*IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*
*e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 3 Ver. VIII (May- Jun. 2014), PP 20-26*
*www.iosrjournals.org*

# Response Surface Methodology for Optimization of Process Parameters in Abrasive Jet Drilling of Composites

D. V. Srikanth[1], Dr. M. Sreenivasa Rao[2]
*[1]Department of Mechanical Engineering, St Martin's Engineering College, Secunderabad, A.P. India*
*[2]Dept. Of Mechanical Engineering, JNTUH, Kukatpally, Hyderabad, A.P. India.*

***Abstract:*** *Abrasive jet machining is an Emerging machining process in which the metal removal takes place due to abrasion. A stream of abrasive particles mixed with carrier gas (generally air) is subjected to the work surface with high velocity (150-300 m/Sec). The abrasive particles used for this machining are Silicon carbide, Aluminium oxide, boron carbide, etc. This process is effectively adopted for cleaning, polishing, deburring, drilling and cutting of Hard and Brittle materials. Abrasive jet cutting involves a high velocity jet of air with entrained Abrasive particles onto the material to be cut. In the present study focused on experimental research and evaluation of the abrasive jet drilling process in order to evaluate the technological factors affecting the Metal Removal rate of FRP Composite of various thickness using Optimization modelling called Response Surface Methodology and The adequacy of the model is evaluated using analysis of variance (ANOVA) technique.*
***Keywords****: abrasive jet cutting, optimization, CFRP composite, analysis of variance*

## I. Introduction

Composites are the type of materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter or less expensive when compared to traditional materials.

Composite materials are commonly used for bridges and structures such h as boatulls, swimming pool panels, race car bodies, bath tubs, storage tanks, imitation granite and cultured marble sinks and counter tops. The most advanced examples perform routinely on spacecraft in demanding environments.

FRP Composite is most widely used fiber in high performance applications which is produced from a variety of precursors, including polycrylonitrile, rayon and pitch. The precursor fibers are heated and stretched to create the high strength fibers.

Abrasive jet machining (AJM) removes material through the action of abrasion where a focused stream of abrasive- gas mixture on to the work area. Micro-abrasive particles are propelled by inert gas (air) at velocities of up to 300 m/sec. By directing the beam at a work piece, the result in erosion can be used for cutting, etching, cleaning, deburring, polishing, and drilling. Material removal occurs through a chipping action, which is especially effective on hard, brittle materials such as glass, composites, silicon, tungsten, and ceramics. Soft, resilient materials, such as rubber and some plastics resist the chipping action and thus are not effectively processed by AJM.

No work piece chatter or vibration occurs with this process because the large enables AJM to produce fine, intricate detail extremely brittle objects. The AJM processed eggshell provides a graphic example of the delicate nature of the process. In addition because heat carried away by the abrasive propellant gas, work pieces experience no thermal damage.

A few attempts have been made to model and optimize the process parameters in AJM. The approaches employed in this direction include design of experiments (DOE), Taguchi, RSM & analysis of variance (ANOVA) etc.

*Fig 1: Setup of AJM at St Martin's Engg College*

*Fig 2: Impingement of mixer through Nozzle*

Some of these studies gave rise to various mathematical equations developed for predicting the output parameters. Domiaty et al [3] was among the first who developed a set of mathematical model to relate the process parameters settings to the process output variables in jet technique. Later U.D.Gulhani et al [1] used design of experiments for finding optimality.

In recent years, determining an optimal set of process parameters values to achieve a certain output characteristics has been the prime interest by many researchers. Their study aims at selecting suitable process parameters that can control the depth of cut Kerf width within the desired limits; although there are few studies in modelling and optimization of process parameters in AJM, most of them are limited to the particular circumstances and are computationally complex. The present study attempts to make use of available experimental data to relate important process parameters to process output variables, through developing Regression models through Response surface methodology.

## II. Methodology

Design of Experiments (DOE) techniques accommodates the designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. DOE also provides a full insight of interaction between design elements; therefore, it helps turn any standard design into a robust one. Simply put, DOE helps to pin point the sensitive parts and sensitive areas in designs that cause problems in Yield. Designers are then able to fix these problems and produce robust and higher yield designs prior going into production.

The Response Surface Methodology (RSM) emerged in the 1950s within the context of Chemical Engineering in construction of empirical models which enables to find useful statistical relationships between all the variables making up a system. This methodology is based on experimental design with the final goal of evaluating optimal functioning of industrial facilities, using minimum experimental effort. These methods are used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. Here, the inputs are called factors or variables and the outputs represent the response that generates the system under the causal action of the factors.

