International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Process Parameters Optimization by using the Regression Method in Micro Abrasive Air Jet Machining on Alumina Reinforced Zerconia Composite Materials

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***Abstract:** It is very difficult to make a hole in brittle materials like glass and ceramic materials by using conventional machining methods like turning and milling therefore non conventional machining such as micro abrasive air jet machine is used to overcome the above problem. In this research work to prepare alumina reinforced zerconia ceramic composite materials using powder metallurgy sintering method experiments have been conducted on micro abrasive air jet erosion tester. In this work to varied abrasive air jet machining parameters i.e. Pressure, Abrasive flow rate, Standoff distance and different Weight percentage of zirconium added into alumina i.e. 5wt%, 10wt% and 15wt% and responses are Material Removing Rate and Surface Roughness. 30µm size of Silicon carbide (sic) sand particles are impinged Ceramic composite plates with given input process parameters. L_{27} Orthogonal array of Taguchi and Regression analysis is used to determine the Signal to Noise ratios of all experiments and process parameters impact, Percentage contribution of each process parameters, square parameters and interaction parameters on MRR and Surface Roughness and check weather parameters, square and interaction parameters are significant are not, to eliminate insignificant parameters by using backward elimination method. To improve R^2 value by eliminated insignificant parameters.*

***Keywords:** Al_2o_3 Reinforced Zro_2 Composite materials, Taguchi, DOE, ANOVA, Regression, SIC abrasive particles, MAAJM*

I. INTRODUCTION

Micro abrasive air jet machine is a non conventional machining process in which high energy jet composed as an abrasive particles and compressed air is impinged on the target of the work material. In recent years abrasive air jet machining as been gaining increasing acceptability for debarring applications abrasive air jet machine debarring has the advantage over manual debarring method that generates edge radius automatically [1,9&10]. In this research work fine abrasive silicon carbide (SIC) particles mixed with compressed air in mixing chamber and mixing chamber has been vibrated for proper mixing of the abrasive particles with air. The abrasive particles carried by air the high velocity of air with abrasive particles are generated by converting air into motion energy and hence velocities of particles are increased. Nozzle is connected at one end of the hose pipe the function of nozzle is to increase the velocity of abrasive particles. Nozzle diameter as the significantly affect on the MRR [2,3&8] Increased velocity of abrasive particles are impinged on the targeted point on the work materials i.e Aluminum reinforced zirconium composite work materials these particles are impinged on the work surface with high pressure and erosion caused by their impact enables the removal of material on the work surface. The material removal depends on the pressure, Abrasive flow rate, Standoff distance and Type of the work material here three types of work materials are used 95% Al2o3+5% Zro2, 90% Al2o3+10% Zro2 and 85% Al2o3+15% Zro2.

Manuscript received on March 15, 2020.
Revised Manuscript received on March 24, 2020.
Manuscript published on March 30, 2020.
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II. EXPERIMENTATION AND METHODOLOGY

2.1 Plan Of Experiment:

In any manufacturing industry cost is the most impartment than quality but quality is the best way to reduce manufacturing cost. Taguchi method used to optimize the process parameters. Regression model is a statistical method used in finance, investing and other disciplines that attempts to determine strength and character of the one dependent variable and series of other variables. Regression analysis generates an equation to describe the statistical relationship between one or more predictor variables. Linear regression R^2 value represent the proportion of variance in the dependent variable that can be explained by our independent variable R2 is based on the sample and is a positively biased estimate of the proportion of the variance of the dependent variable accounted by the regression model. An adjusted R2 value which corrects positive bias to provide a value that would be expected in the population. F ratio in the table showing the process parameter impact and P value in the table indicates weather the parameter is significant or not. In this research consider four variables i.e Pressure, Abrasive flow rate, standoff distance and Alumina reinforced zerconia composite specimens and 3 levels as shown in Table.1 and Responses are Material Removing Rate and Surface roughness.

