

# Application of Grey Relation Analysis and Fuzzy logics for Optimization of Abrasive Jet Machining of Haste alloy

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**ABSTRACT:** Process parameters optimization of multiple response characteristics of Abrasive jet machining on Hastelloy one of the most promising super alloy using Grey taguchi Fuzzy- Grey relational analysis is presented in this paper. Response characteristics such as MRR, and KERF are optimized during the machining operation. Process parameters including pressure, Stand off distance, Nozzle diameter are investigated using Taguchi L09 orthogonal array. These response characteristics are studied and examined using Gray touchy and grey-fuzzy approaches and optimal combination of influential input parameters are discovered. Based on the results of verification experiments it is concluded that Taguchi, Fuzzy-Grey Relational Analysis can efficaciously be used to find the optimal combination of influential input parameters of AJM.

**KEYWORDS :** Fuzzy Grey relation, MRR, KERF,

## I. INTRODUCTION

In this section it is discussed about optimization of Abrasive jet machining process parameters with a super alloy as working material. Hastelloy C276 is selected as work material for these experiments.

Numerous nickel-based steel combinations show high imperviousness to erosion, and Hastelloy is one of the best. Notwithstanding extraordinary imperviousness to all way of setting and splitting, parts produced using Hastelloy metal mixes tend to discover great use over an extensive variety of compound applications that may some way or another oxidize the metal. Extra components, for example, molybdenum and chromium round out the profile of a combination that is broadly viewed as one of the world's hardest metal alloy.

Abrasive jet machining is one of the variant and effective approach in non traditional machining process in which the metal removal takes place with the help of abrasion.

**Table: 1. Chemical composition of Hastelloy C276**

Ni	Mo	Cr	Fe	W	Co	Mn	C
Remainder	15.0-17.0	14.5-16.5	4.0-7.0	3.0-4.5	2.5 max	1.0 max	.01 max
V	P	S	Si				
.35 max	.04 max	.03 max	.08 max				

## II. METHODOLOGY(Grey Relation Analysis)

The Grey Relational Analysis is an effective method in which analysis being done among the sequence groups requires that all sequences satisfy comparability conditions, for instance, non- dimension, scaling, and polarization attributes. It can be used for solving the complicated interrelationships among the multi responses. This method is

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used to analyze the multi- performances in experimental studies and has some advantages than statistical methods. When the experimental method cannot be carried out exactly, grey relational analysis helps to compensate for the shortcoming in statistical regression. Grey relation analysis is an effective means of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method.

## III. EXPERIMENTATION

### 3.1. Selection of Process Parameters and Orthogonal Array

The parameters like Pressure, Standoff distance and Nozzle diameter are considered as variable parameters Abrasive flow rate and Abrasive grain size of particles are kept constant.

The variable levels that are considered based on the parameters are, for first variable pressure three levels are taken they are 4,6,8 and the units are(kg/cm<sup>2</sup>),for variable standoff distance three levels are taken(7,8,9mm) , and for variable Nozzle diameter the three levels taken are (2,3,4 mm).The Abrasive flow rate is kept constant.

For conducting experiments Orthogonal array was designed according to Taguchi. The parameters of Abrasive Jet machining in this study are Pressure, Standoff Distance , and Nozzle diameter. Each parameter is taken for three levels.

**Table 2. Shows input Parameters and Levels considered for experimentation**

Process Parameters	Level 1 (Low)	Level 2 (Medium)	Level 3 (High)
PRESSURE	4	6	8
SOD	7	8	9
ND	2	3	4

From the taguchi orthogonal selector, we find that for four parameters and three levels an **L9** Orthogonal array should be selected.

The selection of parameters for experimentation is done as per Fractional factorial design. An array for four controllable parameters is used to construct the matrix of three levels of controllable factors.

Minitab is used to generate the necessary fraction of experiments out of whole set of experiments possible with three factors at three levels. Table 2 indicates the details of Taguchi design of experiments based on L9 Orthogonal array and the method used for this is variable factorial method.