Analysis of Variance (ANOVA): Analysis of Variance (ANOVA) is a powerful analyzing tool to identify which are the most significant factors and it's (%) percentage contribution among all control factors for each of machining response. It calculates variations about mean ANOVA results for the each response. Based on F-value (Significance factor value) important parameters can be identified. Table 5 and Table 6 are ANOVA Table obtained by Minitab 16 software. ANOVA Table contain Degree of freedom (DF), Sum of Squares (SS), Mean squares (MS), Significant Factor ratio (F Ratio), Probability (P) and calculated percentage contribution.

## III. Experimental Details

The Experimental Setup is established at St Martin's Engineering College, Dhulapally, Secunderabad and the Experiments were conducted on the test rig by considering Pressure, NTD, AFR, Nozzle diameter as Process parameters and MRR as performance measure. The material used as work piece in this experimentation was FRP Composite which was cut and shaped in to rectangular blocks. The initial weight of the work piece is noted and after completion of drilling again the weight of the work piece was noted for finding the MRR.

According to the Design of Experiments by considering the Box- Behnken Design of Response surface methodology the parameters (Factors) selected was Pressure, Abrasive flow rate, Stand of distance, Nozzle diameter and MRR as Performance measure. 27 Experiments are conducted and estimated the optimal values of Experiments.

Table 1: Parameters with levels for Experimentation

| Process Parameters | Units | Levels | | |
|---|---|---|---|---|
| | | -1 | 0 | 1 |
| Pressure | Kg/cm2 | 4 | 6 | 8 |
| Abrasive Flow Rate | gm/min | 3 | 4 | 5 |
| Stand of Distance | mm | 6 | 8 | 10 |
| Nozzle diameter | mm | 2 | 3 | 4 |

Table 2 : Experiments conducted Based on Box-Behnkn Design

| S.No. | StdOrder | Run Order | PtType | Blocks | Pressure | AFR | SOD | ND | MRR |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 | 1 | 2 | 1 | 6 | 3 | 8 | 4 | 0.0331 |
| 2 | 19 | 2 | 2 | 1 | 4 | 4 | 10 | 3 | 0.0253 |
| 3 | 21 | 3 | 2 | 1 | 6 | 3 | 8 | 2 | 0.0204 |
| 4 | 24 | 4 | 2 | 1 | 6 | 5 | 8 | 4 | 0.0365 |
| 5 | 1 | 5 | 2 | 1 | 4 | 3 | 8 | 3 | 0.0263 |
| 6 | 7 | 6 | 2 | 1 | 6 | 4 | 6 | 4 | 0.0393 |
| 7 | 9 | 7 | 2 | 1 | 4 | 4 | 8 | 2 | 0.0261 |
| 8 | 5 | 8 | 2 | 1 | 6 | 4 | 6 | 2 | 0.0152 |
| 9 | 27 | 9 | 0 | 1 | 6 | 4 | 8 | 3 | 0.0353 |
| 10 | 8 | 10 | 2 | 1 | 6 | 4 | 10 | 4 | 0.0467 |
| 11 | 18 | 11 | 2 | 1 | 8 | 4 | 6 | 3 | 0.0403 |
| 12 | 26 | 12 | 0 | 1 | 6 | 4 | 8 | 3 | 0.0353 |
| 13 | 6 | 13 | 2 | 1 | 6 | 4 | 10 | 2 | 0.0287 |
| 14 | 11 | 14 | 2 | 1 | 4 | 4 | 8 | 4 | 0.0239 |
| 15 | 15 | 15 | 2 | 1 | 6 | 3 | 10 | 3 | 0.0352 |
| 16 | 12 | 16 | 2 | 1 | 8 | 4 | 8 | 4 | 0.0657 |
| 17 | 14 | 17 | 2 | 1 | 6 | 5 | 6 | 3 | 0.0209 |
| 18 | 22 | 18 | 2 | 1 | 6 | 5 | 8 | 2 | 0.0297 |
| 19 | 16 | 19 | 2 | 1 | 6 | 5 | 10 | 3 | 0.0301 |
| 20 | 3 | 20 | 2 | 1 | 4 | 5 | 8 | 3 | 0.0236 |
| 21 | 25 | 21 | 0 | 1 | 6 | 4 | 8 | 3 | 0.0338 |
| 22 | 17 | 22 | 2 | 1 | 4 | 4 | 6 | 3 | 0.0182 |
| 23 | 10 | 23 | 2 | 1 | 8 | 4 | 8 | 2 | 0.0576 |
| 24 | 20 | 24 | 2 | 1 | 8 | 4 | 10 | 3 | 0.0643 |
| 25 | 4 | 25 | 2 | 1 | 8 | 5 | 8 | 3 | 0.0614 |
| 26 | 13 | 26 | 2 | 1 | 6 | 3 | 6 | 3 | 0.0232 |
| 27 | 2 | 27 | 2 | 1 | 8 | 3 | 8 | 3 | 0.0584 |