Table.1 Control Process parameters:

		Levels		
Parameter	**Unit**	**1**	**2**	**3**
P	**bar**	**2**	**4**	**6**
AFR	**g/min**	**4**	**6**	**8**
SOD	**mm**	**5**	**10**	**15**
M	**%**	**5**	**10**	**15**

Fig.1 Micro abrasive air jet erosion Tester

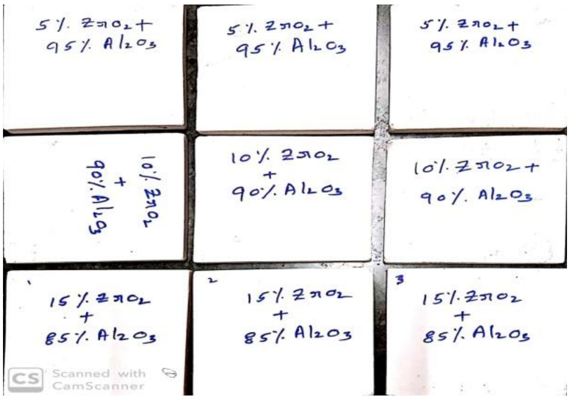

Fig.2 Composite ceramic plates (Before Machining)

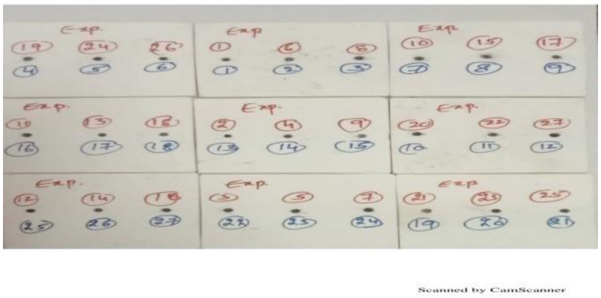

Fig.3 Composite ceramic plates (After Machining)

Fig.4 Surface roughness Tester

2.2 Measurements

2.2.1 Material: Al_2o_3 Reinforced Zro_2 Zerconia composite materials Size 50mm*50mm*5mm thickness of plate before machining and after machining as shown in fig. 2&3.

2.2.2 **Material Removing Rate:** 30 micrometer size of silicon carbide abrasive particles is impinged on the targeted surface of the work material with given parameters material was eroded on the work piece was determined by weight method. MRR= $(W_b - W_a)/T$

2.2.3 Surface Roughness:

Surface roughness measurement is the high quality measuring output in any manufacturing industry so quality and working of the product depends on the surface roughness. In this research work MITUTOYO SJ-210 Surface roughness tester was used to measure surface roughness shown in fig.4

III. RESULTS AND DISCUSSION

Table 2: Signal to Noise Ratio of MRR and Surface Roughness

Exp No.	P (bar)	AFR (g/min)	SOD (mm)	Mate. (%)	MRR (mg/min)	S/N (db)	Ra (µm)	S/N (db)
1	2	4	5	5	0.365	-8.754	0.32	9.897
2	2	4	10	10	0.485	-6.285	0.31	10.17
3	2	4	15	15	0.245	-12.21	0.3	10.45
4	2	6	5	10	0.596	-4.495	0.31	10.17
5	2	6	10	15	0.557	-5.082	0.33	9.629
6	2	6	15	5	0.348	-9.168	0.34	9.37
7	2	8	5	15	0.463	-6.688	0.29	10.75
8	2	8	10	5	0.456	-6.82	0.27	11.37
9	2	8	15	10	0.245	-12.21	0.25	12.04
10	4	4	5	5	0.425	-7.432	0.27	11.37

