Experimental Exploration of MRR and Kerf on MAAJDM of Alumina Reinforced with Zerconia Composites

Dr.B.Anjaneyulu, Dr.R.Meenakshi Reddy, Dr. T.Hariprasad, Ms.V.Deepthi and Mr. Y. Sankara
Department of Mechanical Engineering
SRIT (Autonomous), Anantapur, Andhra Pradesh India
anjan343@gmail.com, anjaneyulub.mec@srit.ac.in, rmreddy123@gmail.com, thprasads@gmail.com, deepthi.mec@srit.ac.in, sankaramtech@gmail.com

Abstract

A ceramic material is a brittle hard heat resistance and corrosion resistance material it is a made by non material such as clay in this research work alumina as a base material and zerconia as a reinforcement material, alumina reinforced with zerconia matrix composites made by powder metallurgy sintering method with different weight percentage of reinforcement such as 5%, 10% and 15% respectively. Nontraditional machines are used to machining the brittle material because to improve dimensional accuracy of the cutting portion in this work micro abrasive air jet drilling machine is used to remove the unwanted material on the work piece (ceramic composites) in this case 30 µm size of non uniform shaped silicon carbide (SiC) as a abrasive, this present work to optimize the machining parameters on the MRR and kerf by using Taguchi technique, consider input parameters are pressure, abrasive flow rate, standoff distance and nozzle diameter. To conducted experiment on micro abrasive air jet drilling machine (MAADM) as per L_{27} Orthogonal array (OA) with four input parameters three levels and to analyze the process parameters impact on MRR and kerf and determine the percentage contribution of each parameter on response by ANOVA (General Linear Model) to check the predicted values at 99% confidence level.

Keywords
Al_2O_3, ZrO_2, DOE, ANOVA, MAAJDM

1. Introduction
Selection of the material is vital role in modern manufacturing industries, machining means raw material is converted into final finished products two types of machining was done on any material namely conventional and unconventional machining, in conventional machining process during the operation single point or multipoint cutting tool is directly contact with the work piece then remove the unwanted material in the form of chip on the work piece (Kumar et al. 2014). the contact between the tool and work piece result is friction induced between them and many frictional forced are presented conventional machines are used to machining the ductile material only to overcome the above non conventional machines are used to remove the unwanted material on the work piece in this case to remove the unwanted material there is no direct contact between the work piece and tool in case of un conventional machining no tool is used to remove excess material on the work piece so tool wear rate and frictional forces are negligible(Jain N et al. 2007). Non conventional machines are used to machining on thin brittle material, In recent trends industries are used non conventional machines to remove excel material on the work piece, in this research work Micro abrasive air jet drilling machine is used to make the holes on the work piece in which 30 micron size of the Silicon Carbide (SiC) is used as a abrasive particle with smooth surface (Sridhar. A et al. 2019), the abrasive particles coming out from the exit of the nozzle with high velocity (Ghobeit. A et al. 2009). These high velocity particles are impinged on the targeted surface of the work, the abrasive particles mixed with air in mixing chamber at the out let of the nozzle pressure energy is converted into kinetic velocity (Bhalekar.P et al. 2018) due to erosion principle these high pressure abrasive particle erode the material on the work piece, abrasive jet machining operation is good for machining grooves and slots with good surface finish the components of the abrasive air jet drilling machine as shown in Figures 1-5 respectively.
Taguchi method involves reducing the variation in a process through robust design of experiment (c. Hiremath et al. 2012). The overall objective of the method is to produce high quality product at least cost (Li. H.Z et al. 2009) therefore, poor quality in a process affects not only the manufacturer but also society. This is a method for designing

experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic (Reddy. S. et al. 2015). The components of the abrasive jet machine as shown in fig. 1 to fig. 5.