**Table 3 . L9 Orthogonal array according to Taguchi design of experiments for the corresponding levels of various Variables Factorial method**

S.No	Pressure	SOD	ND
1	4	7	2
2	4	8	3
3	4	9	4
4	6	7	3
5	6	8	4
6	6	9	2
7	8	7	4
8	8	8	2
9	8	9	3

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By considering the above input parameters experiments are carried out and Process parameters such as Material removal rate ,Kerf is calculated.



Fig 1. Shows the machining of Hastelloy using AJM and the Hastelloy machined based on L9 orthogonal array

Table 4. L9 Orthogonal Array Design of Experiments

S.No	Pressure	SOD	ND	MRR	KERF
1	4	7	2	0.09187	1.5
2	4	8	3	0.06391	2
3	4	9	4	0.0956	2.5
4	6	7	3	0.057129	2
5	6	8	4	0.069821	2.2
6	6	9	2	0.0713	2
7	8	7	4	0.07178	2.5
8	8	8	2	0.065585	2
9	8	9	3	0.02094	2.5

### 3.2 Signal - To - Noise Ratio Calculation

The taguchi method aims to find an optimal combination of parameters that have the smallest variance in performance. The signal to noise ratio (S/N ratio,  $\eta$ ) is an effective way to find significant parameters by evaluating minimum variance. From this experimental setup 9 experiments should be conducted to optimize the parameters to get a optimized minimum Kerf, maximum material removal rate. The S/N ratios for each Kerf values is generated with the formulae of “smaller is better” and S/N ratios of MRR are generated with the formulae of “higher-is-better” because the MRR must be always maximum.

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**Table 5 .Signal to Noise ratios for response variables**

S NO	PSNRA/MRR	PSNRA/KERF
1	-18.93095251	-3.893140965
2	-24.65988611	-5.834942021
3	-21.42515285	-7.773142281
4	-25.89717826	-5.834942021
5	-21.31470555	-7.219769401
6	-23.70947186	-5.834942021
7	-23.65119338	-7.773142281
8	-24.69822024	-5.834942021
9	-31.77489329	-8.330115958

### 3.3 Grey Relational Generating & Grade Calculation

When the units in which performance is measured are different for different attributes, the influence of some attributes may be neglected. This may also happen if some performance attributes have a very large range. In addition, if the goals and directions of these attributes are different, this will cause incorrect results the analysis. It is thus necessary to process all performance values for every alternative into a compatibility sequence, in a process analogous to normalization. This processing is called grey relational generating in GRA

For **Higher-the-better** quality, normalizing data is calculated by

$$x^{*i}(k) = \frac{(x_i^0(k) - \min x_i^0(k))}{(\max x_i^0(k) - \min x_i^0(k))}$$

For **Lower-the-better** quality, normalizing data is calculated by

$$x^{*i}(k) = \frac{(\max x_i^0(k) - x_i^0(k))}{(\max x_i^0(k) - \min x_i^0(k))}$$

Where,

k = 1 to n, i = 1 to 9 ; “n” is the performance characteristic and “i” is the trial number

$x^{*i}$  → is the sequence after data normalizing

$x_i^0$  → is the original sequence

$\max x_i^0(k)$  → is the largest value of  $x_i^0(k)$

$\min x_i^0(k)$  → is the smallest value of  $x_i^0(k)$

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**Table .6: Grey relational generation of each Response variable**

S.NO	MRR normalized	KERF normalized
1	1	1
2	0.605809	0.5
3	1.052587	0
4	0.510207	0.5
5	0.689144	0.3
6	0.709996	0.5
7	0.716763	0
8	0.629423	0.5
9	0	0

The grey relational coefficient is calculated from the normalized experimental data to express the relationship between the ideal and the actual experiment.

