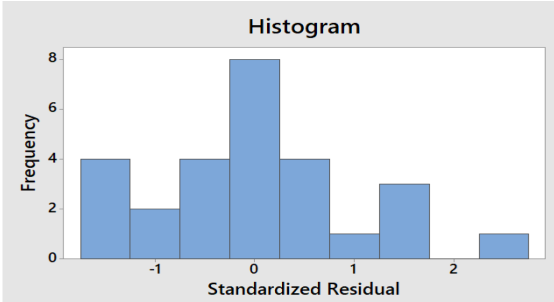


Fig 14: Histogram plots for Tool Wear

From fig 9 the histogram we can observe that we have the highest frequency of residuals(error) in the region – [-1,0].

From fig 10 the histogram we can observe that we have the highest frequency of residuals(error) around the zero-mean region

Predicted and experimental values

Table-1: Comparison table for MRR in terms of actual vs predicted values

The material removal rate is predicted by using the regression equation obtained from Minitab.

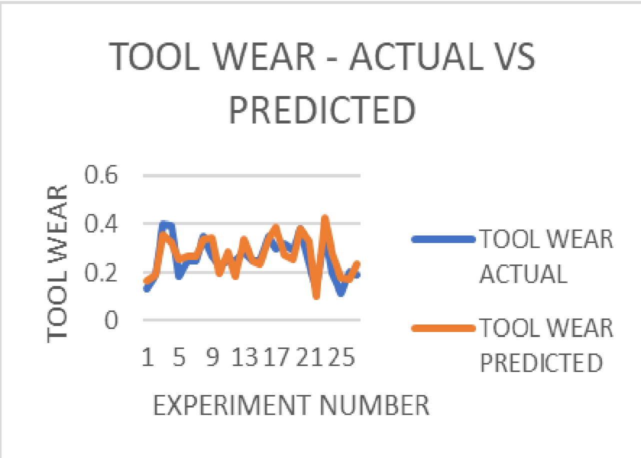
MRR ACTUAL(MM3/MIN)	MRR PREDICETD(MM3/MIN)	%ERROR
759.49	611.81	19.44462732
805.97	871.658	-8.150179287
1258.8	1079.53	14.24134096
812.61	894.298	-10.05254673
756.3	851.868	-12.63625545
2148.9	2143.583	0.247428917
2148.9	2143.583	0.247428917
956.3	1072.81	-12.18341525
1406.3	1193.45	15.13546185
834.45	690.533	17.24692911
1506.3	1712.398	-13.68240058
805.97	895.258	-11.07832798
2111.1	1846.633	12.52745014
2148.9	2143.583	0.247428917
1043.5	848.468	18.69017729
1126	1259.073	-11.81820604
2201.7	2241.493	19.6799011
1303.6	1119.458	14.12565204
762.71	733.768	3.794627054
1463.4	1810.348	-23.70835042
2109.4	2218.873	-5.189769603
698.82	746.458	-6.816919951
2160	2289.937	-6.015601852
925.98	1286.973	-38.98496728
1088.7	859.633	21.04041517
734.13	875.448	-19.24972416
812.61	895.349	-10.18188307

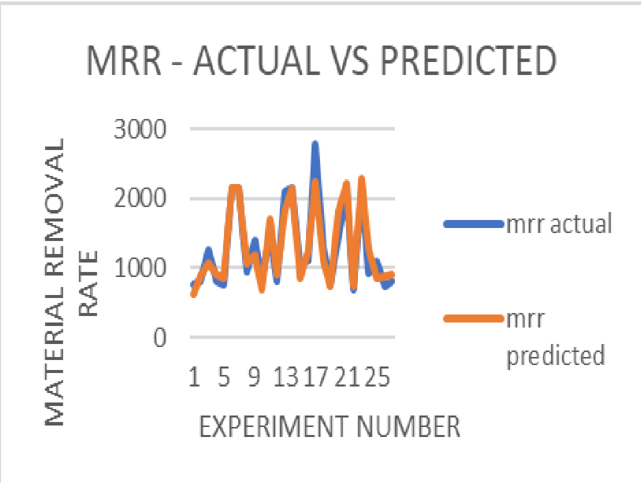
Table-2: Comparison table for Tool Wear in terms of actual vs predicted values

The tool wear is predicted by using the regression equation obtained from Minitab.