Figure 1. Dehumidifier with air filter

Figure 2. Experimental Setup

Figure 3. Nozzle Arrangement

Figure 4. Compressor

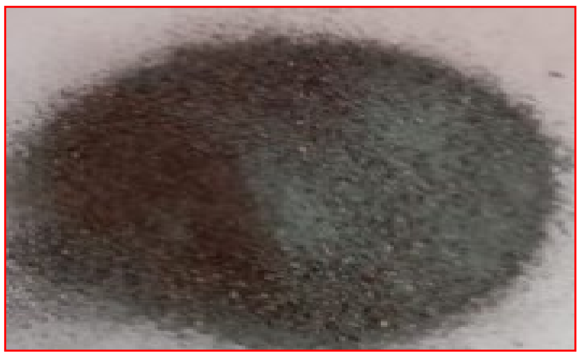

Figure 5. SiC Particles

2. Experimentation and Methodology

Experimentation is one of the most common activities performed by everyone including scientist and engineers. It covers wide range of applications from manufacturing sector. Experimentation is used to understand and/or improve a system. Experimentation can be used for developing new products/processes as well as for improving the quality of existing products/processes. In any experimentation the investigator tries to find out the effect of input variables on the output /performance of the product/process. This enables the investigator to determine the optimum settings for the input variables (Neseli.S et al. 2014).

The traditional approach in the industrial and the scientific investigation is to employ trial and error methods to verify and validate the theories that may be advanced to explain some observed phenomenon. This may lead to prolonged experimentation and without good results. Some of the approaches also include one factor at time experimentation, several factors one at a time and several factors all at the same time, in this research work experiment conducted on micro abrasive air jet drilling machine as per L_{27} orthogonal Array (OA) in Taguchi method (Figure 6 and 7).

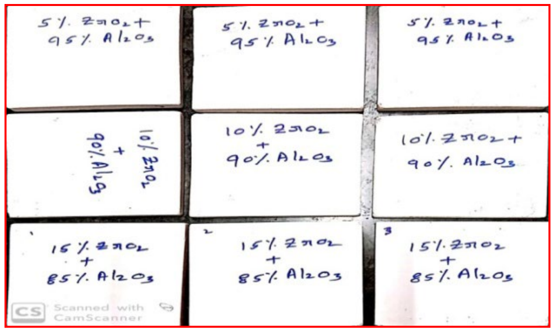

Figure 6. Ceramic Plates before machining

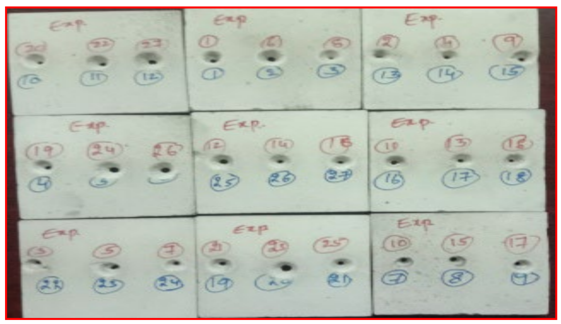

Figure 7. Ceramic plates after machining

2.1 Analysis of Variance (ANOVA)

The statistical foundations for design of experiments and the Analysis of Variance (ANOVA) were first introduced by Sir Ronald A, Fisher, and the British biologist(Grover.P et al. 2014). ANOVA is a method of partitioning total variation into accountable sources of variation in an experiment. It is a statistical method used to interpret experimented data and make decisions about the parameters under study (Table 1, 2 and 3).

Measured Responses

1. Kerf = Upper side diameter in mm – bottom side diameter in mm …….. (2.1)
2. MRR = (Wb – Wa) / T ...…… (2.2)

Where,
MRR = Material Removing Rate in gm/sec.
Wb = Weight of the work piece before machining in gms
Wa = Weight of the work piece after machining in gms
T = Machining time in Sec.