$I(k)$  for the  $K_{th}$  Performance characteristics in  $i_{th}$  experiment is

$$I(K) = (\Delta_{min} + \Psi \Delta_{max}) / (\Delta_{oi} + \Psi \Delta_{max})$$

$$\Delta_{oi} = \|X^*_o(k) - X^*_i(k)\|$$

$$\Delta_{min} = \min \|x^*_o(k) - x^*_i(k)\|$$

$$\Delta_{max} = \max \|x^*_o(k) - x^*_i(k)\|$$

Where,  $x^*_o(k)$  is the reference sequence  $x^*_i(k)$  is the compatibility sequence

$\Psi$  is 0 to 1, in general  $\Psi = 0.5$

**Table .7: Grey relational Coefficient for each output parameter ( $\Psi=0.5$ )**

S NO	GRC of MRR	GRC of KERF
1	1	1
2	0.559	0.5
3	1.118	0.333333
4	0.505	0.5
5	0.617	0.416667
6	0.633	0.5
7	0.638	0.333333
8	0.574	0.5
9	0.333	0.333333

The grey relational grade is computed by averaging the grey relational coefficients corresponding to each process response. The overall evaluation of the multiple process responses is based on the grey relational grade. High Grey relational grade gives the optimal solutions.

The grey relational grade is obtained by :

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$$y_i = \frac{1}{n} \sum_{k=1}^n \varepsilon_i(k)$$

Where,  $y_i$  is the grey relational grade and  $n$  is the number of performance characteristics. High grey relational grade gives the optimal conditions.

**Table .8 :Summary of Grey relational grades and their ranks**

Exp No	Overall grey relational grade	order
1	1	1
2	0.529582	5
3	0.725435	2
4	0.502578	7
5	0.51665	6
6	0.566454	3
7	0.485855	8
8	0.537166	4
9	0.333333	9

From table, it is observed that the experiment no. 8 has the highest grey relational grade. The levels of machining characteristics in the above experiment are Material Removal Rate (0.0918 g/s), Kerf (1.5 mm).

Table.9 : Resonse table for Grey Relational Grades

Level	PRESSURE	SOD	ND
1	0.4026	0.4752	0.6818
2	0.6701	0.6071	0.4813
3	0.5620	0.5524	0.4716
Delta	0.2675	0.1319	0.2102
Rank	1	3	2

However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining parameter levels can be determined more accurately. The main effect plot of GRG is drawn. The ordinate of it represents the means of grey relational grade calculated using larger - the - better criteria.

The larger the grey relational grade, the better are the multiple performance characteristics. From the main effects plot graph, the optimal parametric combination is determined. The graphs generated shows the optimum combination of parameters with corresponding values

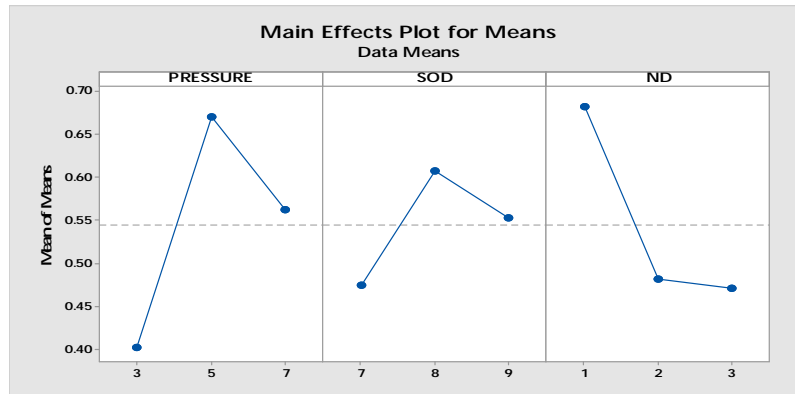
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Graph .1: Main effect plot of means