11	4	4	10	10	0.546	-5.256	0.29	10.75
12	4	4	15	15	0.546	-5.256	0.31	10.17
13	4	6	5	10	0.632	-3.985	0.33	9.629
14	4	6	10	15	0.532	-5.481	0.33	9.629
15	4	6	15	5	0.362	-8.825	0.3	10.45
16	4	8	5	15	0.643	-3.835	0.29	10.75
17	4	8	10	5	0.486	-6.267	0.31	10.17
18	4	8	15	10	0.489	-6.213	0.31	10.17
19	6	4	5	5	0.636	-3.93	0.3	10.45
20	6	4	10	10	0.716	-2.901	0.29	10.75
21	6	4	15	15	0.551	-5.177	0.33	9.629
22	6	6	5	10	0.714	-2.926	0.35	9.118
23	6	6	10	15	0.936	-0.574	0.36	8.873
24	6	6	15	5	0.725	-2.793	0.31	10.17
25	6	8	5	15	0.876	-1.149	0.35	9.118
26	6	8	10	5	0.868	-1.229	0.32	9.897
27	6	8	15	10	0.664	-3.556	0.31	10.17

TABLE.3: ANOVA For Material Removing Rate (Before Elimination):

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Effect	% contribution
Regression	13	0.728679	0.056052	8.18	0.000	significant	89.10
P	1	0.015411	0.015411	2.98	0.058	significant	2.50
AFR	1	0.020432	0.020432	2.25	0.008	significant	1.88
SOD	1	0.017189	0.017189	2.51	0.037	significant	2.10
Samples	1	0.001970	0.001970	0.29	0.001	significant	0.24
P*P	1	0.023396	0.023396	3.41	0.088	significant	2.86
AFR*AFR	1	0.022367	0.022367	3.26	0.094	significant	2.73
SOD*SOD	1	0.040565	0.040565	5.92	0.030	significant	4.96
Samp.*Samp.	1	0.003055	0.003055	0.45	0.516	insignificant	0.37
P*AFR	1	0.015841	0.015841	2.31	0.152	insignificant	1.94
P*SOD	1	0.007500	0.007500	1.09	0.315	insignificant	0.92
P*Samples	1	0.000120	0.000120	0.02	0.897	insignificant	0.01
AFR*SOD	1	0.005512	0.005512	0.80	0.386	insignificant	0.67
AFR*Samples	1	0.000272	0.000272	0.04	0.845	insignificant	0.03
Error	13	0.089130	0.006856	--	--	--	10.90
Total	26	0.817809		--	--	--	--

R^2=89.10%, R^2 adjusted=78.20%

Regression Equation for MRR Before elimination:

MRR^0.1	=	-0.332 - 0.1263 P + 0.193 AFR + 0.0747 SOD + 0.0189 Samples + 0.01561 P*P - 0.01526 AFR*AFR - 0.00380 SOD*SOD - 0.00104 Samples*Samples + 0.00908 P*AFR + 0.00250 P*SOD + 0.00032 P*Samples - 0.00350 AFR*SOD + 0.00078 AFR*Samples……(I)

Table.4: ANOVA for Surface roughness (Before Elimination)

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Effect	% Contribution
Regression	13	0.013259	0.001020	3.46	0.017	Significant	87.56
P	1	0.001792	0.001792	6.07	0.028	Significant	10.48
AFR	1	0.002956	0.002956	10.01	0.007	Significant	17.29
SOD	1	0.000009	0.000009	0.03	0.067	significant	0.05
Samples	1	0.000108	0.000108	0.37	0.055	Significant	0.63
P*P	1	0.000474	0.000474	1.61	0.227	Insignificant	2.77
AFR*AFR	1	0.004630	0.004630	15.69	0.002	Significant	27.08
SOD*SOD	1	0.000001	0.000001	0.00	0.946	Insignificant	0.01
Samp.*Samp.	1	0.000272	0.000272	0.92	0.354	Insignificant	1.59
P*AFR	1	0.002700	0.002700	9.15	0.010	Significant	15.79
P*SOD	1	0.000033	0.000033	0.11	0.742	Insignificant	0.19
P*Samp.	1	0.001200	0.001200	4.07	0.065	Significant	7.02
AFR*SOD	1	0.000006	0.000006	0.02	0.893	Insignificant	0.04
AFR*Samp.	1	0.000200	0.000200	0.68	0.425	Insignificant	1.17
Error	13	0.003837	0.000295	--	--	--	22.44
Total	26	0.017096		--	--	--	--