Table 1. Factor Information

Factor	Unit	Type	Levels	Values
P	bar	Fixed	3	3, 4, 5
AFR	g/min	Fixed	3	4, 6, 8
ND	mm	Fixed	3	1.5, 2.0, 2.5
SOD	mm	Fixed	3	3, 5, 7

Table 2. L_{27} Orthogonal Array (OA) DOE Experimental Values of kerf and MRR

Exp. No	Pressure (bar)	AFR (g/min)	ND (mm)	SOD (mm)	Kerf (mm)	MRR (gm/sec.)
1	3	4	1.5	3	3.1	0.0957
2	3	4	2.0	5	3.9	0.1840
3	3	4	2.5	7	4.6	0.1250
4	3	6	1.5	5	4.2	0.0240
5	3	6	2.0	7	4.4	0.1640
6	3	6	2.5	3	5.0	0.2620
7	3	8	1.5	7	4.9	0.0240
8	3	8	2.0	3	5.4	0.2110
9	3	8	2.5	5	5.2	0.2520
10	4	4	1.5	3	3.1	0.0258
11	4	4	2.0	5	3.9	0.1013
12	4	4	2.5	7	4.2	0.2670
13	4	6	1.5	5	4.0	0.0583
14	4	6	2.0	7	4.1	0.1750
15	4	6	2.5	3	4.8	0.4390
16	4	8	1.5	7	4.2	0.0254
17	4	8	2.0	3	5.4	0.2580
18	4	8	2.5	5	7.1	0.2880
19	5	4	1.5	3	3.1	0.0277
20	5	4	2.0	5	2.7	0.1550
21	5	4	2.5	7	3.1	0.1880
22	5	6	1.5	5	3.9	0.1096
23	5	6	2.0	7	2.7	0.2600
24	5	6	2.5	3	3.9	0.3230
25	5	8	1.5	7	4.1	0.0242
26	5	8	2.0	3	3.5	0.0240
27	5	8	2.5	5	5.26	0.1340

3. Results and Discussion

Table 3. S/N Ratio, Means, Prediction and Residual of Kerf

Exp. No	Pressure	AFR	ND	SOD	S/N Ratio	Mean	Prediction	Residual
1	3	4	1.5	3	-9.827	3.10	3.393	-0.293
2	3	4	2.0	5	-11.821	3.90	3.867	0.033
3	3	4	2.5	7	-13.255	4.60	4.233	0.367
4	3	6	1.5	5	-12.465	4.20	4.300	-0.100
5	3	6	2.0	7	-12.869	4.40	4.027	0.373
6	3	6	2.5	3	-13.979	5.00	4.933	0.067
7	3	8	1.5	7	-13.804	4.90	4.767	0.133
8	3	8	2.0	3	-14.648	5.40	5.033	0.367
9	3	8	2.5	5	-14.320	5.20	6.147	-0.947
10	4	4	1.5	3	-9.827	3.10	3.404	-0.304
11	4	4	2.0	5	-11.821	3.90	3.878	0.022
12	4	4	2.5	7	-12.465	4.20	4.244	-0.044
13	4	6	1.5	5	-12.041	4.00	4.311	-0.311
14	4	6	2.0	7	-12.256	4.10	4.038	0.062
15	4	6	2.5	3	-13.625	4.80	4.944	-0.144

16	4	8	1.5	7	-12.465	4.20	4.778	-0.578
17	4	8	2.0	3	-14.648	5.40	5.044	0.356
18	4	8	2.5	5	-17.025	7.10	6.158	0.942
19	5	4	1.5	3	-9.827	3.10	2.456	0.644
20	5	4	2.0	5	-8.627	2.70	2.929	-0.229
21	5	4	2.5	7	-9.827	3.10	3.296	-0.196
22	5	6	1.5	5	-11.821	3.90	3.362	0.538
23	5	6	2.0	7	-8.627	2.70	3.089	-0.389
24	5	6	2.5	3	-11.821	3.90	3.996	-0.096
25	5	8	1.5	7	-12.256	4.10	3.829	0.271
26	5	8	2.0	3	-10.881	3.50	4.096	-0.596
27	5	8	2.5	5	-14.420	5.26	5.209	0.051