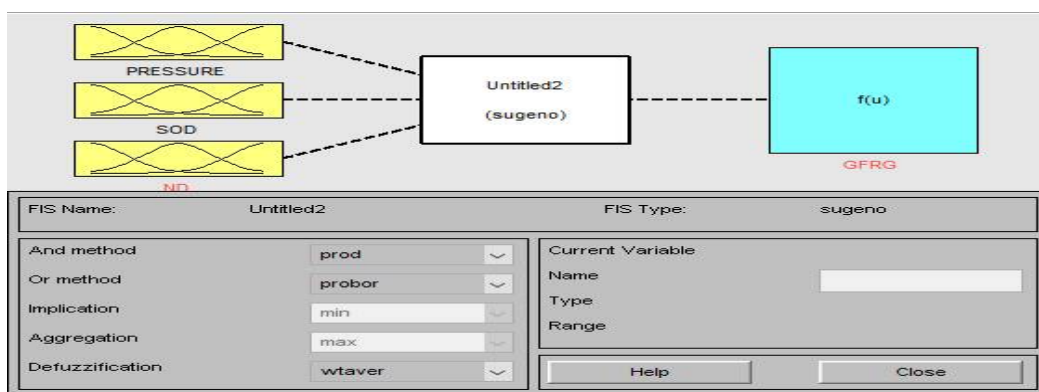


### 3.4 Grey Fuzzy Logic Analysis:

In fuzzy logic system, the fuzzifier uses the membership functions to fuzzify Grey Relational Coefficient (GRC) of each performance characteristic. The inference engine (Mamdani fuzzy inference system) performs fuzzy reasoning with fuzzy rules to generate a fuzzy value. These fuzzy rules are presented in the form of if-then control rule. For each rule, the three inputs are assigned in the fuzzy subsets of Low, Medium and High and the corresponding membership functions,  $\mu_{x1}$ ,  $\mu_{x2}$  and  $\mu_{x3}$ , respectively.

The output is assigned to any of the Five fuzzy subset (Very Low, Low, Medium, High, Very High) membership functions  $\mu_Y$ . Fuzzy rules are directly derived based on the fact that larger-the- better characteristic. By tracking maximum- minimum compositional operation, the fuzzy reasoning of these rules yields a fuzzy output. Finally, the defuzzifier converts fuzzy predicted value into a GFRG (Grey Fuzzy Reasoning Grade).

Graph.2: Selection of inputs and outputs in Fuzzylogics



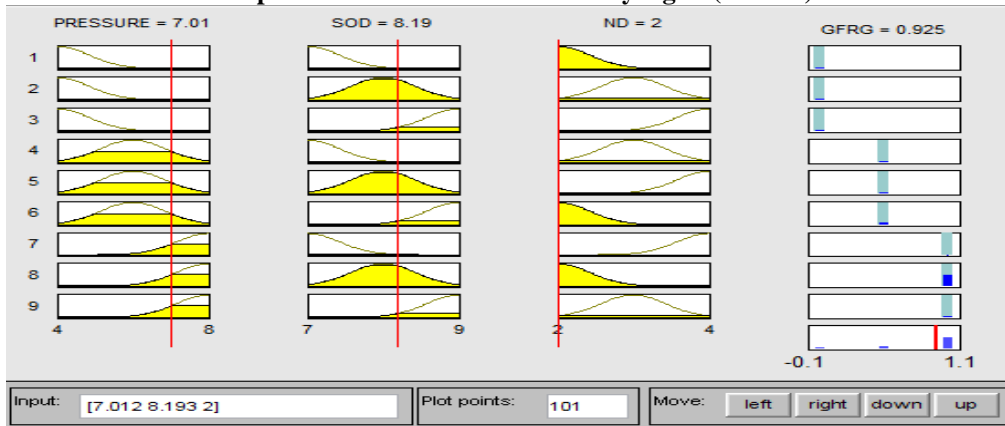
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**Graph .3: Grade attainment in Fuzzy logics (Matlab)**