R^2=87.56%, R^2 adjusted=75.11%

Regression Equation for Surface Roughness (Ra) before elimination:

Ra^0.1 = 0.2019 - 0.0431 P + 0.0733 AFR - 0.00167 SOD - 0.00444 Samples + 0.00222 P*P - 0.00694 AFR*AFR + 0.000022 SOD*SOD + 0.000311 Samples*Samples + 0.00375 P*AFR - 0.000167 P*SOD + 0.001000 P*Samples + 0.000111 AFR*SOD - 0.000667 AFR*Samples..(II)

Table.5: ANOVA for Material Removing Rate (After backward Elimination):

α to remove = 0.1

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Effect	% Contribution
Regression	7	0.698699	0.099814	15.92	0.000	Significant	85.44
P	1	0.002795	0.002795	5.24	0.0001	Significant	4.01
AFR	1	0.026931	0.026931	4.07	0.0001	Significant	3.12
SOD	1	0.032829	0.032829	4.30	0.0003	Significant	3.29
Samples	1	0.025538	0.025538	0.45	0.0002	Significant	0.34
P*P	1	0.023396	0.023396	3.73	0.0012	Significant	2.86
AFR*AFR	1	0.022367	0.022367	3.57	0.0002	Significant	2.73
SOD*SOD	1	0.049747	0.049747	7.94	0.0011	Significant	6.08
Error	19	0.119110	0.006269	--	--	--	--
Total	26	0.817809		--	--	--	--

R^2=85.44%, R^2 adjusted=80.07%

Regression Equation for MRR After elimination:

MRR^0.1 = -0.427 - 0.0436 P + 0.2019 AFR + 0.0598 SOD + 0.00753 Samples + 0.01561 P*P - 0.01526 AFR*AFR - 0.00364 SOD*SOD……………………………….(III)

Table.6: ANOVA for Surface Roughness (After backward Elimination):

α to remove = 0.1

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Effect	% Contribution
Regression	6	0.012024	0.002004	7.90	0.000	Significant	70.33
P	1	0.002550	0.002550	10.05	0.001	Significant	14.92
AFR	1	0.002876	0.002876	11.34	0.003	Significant	16.82
SOD	1	0.00034	0.00034	0.35	0.0001	Significant	1.03

Samples	1	0.000350	0.000350	1.38	0.002	Significant	2.05
AFR*AFR	1	0.004630	0.004630	18.25	0.001	Significant	27.08
P*AFR	1	0.002700	0.002700	10.65	0.003	Significant	15.79
P*Samples	1	0.001200	0.001200	4.73	0.002	Significant	7.02
Error	20	0.005072	0.000254	--	--	--	29.67
Total	26	0.017096	--	--	--	--	--

R^2=70.33%, R^2 adjusted=61.43%

Regression Equation for Surface Roughness (Ra) after elimination:

Ra^0.1 = 0.1733 - 0.02694 P + 0.0678 AFR - 0.00332 - 0.00233 Samples - 0.00694 AFR*AFR + 0.00375 P*AFR+ 0.001000 P*Samples……(IV)

The fit summery recommended that the quadratic model is statistically significant for analysis of material removing rate and surface roughness. The results of the quadratic model for MRR and surface roughness in the form of ANOVA are given in Table3&4.The value of R^2 for MRR and surface roughness are 89.10% and 87.56% respectively. This means that regression model provides an excellent explanation of the relationship between the independent factors and responses. The associated P Value for the model is less than 1% (at 99% confidence level), which shows that the model is considered to be statistically significant. Furthermore factors P, AFR, SOD and sample type, their square effects and interactions have significant effect.