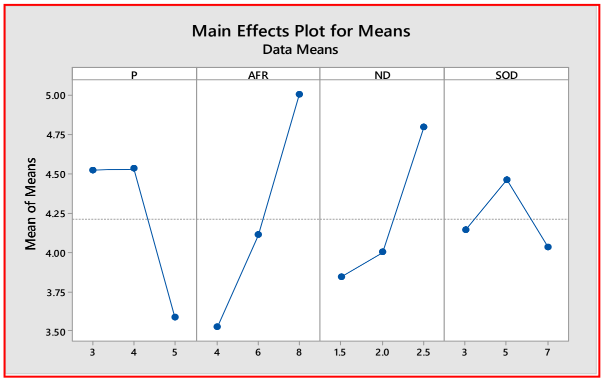

Figure 8. Main effect plots for Means of kerf

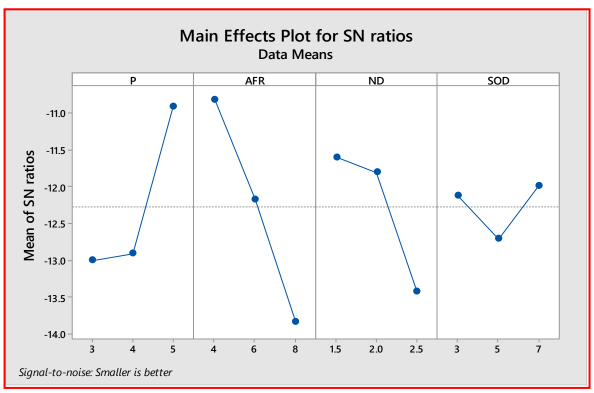

Figure 9. Main effects Plot for S/N ratio of Kerf

It can observe the Figure 8 and 9 the relation between the input parameters and the mean of the kerf while selecting smaller is better (Nagendra Prasad. K. et al. 2017), mean value is slightly increase with pressure increase from 3 to 4 bar then mean value is gradually decreased when pressure in further increased from 4 to 5 bar, AFR is increasing kerf width also increasing continuously and the effect of nozzle diameter on kerf width, it is slightly increasing when diameter in increased from 1.5 mm to 2mm further increase diameter of the nozzle the kerf width is suddenly increased finally the relation between standoff distance and response is SOD in increased from 3mm to 5mm kerf is increased slightly and SOD is further increased kerf is decreased suddenly.
It can observe fig. 9 the relation between input parameters and Signal to Noise ratio, initially when the pressure is increased SN ratio is slightly increased, Abrasive flow rate is increased SN ratio decreased continuously, the

diameter of the nozzle is increased then the SN ratio gradually decreased the standoff distance is increased SN ratio is first decreases up to certain limit after that increased continuously.

Table 4. Response Values for Signal to Noise Ratio on kerf

Level	P	AFR	ND	SOD
1	-13.00	-10.81	-11.59	-12.12
2	-12.91	-12.17	-11.80	-12.71
3	-10.90	-13.83	-13.42	-11.98
Delta	2.10	3.02	1.82	0.73
Rank	2	1	3	4

From Table 4. shows the responses of the input parameters here delta value decides that the impact on the response[(Kumar. R et al. 2014) from above table abrasive flow rate is highest impact on response, to get maximum SN ratio of AFR is level 1 say -10.81 db and minimum SN ratio is at level 3 say -13.83 so difference between the maximum and minimum SN ratio of AFR is 3.02 db, followed by Pressure its maximum SN ratio obtained at level 3 say -10.90db and minimum SN ratio is at level 1 say -13.00 db so its difference is 2.10db, third impact parameter on response is nozzle diameter its maximum SN ratio is at level 1 say -11.59 db and minimum value is at level 3 say -13.42 db its difference is 1.82 db, final impact parameter on kerf is SOD its maximum SN ratio is at level 2 say -11.98 db and minimum value is at level is -12.71 db its difference is 0.73 db respectively.

