Application of RSM for Parametric Optimization of AJM machined Hastelloy C- 276

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Abstract

In the research and development of novel techniques for cutting high-strength and hard materials without altering their physical and thermal properties, abrasive jet machining (AJM) is a rapidly developing analysis area. it is seen as a potentially successful method for drilling holes in Hastelloy C-276. The topic of the current study is discussed, AJM of Hastelloy In order to assess the performance variables, specifically the material removal rate (MRR), C-276 was investigated. The input criteria considered are nozzle diameter (ND), pressure (P), and stand-off distance (SOD). The remaining parameters like type of abrasive, abrasive floe rate, size of abrasive etc., are kept constant. The response surface methodology (RSM) with a Box–Behnken method was employed in the experimentation, that concerned fifteen machining runs. Analysis of variance (ANOVA) was performed to determine the many parameters of the machining method, and therefore the optimum method With the use of response surface graphs, a parameter combination for achieving a high material removal rate was established. The air pressure is known because the primary determinant of the material removal rate, it is commonly observed that by increase in pressure the MRR increases. The RSM optimal response of process parameters on the MRR of Hastelloy C-276 and the variation in response with ANOVA are the main topics of this study.

Keywords: AJM, MRR, ANOVA, Hastelloy, RSM

Introduction

Alloy C276 (UNS N10276) is an austenitic nickel-molybdenum chromium amalgamation with a minor amount of tungsten added. It's a leading One erosion resistant accoutrements ready for processing diligence. Alloy C276 has excellent erosion resistivity in oxidising and reducing environments surroundings. Alloy C276 has a high molybdenum and chromium content, and the presence of tungsten further increases its resistance to bending, crack erosion, and general erosion caused by chloride stress. Up to 1900 °F (1038 °C) oxidising atmospheres can be used with alloy C276, still, the amalgamation lacks enough chromium to function properly in the most explosively oxidising environments, such as scorching temperatures, concentrated nitric acid. Due to Alloy C276's low carbon concentration, the amalgamation can be used in an as-welded state. It can not be hardened by heat treatment, but can be hardened by cold working. The amalgamation has a advanced work hardening rate than the austenitic pristine brands which should be taken into consideration. Alloy C276 can be fluently welded and reused exercising standard shop fabrication practices for austenitic pristine brands and nickel grounded blends. AJM is an eccentric machining technique that uses mechanical energy to remove unwanted material from a particular work piece. Material crack happens because of the effect of high speed air/gas stream of grating particles on the work piece [6]. Gas utilized is carbon dioxide or nitrogen or compacted air. The choice of grating particles relies upon the hardness and Metal Removal Rate (MRR) of the work piece. Most generally, aluminum oxide or silicon carbide particles are utilized [4]. Grating Jet Machining is utilized for boring, deburring, carving, and cleaning of hard and weak metals, compounds, as well as non-metallic substances [2]. There are no harmful materials radiated by rough water jets, and no oils are essential during the time spent machining [5]. The Important Process Parameters influence the MRR and KERF in AJM are Gas Pressure, Nozzle diameter, Nozzle tip distance [3].

Fig 1: Semi-Automatic Set up of AJM used for the machining

The material removal rate (MRR) can be characterized as the amount of content material eliminated separated by the machining time. One more method for characterizing MRR is to envision an "momentary" material expulsion rate as the rate of material removal from the work piece through the cross-sectional area [1]. The formula used to calculate MRR is

$MRR= \rho \pi d2t\ 4z$

Methodology

The design of experiments (DOE) is a rigorous, exhaustive approach to designing critical thinking that uses information standards and procedures selection phase in order to ensure the age of legitimate, faultless, and legitimate designing ends. Likewise, this is all done under the imperative of a negligible use of designing runs, time, and cash.

Response Surface Methodology (RSM) of the first was a quadratic polynomial. presented by Box and Wilson in 1951. Myers and Montgomery underscored the significance of RSM with DOE. Reaction Surface Methodology is an assortment of numerical and factual strategies valuable for demonstrating and examination of issues in which a reaction of interest is impacted by a few factors and the goal is to streamline this reaction (Montgomery 2005).