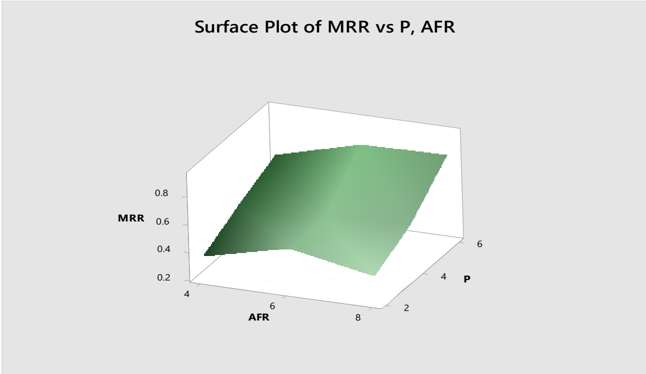

Fig.5 surface plot for MRR Vs P, AFR

IV. SURFACES AND CONTOUR PLOTS FOR MATERIAL REMOVING RATE:

The fig. 5 to fig.16 shows the response surface and contour plots for the effect of pressure, abrasive flow rate, standoff distance and Sample type on Material Removing Rate.

Fig.5 shows the estimated response surface for the material removing rate in relation to the individual parameters of the pressure and abrasive flow rate. As it seen from the figure, the material removing rate tends to increase steadily with an increase in abrasive flow rate and considerably increase in pressure. From the table.3 the model indicates the percentage contribution of the Pressure to a higher percentage of 2.50. It is seen that abrasive flow rate has been less significant on material removing rate when compared with the pressure. When Pressure varies from 2 bar to 2.2 bar and abrasive flow rate varies from 4 gm/min. 4.2 gm/min, the material removing rate value is less than 0.3 mg/min as seen from the contour graph 1. Further, it is also seen that while the pressure is in between 2.2 bar to 3.9 bar and the abrasive flow rate is between 4.2 gm/min. to 7.9 gm/min. the material removing rate value is in between 0.4 mg/min to 0.5 mg/min., pressure is in between 3.9 bar to 5.4 bar and the abrasive flow rate is between 4 gm/min. to 8 gm/min. the material removing rate value is in between 0.5 mg/min to 0.6 mg/min., pressure is in between 5.4 bar to 6.0 bar and the abrasive flow rate is between 4 gm/min. to 8.0 gm/min. the material removing rate value is in between 0.6 mg/min to 0.7 mg/min., pressure is in between 5.4 bar to 6.0 bar and the abrasive flow rate is between 4.5 gm/min. to 8.0 gm/min. the material removing rate value is in between 0.7 mg/min to 0.58mg/min., and lastly pressure is in between 5.9 bar to 6.0 bar and the abrasive flow rate is between 6.2 gm/min. to 7.8 gm/min. the material removing rate value is in between 0.8 mg/min to 0.9 mg/min.