3.1 Box- Behnken Design
Factors: 4 Replicates: 1
Base runs: 27 Total runs: 27
Base blocks: 1 Total blocks: 1

Centre points: 3

3.2 Optimal Design: Pressure, AFR, SOD, ND
Response surface design selected using distance-based optimality
Number of candidate design points: 27
Number of design points in optimal design: 3
Number of factors: 4
Row number of selected design points: 24, 22, 2
Smallest distance between optimal points: 4.0000
Largest distance between optimal points: 5.6569

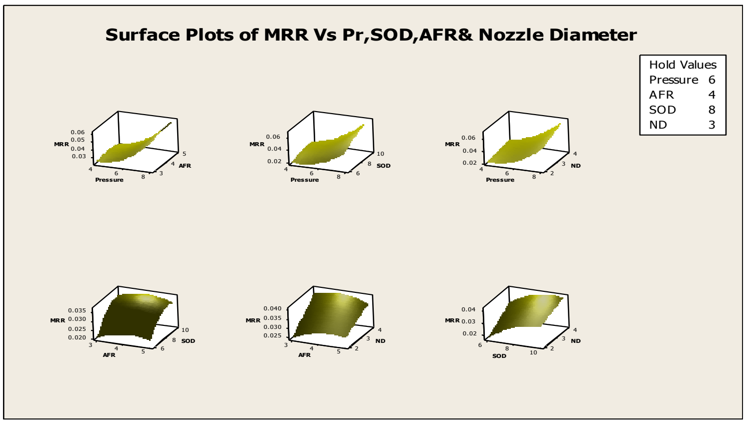


Fig 3: Surface plots of MRR Vs Parameters

3.3 Regression Coefficient

Response Surface Regression: MRR versus Pressure, AFR, SOD, ND

The analysis was done using coded units.

Table 3 : Estimated Regression Coefficients for MRR

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 0.0348 | 0.002981 | 11.674 | 0 |
| Pressure | 0.017027 | 0.001491 | 11.424 | 0 |
| AFR | 0.000467 | 0.001491 | 0.313 | 0.76 |
| SOD | 0.006102 | 0.001491 | 4.094 | 0.001 |
| ND | 0.005625 | 0.001491 | 3.774 | 0.003 |
| Pressure*Pressure | 0.008569 | 0.002236 | 3.833 | 0.002 |
| AFR*AFR | -0.002972 | 0.002236 | -1.329 | 0.208 |
| SOD*SOD | -0.004393 | 0.002236 | -1.965 | 0.073 |
| ND*ND | 0.00004 | 0.002236 | 0.018 | 0.986 |
| Pressure*AFR | 0.001425 | 0.002582 | 0.552 | 0.591 |
| Pressure*SOD | 0.004233 | 0.002582 | 1.639 | 0.127 |
| Pressure*ND | 0.002575 | 0.002582 | 0.997 | 0.338 |
| AFR*SOD | -0.0007 | 0.002582 | -0.271 | 0.791 |
| AFR*ND | -0.001475 | 0.002582 | -0.571 | 0.578 |
| SOD*ND | -0.001525 | 0.002582 | -0.591 | 0.566 |