Table 5. Optimum Process Parameters on Kerf

Parameter	Parameter	Unit	Level	Value
Pressure	P	bar	1	3
Abrasive flow rate	AFR	gm/min	3	8
Nozzle Diameter	ND	mm	3	2.5
Standoff distance	SOD	mm	2	5
Optimum S/N Ratio - 12.1428 db (Mean 4.14667 mm.)				
Experimental S/N Ratio - 14.320 db (Mean 5.20 mm)				

S/N Ratio Improvement is – 2.1772 db
Mean Improvement is 1.05333 mm

After analyzed optimum process parameters on micro abrasive air jet drilling machine to predict and verify the optimization by using the optimum level parameters the experiment is conducted on a machine with optimum level parameters and checked the mean and S/N Ratio the optimum level parameters and optimum mean and S/N ratio is as shown in above Table 5. The progress of the S/N ratio and mean of the kerf from the initial machining parameters to the optimal parameters is -2.1772 db and 1.05333 mm respectively.

Table 6. ANOVA for Kerf

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
P	2	5.3398	2.6699	10.99	0.001	21.06
AFR	2	10.0572	5.0286	20.69	0.000	39.67
ND	2	4.6852	2.3426	9.64	0.001	18.48
SOD	2	0.8918	0.4459	1.83	0.188	3.51
Error	18	4.3748	0.2430	-	-	17.25
Total	26	25.3488	-	-	-	-

Analysis of variance helps to investigate the which design parameters is significantly effects on the response, ANOVA indicates that relative importance of the input parameter with respect to response this analysis is carried out the one way general linear model and check the significant of process parameter at the 99% confidence level (Table 6). Abrasive flow rate (AFR) is highest machining contribution on Kerf say 39.67% followed by pressure (21.06%), Nozzle diameter (18.48%) and finally standoff distance (3.51%) respectively on kerf,

Kerf Regression Equation

$$\text{Kerf} = 4.2133 + 0.309\,P3 + 0.320\,P4 - 0.629\,P5 - 0.691\,AFR4 - 0.102\,AFR6 + 0.793\,AFR8 - 0.369\,ND1.5 - 0.213\,ND2.0 + 0.582\,ND2.5 - 0.069\,SOD3 + 0.249\,SOD5 - 0.180\,SOD7 \quad (3.1)$$