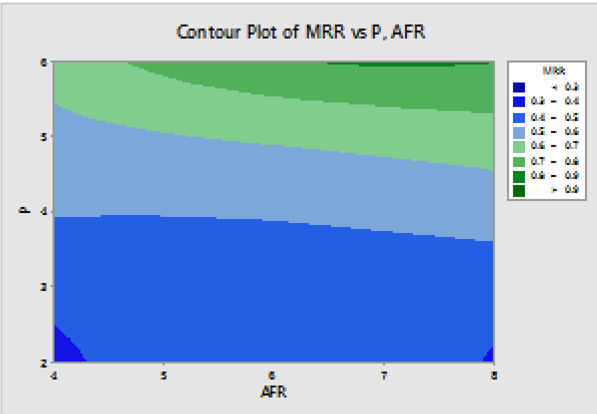

Fig.6 counter plot for MRR Vs P, AFR

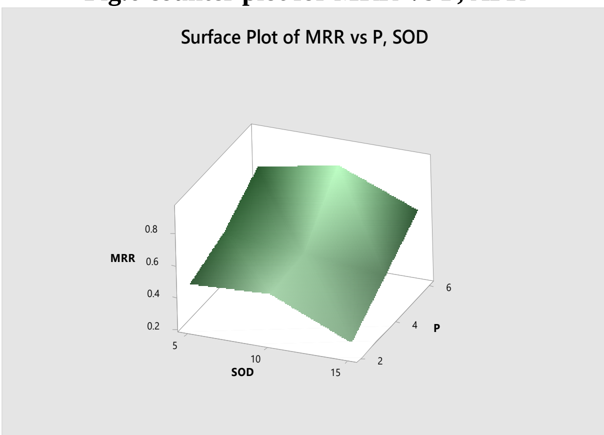

Fig.7 Surface plot for MRR Vs P, SOD

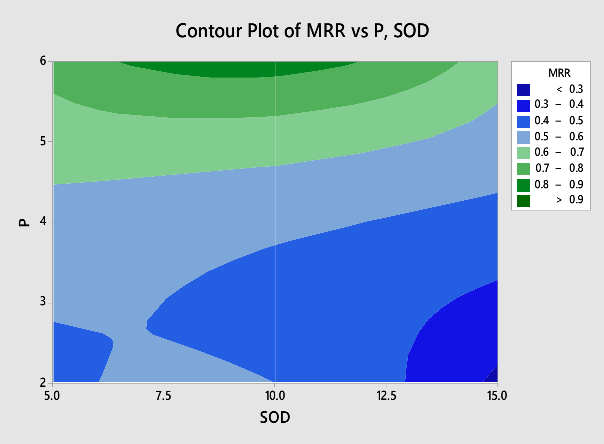

Fig .8 Counter plot for MRR Vs P, SOD

Fig.7 shows the estimated response surface for the material removing rate in relation to the individual parameters of the pressure and standoff distance. As it seen from the figure, the material removing rate tends to increase steadily with an increase in pressure and considerably increase in standoff distance up to 10mm and then decrease from 10 to 15mm. From the table3 the model indicates the percentage contribution of pressure to a higher percentage of 2.50. It is seen that standoff distance has been less significant on material removing rate when compared with pressure.

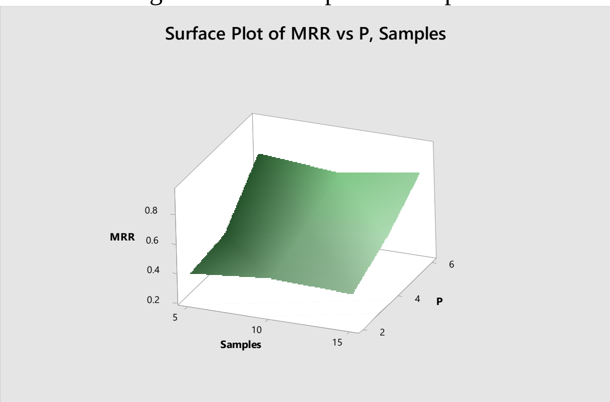

Fig.9: Surface plot for MRR Vs P, sample

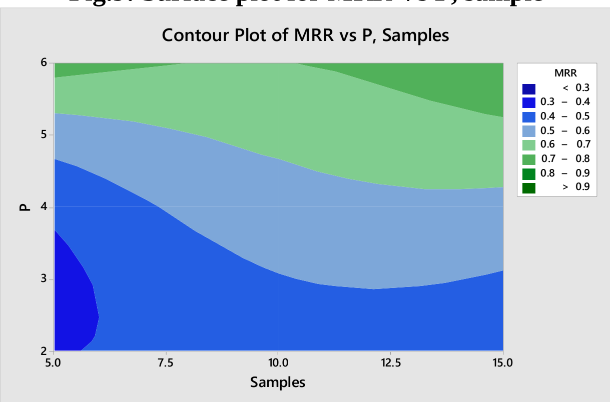

Fig.10: Counter plot for MRR Vs P, sample

Fig.9 shows the estimated response surface for the material removing rate in relation to the individual parameters of the pressure and Sample type. As it seen from the figure, the material removing rate tends to increase steadily with an increase in pressure and considerably increase up to al_2o_3 reinforced 10% zro_2 composite sample and then slightly decrease from al_2o_3 reinforced 10% zro_2 composite sample to al_2o_3 reinforced 15% zro_2 composite sample. From the table3 the model indicates the percentage contribution of the pressure to a higher percentage of 2.50. It is seen that pressure has been higher significant on material removing rate when compared with sample type.