S = 0.00516343 PRESS = 0.00183754

R-Sq = 94.25% R-Sq (pred) = 66.98% R-Sq (adj) = 87.54%

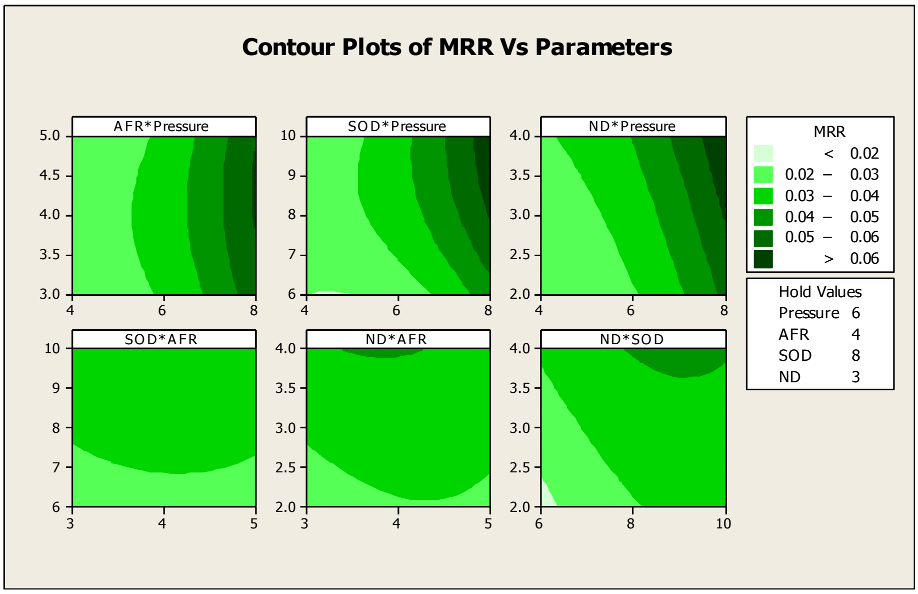


Fig 4: Counter plots of MRR Vs Parameters

3.4 Analysis of Variance for MRR

The RSM values obtained by Box- Behnken Design are validated by Analysis of variance. It calculates variations about mean ANOVA results for the each response. Based on F-value (Significance factor value) important parameters can be identified. Table 5 and Table 6 are ANOVA Table obtained by Minitab 16 software. ANOVA Table contain Degree of freedom (DF), Sum of Squares (SS), Mean squares (MS), Significant Factor ratio (F Ratio), Probability (P) and calculated percentage contribution

3.5 ANOVA VALIDATION

General Linear Model: MRR versus Pressure, AFR, SOD, ND

Table 4 : Factors and their levels with values

| Factor | Type | Levels | Values |
|---|---|---|---|
| Pressure | fixed | 3 | 4, 6, 8 |
| AFR | fixed | 3 | 3, 4, 5 |
| SOD | fixed | 3 | 6, 8, 10 |
| ND | fixed | 3 | 2, 3, 4 |

Analysis of Variance for MRR, using Adjusted SS for Tests

Table 5 : Analysis of Variance for MRR, using Adjusted SS for Tests

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Pressure | 2 | 0.0041505 | 0.00 | 0.0019354 | 78.08 | 0 |
| AFR | 2 | 0.0000253 | 0.00 | 0.0000249 | 1 | 0.386 |
| SOD | 2 | 0.0005634 | 0.00 | 0.0002749 | 11.09 | 0.001 |
| ND | 2 | 0.0003797 | 0.00 | 0.0001898 | 7.66 | 0.004 |
| Error | 18 | 0.0004462 | 0.00 | 0.0000248 | | |
| Total | 26 | 0.0055651 | | | | |

S = 0.00497883 R-Sq = **91.98%** R-Sq(adj) = **88.42%**

3.6 Unusual Observations for MRR

Table 6 :Unusual Observation for MRR with St Residual and Fits

| Obs | MRR | Fit | SE Fit | Residual | St Resid |
|---|---|---|---|---|---|
| 6 | 0.0393 | 0.029970 | 0.0028750 | 0.009330 | 2.30 R |

R denotes an observation with a large standardized residual.

Analysis of variance table gives the significance parameter effect on MRR. The significant parameters can be easily identified. Traverse speed and Stand of distance has p -value almost <0.05. Hence for Surface roughness these parameters are much significant. Abrasive flow rate does not much affect the MRR. Percentage Contribution of residual error is 2.30 %. Pressure has maximum percentage contribution (78.08 %) and % percentage contribution of Stand of distance was 11.09 %, Nozzle diameter has 7.66 %.

3.7 Response Optimization

Table 7: Response optimization parameters

| | Goal | Lower | Target | Upper | Weight | Import |
|---|---|---|---|---|---|---|
| MRR | Target | 0.02 | 0.07 | 0.09 | 1 | 1 |

Global Solution
Pressure = 8
AFR = 3.30816
SOD = 10
ND = 3.76359

Predicted Responses
MRR = 0.0699911 , desirability = 0.999821
Composite Desirability = 0.999821 = 99.98%