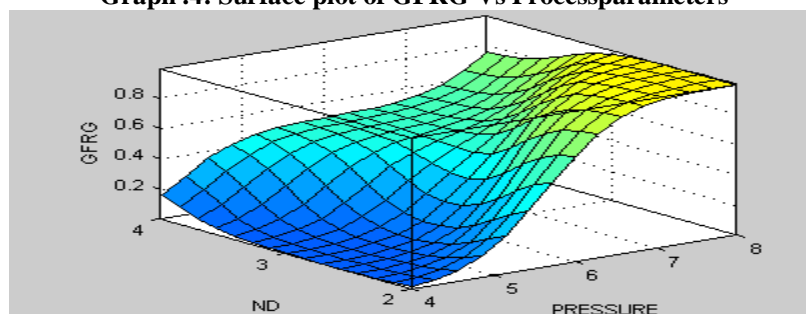


**Table .10. Overall Grey Fuzzy Reasoning Grade (GFRG)**

Exp no	Overall Grey Fuzzy Reasoning Grade	Order
1	<b>0.92</b>	1
2	0.539	5
3	0.561	3
4	0.504	7
5	0.516	6
6	0.576	2
7	0.489	8
8	0.547	4
9	0.39	9

From table it is observed that the experiment no. 1 has the highest grey relational grade. The levels of machining characteristics in the above experiment are Material Removal Rate(0.09187 kg/cm<sup>2</sup> ),Kerf ( 1.5 mm )

**Graph .4: Surface plot of GFRG Vs Processparameters**





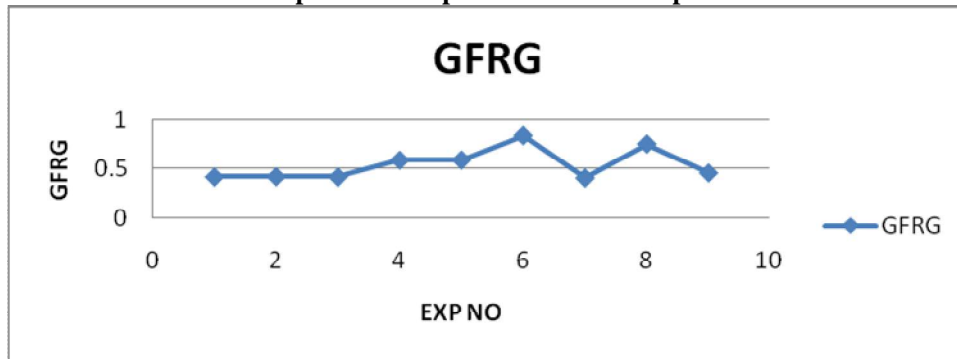
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**Graph 5: Scatter plot of GFRG Vs Exp No**



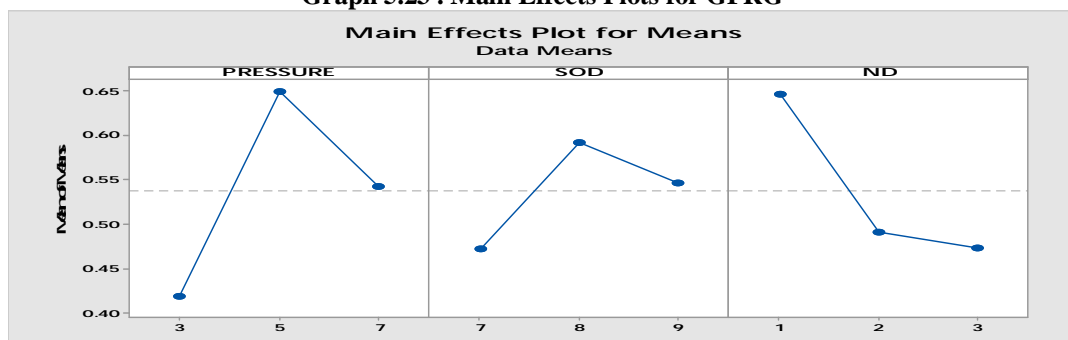
The relative importance among the machining parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining parameter levels can be determined more accurately. The mean response table for overall GFRG is shown in the table . and is represented in figure , The ordinate of it represents the means of grey fuzzy reasoning grade calculated using larger - the - better criteria.

**Table 11. Response table for Grey Relational Grades**

Level	PRESSURE	SOD	ND
1	0.4193	0.4730	0.6463
2	0.6493	0.5917	0.4917
3	0.5430	0.5470	0.4737
Delta	0.2300	0.1187	0.1727
Rank	1	3	2

Based on the table Pressure,SOD,ND are the parameters which highly affect the responses of the study such as MRR, KERF.