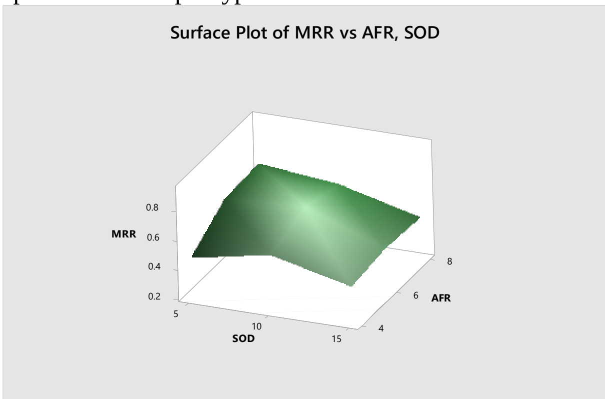

Fig.11: surface plot MRR Vs AFR, SOD

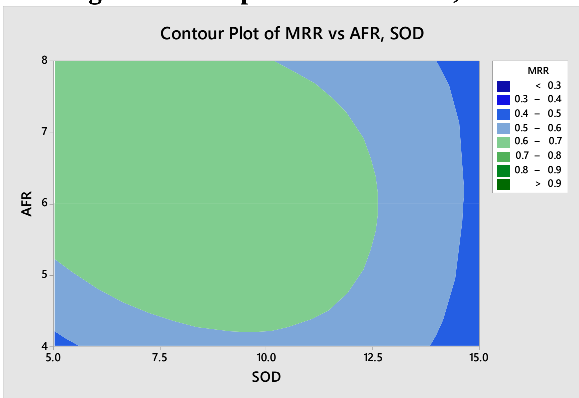

Fig.12: Counter plot for MRR Vs AFR, SOD

Fig.11 shows the estimated response surface for the material removing rate in relation to the individual parameters of the Abrasive flow rate and standoff distance. As it seen from the figure, the material removing rate tends to increase steadily with an increase in Standoff distance from 5mm to 10mm and decrease from 10mm to 15mm and considerably slightly increase in Abrasive flow rate. From the table3 the model indicates the percentage contribution of Standoff distance to a higher percentage of 2.10. It is seen that abrasive flow rate has been less significant on material removing rate when compared with standoff distance.

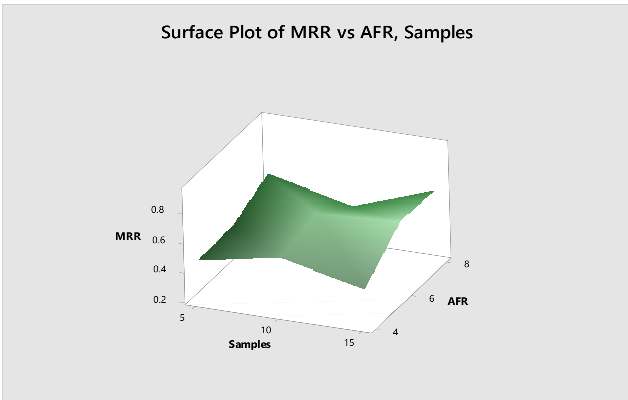

Fig.13: surface plot MRR Vs AFR, sample

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DOI:10.35940/ijrte.F9778.038620
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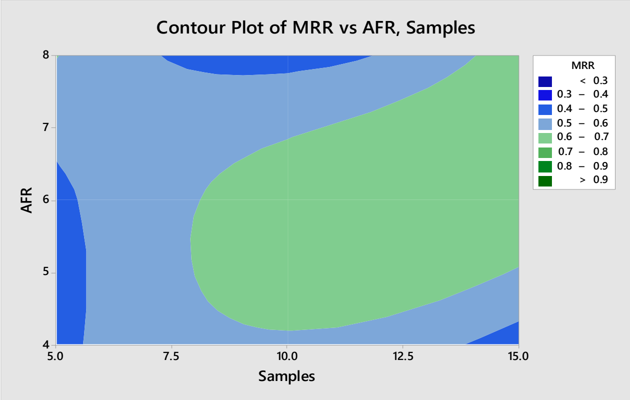