Box-Behnken plans are test plans for reaction surface approach, concocted by George E. P. Confine and Donald Behnken 1960, to accomplish the objectives like assessment change, factorial plan, block plan and so on. For the reaction enhancement of cycle boundaries of AJM the Box-Behnken plans are utilized.

R. A. Fisher created the analysis of variance, often known as ANOVA, which is a group of statistical models used to evaluate the variations in group means and their related processes (such as "variation" within and between groups). In the ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, The t-test is expanded to include more than two groups by using an analysis of variance (ANOVA), which offers a statistical test of whether or not the means of several groups are equal. As doing multiple two-sample t-tests would result in an increased chance of committing a statistical type I error, ANOVAs are helpful for comparing (testing) the statistical significance of three or more means (groups or variables).

Experimentation

The experimentation was carried out on the AJM test rig. The experiment concluded while a constant AFR of 4.5(gm/min). Given the difficulty Hastelloy is, this has been done. To machine at lower flow rates. The main elements of the experimental setup include an air compressor, an air filter, a pressure regulator and gauge, a dehumidifier, a mixing chamber, a nozzle, and a mechanism for holding the workpiece, among others.

For the first variable, the levels of the variables are taken into consideration based on the parameters. Pressure three levels are taken they are 6,7,8 and the units are (kg/cm2), Three levels of standoff distance are used (8, 9,10mm) and for variable Nozzle diameter, the three levels taken are (2, 3,4mm).AFR, Size of abrasive and Type are kept constant. The Response surface is used as the foundation for the experiments methodology’s **Box–Behnken design.** The substance for experimentation is the Hastelloy sheet and the Material Removal Rate (MRR) and KERF are the performance measure of the process parameters. The abrasives used are Silicon Carbide of size 40 microns.

Table 1: Factor selection for Optimal Response

Pr	6	7	8
SOD	7	8	9
ND	2	3	4

Table2 :Based on L15 Orthogonal array of Design of Experiments (Response surface methodology)

Pr	SOD	ND	MRR
6	8	4	0.0541
7	8	3	0.0698
8	8	2	0.0898
8	7	3	0.0892
7	9	2	0.0794
8	9	3	0.0993
7	7	4	0.0731
7	7	2	0.0706
8	8	4	0.0782
6	8	2	0.0531
7	8	3	0.0717
7	8	3	0.0721
6	9	3	0.0622