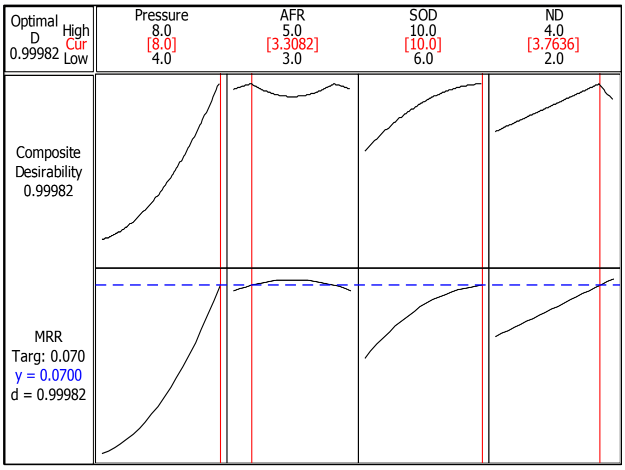


Fig 5 : Graph indicates the effect of Parameters on MRR in Response Optimization

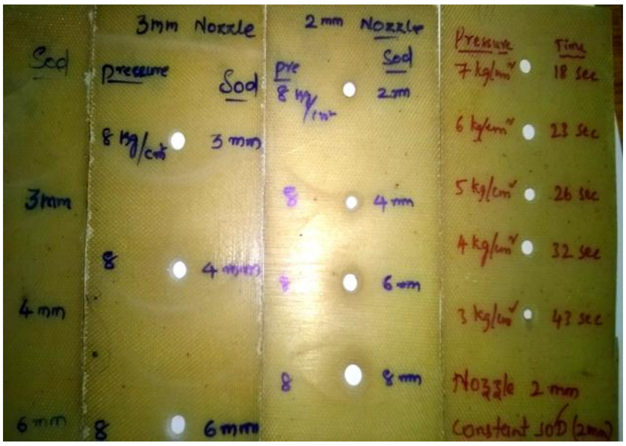


Fig 6 :The composite work pieces machined by **Ajm** at different  ND,SOD,Pressures


Fig 7 : The composite work pieces machined by **Ajm** at different  ND,SOD,Pressures

## IV. Conclusions

The use of the OA with RSM to optimize the AJM process with performance characteristics and Regression analysis has been successfully reported in this paper. Optimization of multiple performance characteristics was simplified through this approach. The experimental result for the optimal setting shows that there is considerable improvement in the process. It is shown that the performance characteristics of the AJM process namely Air pressure, abrasive mass flow rate, standoff distance and Nozzle diameter  are improved together by using this method.

## References


[1] U.D.Gulhani,P.P.Patkar,S.P.Patel,A.A.Patel et al , Analysis of AJM Parameters on MRR, Kerf width of Hard and Brittle Materials like ceramics,--IJDMT-April-2013.

[2] Bhaskar Chandra,, Singh Jagtar , A Study of effect of Process Parameters of Abrasive jet machining, International Journal of Engineering Science and Technology 01/2011 vol 3 pp 504-513.

[3] A.EI-Domiaty, H.M.Abd EI –Hafez, and M.A.Shaker(2009) "Drilling of glass sheets by abrasive jet machining", World Academy of Science , Engineering and Technology 56.

[4] N. Jagannatha1*, S.S. Hiremath2 and K. Sadashivappa3 , Analysis And Parametric Optimization Of Abrasive Hot Air Jet Machining For Glass Using Taguchi Method And Utility Concept, International Journal of Mechanical and Materials Engineering (IJMME), Vol. 7 (2012), No. 1, 9–15.

[5] K.B. Sehgal, Study and Optimization of Process Parameters in Abrasive Jet Machining,Impulse,ITM university,vol 7,2011.

[6] P. Verma and G. K. Lal Publication(1984) "An experimental study of abrasive jet machining", International Journal of Machine Tool Design and Research, Volume 24, Issue 1, pp 19-29.

[7] Modern Machining Processes, P.C.Pandey & H.S.Shan, Tata Mc Graw-Hil.

[8] T. Kuriyagawa, N. Yoshida, K. Syoji, Machining characteristics of abrasive jet machining, J. JSPE 54 (6) (1998) 881–885 (in Japanese)

[9] hen, D.C.and Chen, C.F. 2007.Use of Taguchi method to study a robust design for the sectioned beams curvature during rolling, Journal of Materials Processing Technology190:130-137

[10] Tsai, F.C., Yan, B.H., Kuan, C.Y., Huang, F.Y.(2008). Taguchi and experimental investigation into the optimal processing conditions for the abrasive jet polishing of SKD61 mould steel, International Journal of Machine Tools & Manufacture, Vol. 48, Nos. 7-8, pp.932–945.

[11] Noordin M Y, Venkatesh V C, Sharif S, Elting S, Abdullah A 2004 Application of response surface method-ology in describing the performance of coated carbide tools when turning AISI 1045 steel.J. Materials processing echnol.145: 46–58.