Graph.14: contour plot MRR Vs AFR, sample

Fig.13 shows the estimated response surface for the material removing rate in relation to the individual parameters of the Abrasive flow rate and sample type. As it seen from the figure, the material removing rate tends to increase steadily with an increase in abrasive flow rate and considerably slightly increase in alumina reinforced zerconia composite sample of 5% zro_2 addition to 10% zro_2 addition and then decrease from 10% zro_2 addition to 15% zro2 addition. From the table3 the model indicates the percentage contribution of Abrasive flow rate to a higher percentage of 1.88. It is seen that sample type has been less significant on material removing rate when compared with Abrasive flow rate.

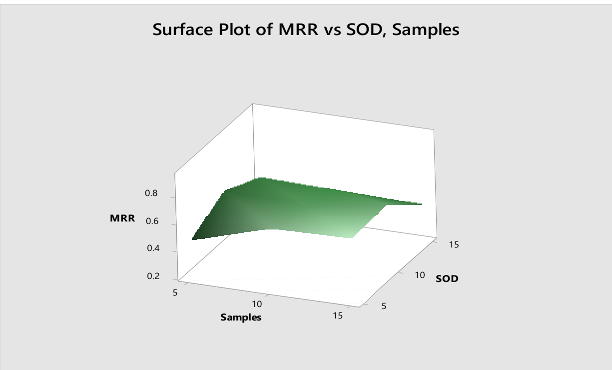

Fig.15: surface plot MRR Vs SOD, sample

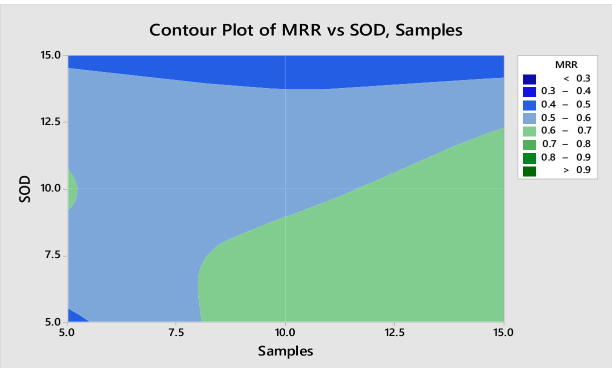

Fig.16: Contour plot MRR Vs SOD, sample

Fig.15 shows the estimated response surface for the material removing rate in relation to the individual parameters of the standoff distance and sample type. As it seen from the figure, the material removing rate tends to increase with an increase in % of zro_2 addition up to certain limit and considerably slightly increase in standoff distance and % of zro_2 is increased further and standoff distance is increased from 10 mm to 15mm Material Removing rate is decreased. From the table3 the model indicates the percentage contribution of standoff distance to a higher percentage of 2.10. It is seen that sample type has been less significant on material removing rate when compared with standoff distance.

V. CONCLUSION:

To make an alumina reinforced zerconia composite materials using powder metallurgy sintering method is to reduce defects, cost and time compared to other fabrication methods like stir casting, coating methods and Good bonding strength between al_2o_3 and zro_2 nano particles.

1) To check the parameters; square and interaction parameters are significant or insignificant at 99% confident level and eliminate insignificant parameters by backward elimination method.
2) ANOVA indicates percentage contribution of each parameter, square and interaction parameters percentage contribution on Material Removing Rate and Surface Roughness Responses.
3) Highest percentage contribution was pressure (2.50%) on Material Removing rate followed by standoff distance, abrasive flow rate and Material type respectively (2.10%, 1.88%0.24%).
4) Highest percentage contribution was Abrasive flow rate (17.29%) on surface roughness followed by Pressure, Material type and lastly standoff distance respectively (10.48%, 0.63%0, and 0.05%).

ACKNOWLEDGEMENT

This work was supported by Department of Tribology, NITW, Warangal, Telangana, India.

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