6	7	3	0.0587
7	9	4	0.0726

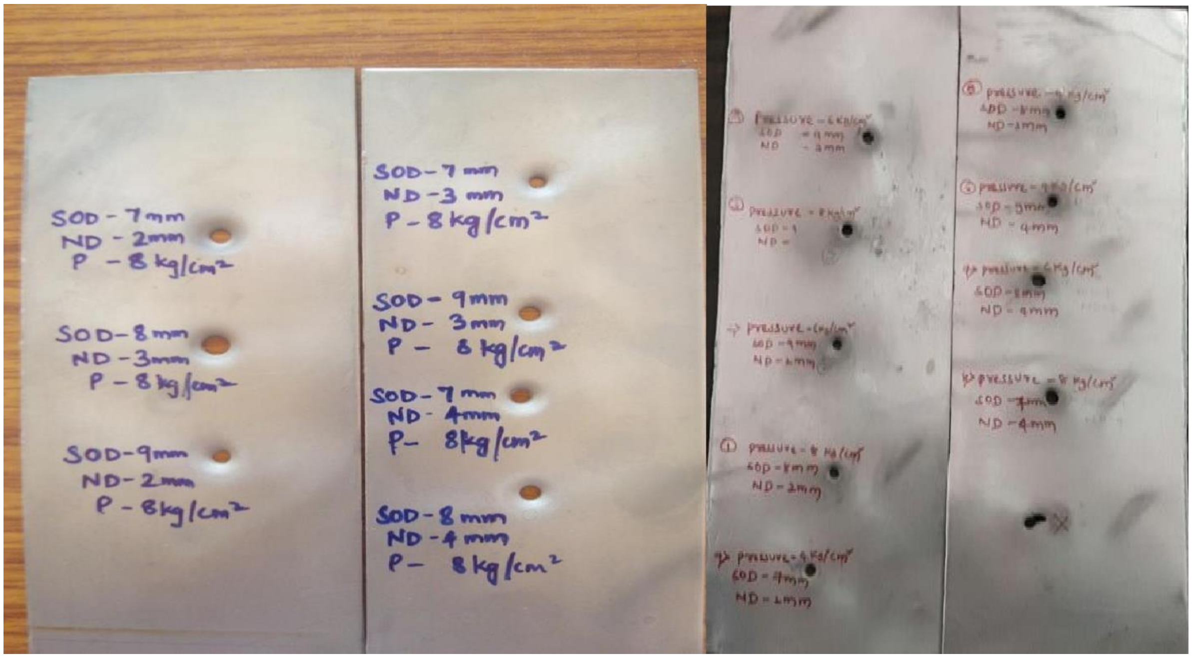

Figure 2 . AJM has machined a variety of thicknesses of haste alloy plates.

Response surface regression for metal removal rate

The metal evacuation rate is determined in light of the standard equations and got the MRR values for 15 examinations in view of arbitrary request need as shown in Table 2. The basic orders and the run orders are laid out in view of plan of tests. The Box-Behnken plan framework of three factors and a reaction (MRR) is displayed in Table . The quantities of elements with base runs, complete runs with the middle focuses are referenced underneath.

Box-Behnken Design

Design Summary

Factors:	3	Replicates:	1
Base runs:	15	Total runs:	15
Base blocks:	1	Total blocks:	1

Center points: 3

Response Surface Regression: MRR versus Pr, SOD, ND

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.07120	0.00107	66.35	0.000	
Pr	0.016050	0.000657	24.42	0.000	1.00
SOD	0.002737	0.000657	4.17	0.009	1.00
ND	-0.001863	0.000657	-2.83	0.036	1.00
Pr*Pr	0.000513	0.000967	0.53	0.019	1.01
SOD*SOD	0.005637	0.000967	5.83	0.002	1.01
ND*ND	-0.002912	0.000967	-3.01	0.030	1.01
Pr*SOD	0.001650	0.000929	1.78	0.036	1.00
Pr*ND	-0.003150	0.000929	-3.39	0.019	1.00
SOD*ND	-0.002325	0.000929	-2.50	0.054	1.00

In the model overview, it shows that R-square value is 99.28 % which shows that the regression is successful.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0018586	99.28%	97.98%	90.20%

Based on Box-Behnken The response surface regression design has been created and F-values are used to illustrate how variables affect response (MRR), as shown in Table.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.002380	0.000264	76.55	0.000
Linear	3	0.002149	0.000716	207.32	0.000
Pr	1	0.002061	0.002061	596.56	0.000
SOD	1	0.000060	0.000060	17.35	0.009
ND	1	0.000028	0.000028	8.03	0.036
Square	3	0.000159	0.000053	15.37	0.006
Pr*Pr	1	0.000001	0.000001	0.28	0.019
SOD*SOD	1	0.000117	0.000117	33.97	0.002
ND*ND	1	0.000031	0.000031	9.07	0.030
2-Way Interaction	3	0.000072	0.000024	6.97	0.031
Pr*SOD	1	0.000011	0.000011	3.15	0.036
Pr*ND	1	0.000040	0.000040	11.49	0.019
SOD*ND	1	0.000022	0.000022	6.26	0.054
Error	5	0.000017	0.000003		
Lack-of-Fit	3	0.000014	0.000005	3.15	0.250
Pure Error	2	0.000003	0.000002		
Total	14	0.002397			

Based on the Analysis of variance of RSM it is noticed that the Pressure is highly influenced by MRR followed by SOD.