**Graph 5.23 . Main Effects Plots for GFRG**



The larger the grey fuzzy reasoning grade, the better are the multiple performance characteristics. From the main effects plot graph, the optimal parametric combination is determined. The graphs generated shows the optimum combination of parameters with corresponding values.

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## IV. CONFIRMATION OF RESULTS

The confirmation test for the optimal parameters with its levels was conducted to evaluate quality characteristics for AJM of Glass. From the grey relational analysis shows the highest GRG indicating the initial process parameter set of (A3 B2 C2) for the best multiple performance characteristics among the nine experiments. The optimal grey relational grade (GRG<sub>opt</sub>) is predicted by using the following equation:

$$GRG_{opt} = GRG_{mean} + \sum_{i=1}^n (GRG_i - GRG_{mean})$$

Where GRG<sub>mean</sub> is the average of Grey relational grade, GRG<sub>i</sub> is the average of grey relational analysis at optimum level and n is the significantly affecting process parameters. The predicted value of optimal grey relational grade is expressed by taking n = 3 since there are four significant parameters.

The predicted value of optimal Grey Relational Grade is calculated as :

$$\begin{aligned} GRG_{opt} &= 0.5448 + (0.6701 - 0.5448) + (0.6071 - 0.5448) \\ &\quad + (0.6818 - 0.5448) \\ &= 0.8694 \end{aligned}$$

**Table 12. Experimental and predicted values of GRG**

Optimal process parameters	Predicted Value	Experimental Value
Level	A2 B2 C3	A2 B2 C3
MRR (gm/sec)	0.9187	0.887
KERF(mm)	2.92	2.7
GRG	0.8694	1

Similarly the confirmation of results is done to GFRG. From the fuzzy logic, shows the highest GFRG indicating the initial process parameter set ( A2 B2 C2 D1) for the best multiple performance characteristics. The predicted process parameter set is ( A2 B2 C2 D1).

**Table 13. Experimental and predicted values of GFRG**

Optimal process parameters	Predicted Value	Experimental Value
Level	A2 B2 C1	A2 B2 C1
MRR (gm/sec)	0.09187	0.09817
KERF(mm)	1.5	1.5
GFRG	0.8128	0.7560

From the Experimental and predicted value tables of Grey relational grade and GFRG for optimal process parameters, we observe that the experimental values of both the GRG and GFRG are near to their respective predictive values

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obtained by using Grey relational analysis and Fuzzy logic, hence we confirm that the results obtained through grey relational analysis and Fuzzy logic are correct and AJM of Glass is successfully optimized.

#### 4.1 Comparison of Results obtained by Grey taguchi method and Fuzzy logic

According to Grey taguchi technique we obtained experiment number 5 as the optimized experiment. But when we applied fuzzy logic we obtained experiment number 5 as the optimized experiment. By the application of Fuzzy logic there is 46.78% reduction in Material removal Rate, and 29.54% reduction in Kerf.

**Table 14. Comparison of results obtained by optimization techniques**

Optimization Technique	Optimized Experiment	MRR	KERF
Grey Touchy	1	0.09187	1.5
Fuzzy Logics	1	0.09187	1.5
% Change		0	0

## V.CONCLUSIONS

The conclusions derived from the grey-fuzzy logic approach in optimizing machining parameters in drilling of Hastelloy C276 are as follows. Experiments are performed based on L9 OA chosen using Taguchi's DoE and analysis is done using grey relational analysis and fuzzy logic approach for optimizing multiple performance characteristics viz. MRR and KERF.

Grey-fuzzy reasoning grade is acquired to evaluate the multiple responses with the available 27 sets of framed rules, which shows an improvement when compared with the obtained grey relational grade, thereby reducing the fuzziness. The optimum level of input control parameters obtained are Pressure 8 kg/cm<sup>2</sup>, SOD is 8mm and the nozzle diameter is 2mm. Interaction plot shows that, a significant level of interaction exists between all the input parameters over each other. The results of GRG and GFRG are compared and found that the values of the both relation grading values are matching.

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