TOOL WEAR ACTUAL(MM)	TOOL WEAR PREDICTED(MM)	%ERROR
0.135	0.167	-23.7037037
0.188	0.192	-2.127659574
0.401	0.355	11.4713217
0.395	0.326	17.46835443
0.184	0.251	-36.41304348
0.249	0.266	-6.827309237
0.249	0.266	-6.827309237
0.347	0.335	3.458213256
0.266	0.341	-28.19548872
0.231	0.197	14.71861472
0.25	0.286	-14.4
0.249	0.184	26.10441767
0.288	0.334	-15.97222222
0.249	0.249	0
0.247	0.232	6.072874494
0.351	0.337	3.988603989
0.298	0.389	-30.53691275
0.316	0.272	13.92405063
0.289	0.251	13.14878893
0.379	0.38	-0.263852243
0.233	0.328	-40.77253219
0.136	0.104	23.52941176
0.359	0.426	-18.66295265
0.199	0.279	-40.20100503
0.116	0.177	-52.5862069
0.202	0.17	15.84158416
0.188	0.233	-23.93617021

LINE PLOT FOR TOOL WEAR and MRR



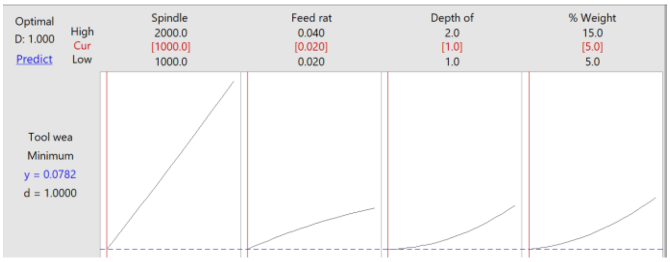


Optimization Plot

Optimization of tool wear

During the machining process tool wear should be as minimum as possible , so the tool wear is minimized and the following optimized value of tool wear is shown below:

During the machining process tool wear should be as minimum as possible , so the tool wear is minimized and the following optimized value of tool wear is shown below:



From the above data it is clear that the tool wear is minimum when the input factors are

Spindle speed (RPM) = 1000

Feed rate (F) = 0.02mm/min

Depth of cut (D) = 1.0mm

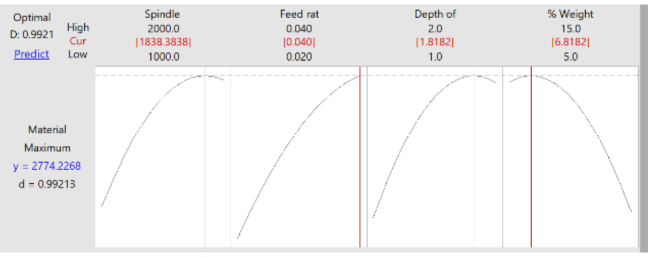
% weight of Sic = 5

CONFIRMATION TABLE-3:

spindle speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	%weight of Sic	Tool wear (mm)
1000	0.02	1	5	0.0782
1000	0.02	1	5	0.103

Optimization of Material Removal Rate

During the machining process material removal rate should be as maximum as possible , so the material removal rate is maximized and the following optimized value of material removal rate is shown below:



From the above data maximized material removal rate will be obtained when input parameters are

Spindle speed (RPM) = 1838.3838

Feed rate (F) = 0.04mm/min

Depth of cut (D) = 1.818mm

% weight of Sic = 6.818

CONFIRMATION TABLE-4:

spindle speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	%weight of Sic	Material removal rate (mm3/min)
1838.3838	0.04	1.818	6.818	2774.2268
1838.3838	0.04	1.818	6.818	2947.615

V. CONCLUSION

RSM with different cutting parameter settings for predicting the machinability characteristics such as tool wear and MRR in the end milling of Al7075/Al2O3/Sic hybrid composites by adopting specific weightages for the characteristics. As the process requirements are varied, the weightages used in the grey relational analysis are also varied. From the analysis, the best combination of values for simultaneously minimizing the surface roughness, tool wear, cutting force and maximizing MRR was found. The best combination of parameters is noted as spindle speed of 1000 rpm, feed of 0.02 mm/rev, depth of cut of 1 mm and 5% of Sic produce best tool wear outcome and a spindle speed of 1838 rpm, feed of 0.04 mm/rev, depth of cut of 1.81 mm and 6.81 % of Sic for material removal rate. Confirmation tests validated the improvement in performance measures. From the ANOVA, it is noted that spindle speed and weight percentage of Sic are the most significant factors affecting.

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