The regressions equation is generated based on uncoded units and the equation is shown below

Regression Equation in Uncoded Units

MRR = 0.273 + 0.0051 Pr - 0.0920 SOD + 0.0563 ND + 0.000513 Pr*Pr
+ 0.005637 SOD*SOD
- 0.002912 ND*ND + 0.001650 Pr*SOD - 0.003150 Pr*ND -
0.002325 SOD*ND

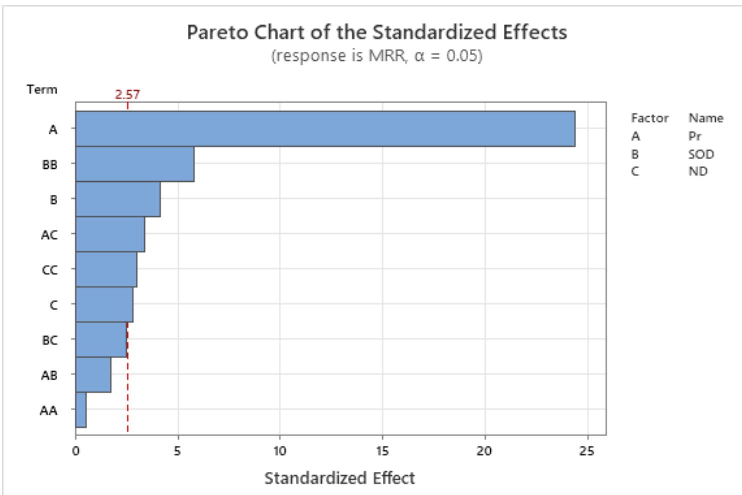

Fig 3 : Pareto Chart of parameter effect on MRR

Optimal Design: Pr, SOD, ND

Response surface design selected according to D-optimality

Number of candidate design points: 15

Number of design points in optimal design: 16

Model terms: A, B, C, AA, BB, CC, AB, AC, BC

Initial design generated by Sequential method

Initial design improved by Exchange method

Number of design points exchanged is 1

Optimal Design

Row number of selected design points: 1, 4, 5, 6, 8, 9, 3, 10, 7, 2, 15, 13, 14, 2, 1, 9

Condition number:	2.43269
D-optimality (determinant of XTX):	51380224
A-optimality (trace of inv(XTX)):	2.40179
G-optimality (avg leverage/max leverage):	0.853659
V-optimality (average leverage):	0.625
Maximum leverage:	0.732143

Response Optimization: MRR

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
MRR	Maximum	0.0531	0.0993		1	1

Solution

Solution	Pr	SOD	ND	MRR Fit	Composite Desirability
1	8	9	2	0.102212	1

Multiple Response Prediction

Variable	Setting
Pr	8
SOD	9
ND	2

Response	Fit	SE Fit	95% CI	95% PI
MRR	0.10221	0.00220	(0.09657, 0.10786)	(0.09482, 0.10961)

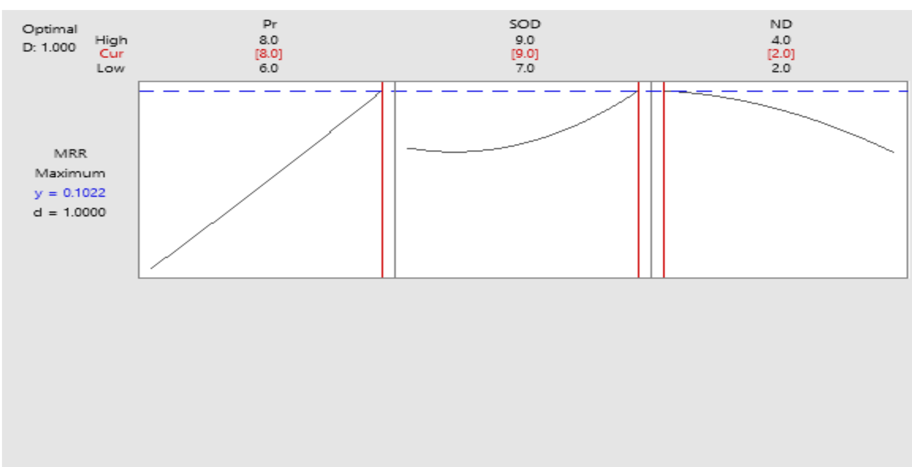

Fig 4: Response optimization of MRR

Prediction for MRR

Regression Equation in Uncoded Units

$$MRR = 0.273 + 0.0051\,Pr - 0.0920\,SOD + 0.0563\,ND + 0.000513\,Pr*Pr + 0.005637\,SOD*SOD - 0.002912\,ND*ND + 0.001650\,Pr*SOD - 0.003150\,Pr*ND - 0.002325\,SOD*ND$$