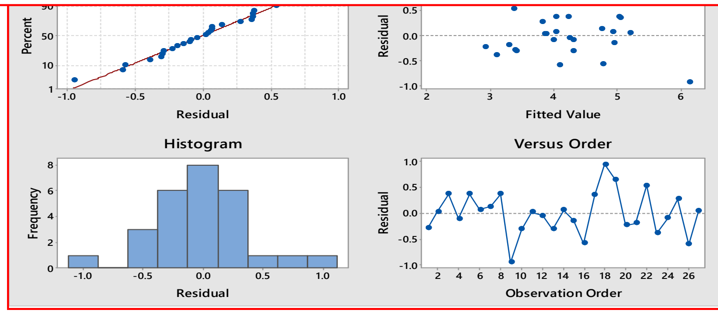

Figure 10. Residual Plots for Kerf

Table 7. S/N Ratio, Mean Prediction and Residuals of MRR

Exp. No	Pressure	AFR	ND	SOD	S/N Ratio	Means	Prediction	Residual
1	3	4	1.5	3	-20.3818	0.0957	0.040789	0.0549
2	3	4	2.0	5	-14.7036	0.1840	0.124967	0.059
3	3	4	2.5	7	-18.0618	0.1250	0.201867	-0.076
4	3	6	1.5	5	-32.3958	0.0240	0.072500	-0.048
5	3	6	2.0	7	-15.7031	0.1640	0.190722	-0.026
6	3	6	2.5	3	-11.6340	0.2620	0.319533	-0.057
7	3	8	1.5	7	-32.3958	0.0240	0.002733	0.021
8	3	8	2.0	3	-13.5144	0.2110	0.172867	0.038
9	3	8	2.5	5	-11.9720	0.2520	0.215722	0.036
10	4	4	1.5	3	-31.7676	0.0258	0.073689	-0.047
11	4	4	2.0	5	-19.8878	0.1013	0.157867	-0.056
12	4	4	2.5	7	-11.4698	0.2670	0.234767	0.032
13	4	6	1.5	5	-24.6866	0.0583	0.105400	-0.047
14	4	6	2.0	7	-15.1392	0.1750	0.223622	-0.048
15	4	6	2.5	3	-7.1507	0.4390	0.352433	0.086
16	4	8	1.5	7	-31.9033	0.0254	0.035633	-0.010
17	4	8	2.0	3	-11.7676	0.2580	0.205767	0.052
18	4	8	2.5	5	-10.8122	0.2880	0.248622	0.039
19	5	4	1.5	3	-31.1504	0.0277	0.030100	-0.002
20	5	4	2.0	5	-16.1934	0.1550	0.114278	0.040
21	5	4	2.5	7	-14.5168	0.1880	0.191178	-0.003
22	5	6	1.5	5	-19.2038	0.1096	0.061811	0.047
23	5	6	2.0	7	-11.7005	0.2600	0.180033	0.079
24	5	6	2.5	3	-9.8159	0.3230	0.308844	0.014
25	5	8	1.5	7	-32.3237	0.0242	-0.007956	0.032
26	5	8	2.0	3	-32.3958	0.0240	0.162178	-0.138
27	5	8	2.5	5	-17.4579	0.1340	0.205033	-0.071

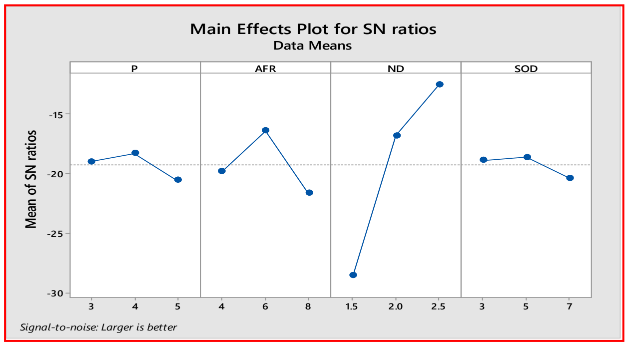

Figure 11. MRR S/N Ratio

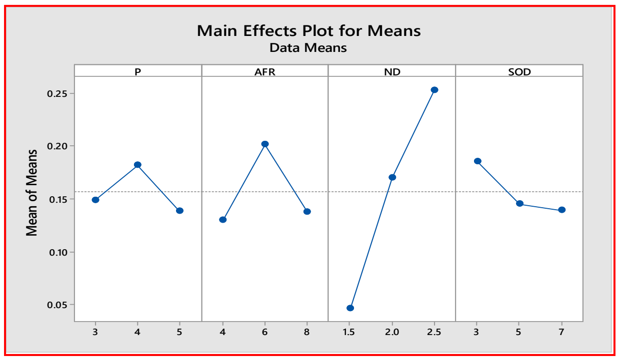

Figure 12. MRR Means

It is seen Figure 11 and 12 the relation between signal to noise ratio of MRR and input parameters such as pressure, abrasive flow rate, nozzle diameter and stand of distance respectively. The pressure is gradually increasing from 3 to 4 bar the S/N ratio value is slightly increasing further increasing air pressure from 4 to 5 bar SN value is decreasing, the relation between AFR and S/N ratio is abrasive flow rate is increasing S/N ratio is increasing up to maximum limit further increase AFR the S/N ratio is decreasing. The relation between nozzle diameter and S/N value, diameter of the nozzle is increasing the S/N ratio increasing continuously finally the relation between SOD and S/N ratio SOD increasing from 3 to 5mm SN ratio increasing slightly further increasing SOD the SN ratio value is decreasing gradually (Table 9).