Factorial Plots for MRR

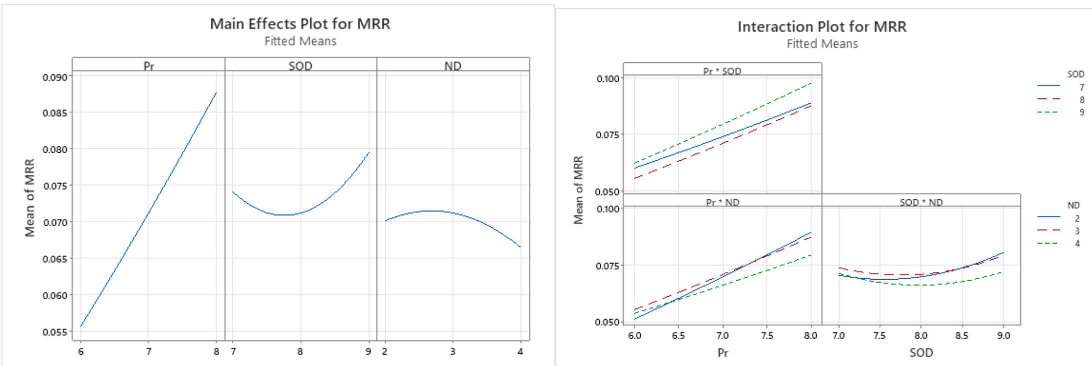

Fig 4 : Factorial plots represents main effect of parameters on MRR

Contour Plot of MRR vs SOD, Pr, ND

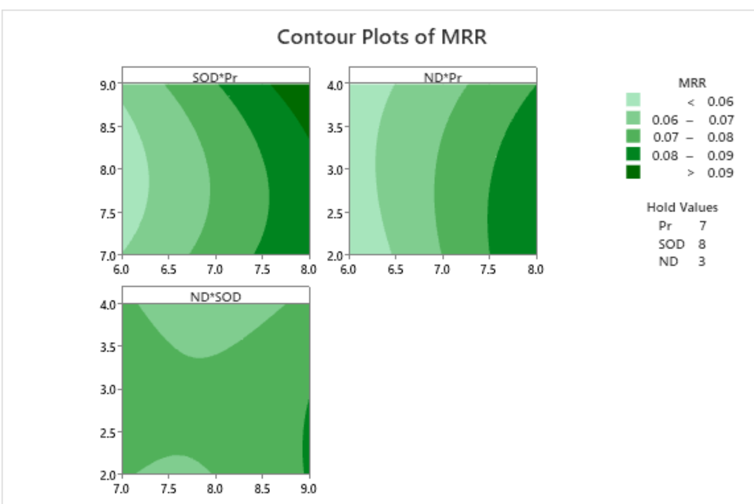

Fig 5: Contour Plot of MRR vs SOD, Pr

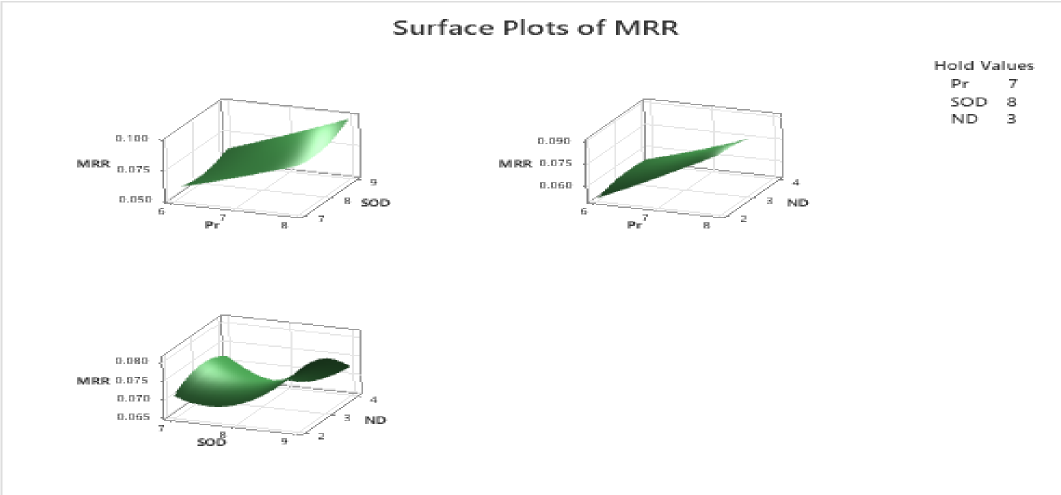

Fig 6: Surface plots on Parameters vs MRR

Validation of RSM values by ANOVA

General Linear Model: MRR versus Pr, SOD, ND

Method

Factor coding (-1, 0, +1)

Factor Information

Factor	Type	Levels	Values
Pr	Fixed	3	6, 7, 8
SOD	Fixed	3	7, 8, 9
ND	Fixed	3	2, 3, 4

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Pr	2	0.002062	0.001031	92.17	0.000
SOD	2	0.000177	0.000089	7.93	0.013
ND	2	0.000059	0.000030	2.64	0.132
Error	8	0.000089	0.000011		
Lack-of-Fit	6	0.000086	0.000014	9.54	0.098
Pure Error	2	0.000003	0.000002		
Total	14	0.002397			

The F-Value of the parameters shows that the pressure is highly influenced by MRR followed by SOD and ND. This is validated with RSM values obtained.

The R-Square value is 96.27%. Any value more than 90% is a validated model summary.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0033443	96.27%	93.47%	85.29%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.073358	0.000965	75.99	0.000	
Pr					
6	-0.01588	0.00132	-12.06	0.000	1.24
7	-0.00034	0.00116	-0.29	0.016	1.25
SOD					
7	-0.00086	0.00132	-0.65	0.033	1.24
8	-0.00376	0.00116	-3.24	0.012	1.25
ND					
2	0.00089	0.00132	0.68	0.017	1.24
3	0.00194	0.00116	1.67	0.033	1.25

Regression Equation

MRR = 0.073358 - 0.01588 Pr_6 - 0.00034 Pr_7 + 0.01622 Pr_8 - 0.00086 SOD_7 - 0.00376 SOD_8+ 0.00462 SOD_9 + 0.00089 ND_2 + 0.00194 ND_3 - 0.00283 ND_4

Fits and Diagnostics for Unusual Observations

Obs	MRR	Fit	Resid	Std Resid	
9	0.07820	0.08299	-0.00479	-2.02	R

R Large residual

Conclusion

Hastelloy is machined using response surface methods with pressure, SOD, and ND as parameters and metal removal rate (MRR) as the end result. For Hastelloy, 15 experiments are carried out in accordance with the design of the experiments. Plots are developed as a means of demonstrating how factors affect outcomes. Regression equations for MRR is developed. Also identified are the response variable values that can be machined. The General Linear Model of ANOVA module was employed to investigate the effect of Parameters on MRR & KERF. Performance at its peak can be found at Larger is Better MRR was identified as Air Pressure (8 kg/cm2) ,SOD (9 mm) ,Nozzle diameter (4 mm). Optimal levels of Performance Found at Smaller is Better KERF was identified as Air Pressure (8 kg/cm2) , SOD (9 mm) & Nozzle diameter (3 mm). The R-square resulted in found to be 94.88% for MRR. The experiment's design has been verified, and the R-square value should be between (90 and 100) percent.

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