Table 8. MRR Signal to Noise Ratio

Level	P	AFR	ND	SOD
1	-18.97	-19.79	-28.47	-18.84
2	-18.29	-16.38	-16.78	-18.59
3	-20.53	-21.62	-12.54	-20.36
Delta	2.24	5.23	15.92	1.77
	3	2	1	4

Table 8. shows that the input parameters impact on MRR, here delta value decides the parameter impact on the response, from above Table 8 nozzle diameter is highest impact on MRR to get maximum SN ratio of Nozzle diameter is at level 3 say -12.54 db and minimum SN ratio is at level 1 say -28.47 so difference between the

maximum and minimum SN ratio of ND is 15.92 db, followed by abrasive flow rate its maximum SN ratio obtained at level 2 say -16.38 db and minimum SN ratio is at level 3 say – 21.62 db so its difference is 5.23 db, third impact parameter on response is pressure its maximum SN ratio is at level 2 say -18.29 db and minimum value is at level 2 say -20.53 db its difference is 2.24 db, final impact parameter on MRR is SOD its maximum SN ratio is at level 2 say -18.59 db and minimum value is at level is -20.36 db its difference is 1.77 db respectively.

Table 9. Optimum Process Parameters on MRR

Parameter	Parameter	Unit	Level	Value
Pressure	P	bar	2	4
Abrasive flow rate	AFR	gm/min	2	6
Nozzle Diameter	ND	mm	3	2.5
Standoff distance	SOD	mm	1	3
Experimental S/N Ratio - 8.2642 db (Mean 0.3524 gm/sec.)				
Optimum S/N Ratio - 7.1507 db (Mean 0.4390 gm/sec)				

S/N Ratio Improvement is – 1.114 db
Mean Improvement is 0.0866 gm/sec.

Table 10. Analysis of Variance of MRR

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
P	2	0.009290	0.004645	1.04	0.375	2.86
AFR	2	0.027830	0.013915	3.10	0.070	8.576
ND	2	0.195444	0.097722	21.79	0.000	60.21
SOD	2	0.011242	0.005621	1.25	0.309	3.45
Error	18	0.080725	0.004485	-	-	-
Total	26	0.324532	-	-	-	-

Analysis of variance helps to investigate the which design parameters is significantly effects on the response, ANOVA indicates that relative importance of the input parameter with respect to response the analysis is carried out the one way general linear model and check the significant of process parameter at the 99% confidence level. From Table 10 shows ANOVA results Nozzle diameter is highest contribution on MRR say 60.21% followed by Abrasive flow rate (8.576%), standoff distance (3.45%) and finally pressure (2.86%) respectively on material removing rate.

MRR Regression Equation

MRR= 0.1565 - 0.0074 P3 + 0.0255 P4 - 0.0181 P5 - 0.0265 AFR4 + 0.0452 AFR6 - 0.0186 AFR8 - 0.1104 ND1.5 + 0.0138 ND2.0 + 0.0966 ND2.5 + 0.0287 SOD3 - 0.0113 SOD5 - 0.0173 SOD7 ….(3.2)

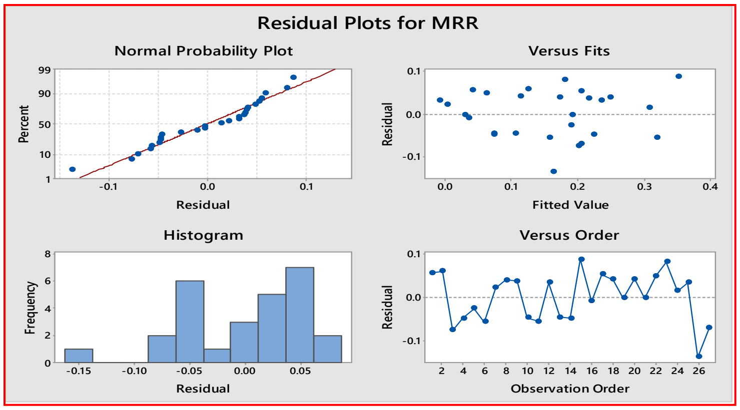

Figure 13. Residual Plots for MRR

Figures 10 and 13 shows the Residual plot for Kerf and MRR respectively. From these figures (Figure 11, 12 and 13) it is inferred that the model is a good fit of the data.

4. Conclusion

- L_{27} Orthogonal Array was adapted to conduct experiment on Micro Abrasive Air Jet Machine
- Abrasive flow rate exerted the greatest effect on kerf followed by Pressure, Nozzle diameter and finally standoff distance.
- The ANOVA indicated that the standoff distance is high significant on kerf followed P, AFR, and type of specimen checked at 95% confidence level.
- The % contribution of AFR, P, ND and standoff distance approximately 39.67%, 21.06%, 18.48% and 3.51% respectively neglected interaction and their square parameters.
- R^2 value of Kerf is approximately 85.98%.
- Nozzle diameter exerted the greatest effect on MRR followed by Abrasive, Pressure and finally standoff distance.
- The ANOVA indicated that the Nozzle diameter is high significant on MRR followed AFR, SOD, and Pressure checked at 99% confidence level.
- The % contribution of ND, AFR, SOD and Pressure approximately 60.21%, 8.576%, 3.45% and 2.86% respectively neglected interaction and their square parameters.
- R^2 value of MRR is approximately 83.29%.
- From the residual graphs, good agreement between the experimental and prediction values of both Kerf and MRR.

Finally it is concluded that to add interaction and square parameters on responses to reduce residual error.

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Biographies

Dr.B.Anjaneyulu is graduated in Mechanical Engineering from MeRITS, Udayagiri, Earned his post graduation in Industrial Engineering from SVUCE, Tirupati, Ph.D from JNTUA, Anantapur. Presently he is serving as an Associate Professor at Srinivasa Ramanujan Institute of Technology (Autonomous), Anantapur, India. He has published more than 30 papers in international journals, 9 books published and 1 Indian patent filed and has participated in several conferences and presenting 8 technical papers. He has reviewed more than 40 papers in reputed journals. He is a life member of professional societies such as IAENG and IE. He has established a NPTEL Local chapter at GATESIT; Gooty. Research interests include Composite materials, Industrial Engineering and Production &Operations Management.

Dr. R. Meenakshi Reddy working as an Associate Professor in the Department of Mechanical Engineering at G. Pulla Reddy Engineering College, Kurnool. He graduated in Mechanical Engineering at Maharashtra College of Engineering, Latur, Maharashtra, India. He secured Master of Energy Systems Engineering in Energy Systems Department at BVB College of Engineering & Technology, Hubli, Karnataka, India. He secured Ph.D., in Mechanical Engineering Department at JNUTA, Ananthapuramu, Andhra Pradesh, India. He is in the field of Thermal Engineering at G. Pulla Reddy Engineering College, Kurnool, and A.P. India. He is in teaching profession for more than 20 years. He has presented and published 68 papers in national and international journals. He also visited China, Malaysia and Singapore for paper presentations. His main area of interest includes Heat transfer and Composites.

Dr.T.Hariprasad is graduated in Mechanical Engineering from JNTU, Hyderabad. Earned his post-graduation in Thermal Engineering from JNTUA, Anantapur. Ph.D from JNTUA, Anantapur presently, he is serving as an Professor at Mohan babu University,Tirupati India. He has published more than 70 papers in international journals, and has participated in several conferences and presenting technical papers. Research interests include Composite materials, Heat and mass transfer,CFD and Renewable Energy sources.

Ms.V. Deepthi is an Assistant Professor in Mechanical Engineering Department having 6 years of Teaching Experience. Obtained B.Tech from Sri Krishnadevaraya Engineering College, M. Tech in Refrigeration and Air Conditioning from JNT University, Anantapuramu. Published a journal in National conference on Emerging Trends in Mechanical Engineering (e-TIME'16), 14t[h]July 2016, JNTUACE- Ananthapuramu with a Title of Experimental Analysis and Design Ofhexagonal Spiral Condenser on The performance of Domestic refrigerator.

Mr.Y.Sankara working as senior lecturer and also worked as HOD of mechanical engineering section in last 10 year in mechanical engineering department at GMR Polytechnic Srisailam, in department of technical education. He graduated Under graduate from SVCET, Chittoor and post graduated from SVUCE, Tirupati with Industrial Engineering. He has published 10 international journals.