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MULTI OBJECTIVE OPTIMIZATION DURING ABRASIVE WATER JET MACHINING OF MONEL– 400 METAL USING GREY RELATIONAL ANALYSIS

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ABSTRACT

This paper investigates the optimal setting of process parameters such as traverse speed, abrasive flow rate and standoff distance which influences the surface roughness and material removal rate during Abrasive water Jet machining of Monel-400 work-material and Garnet-80 mesh as abrasive particles. Experiments are carried-out based on Taguchi and Grey relational analysis is used to analyze the data. For the purpose of experimentation L9 orthogonal array is used as per Taguchi design of experiments. Grey relational analysis is used to find the optimal conditions of each process parameters on response variables such as surface roughness and MRR. Finally confirmatory test is carried-out and checked the adequacy of the process.

Keywords: Monel-400, Garnet-80 mesh, Transverse speed, abrasive flow rate, stand-off distance, surface roughness, material removal rate, Taguchi method, Grey relational analysis.

I. INTRODUCTION

Abrasive water jet machining also known as a water jet is an industrial tool capable of cutting a wide variety of materials using a very high-pressure jet of water, or a mixture of water and an abrasive substance. The term abrasive jet refers specifically to the use of a mixture of water and abrasive to cut hard materials, while the terms pure water jet and water-only cutting refer to water jet cutting without the use of added abrasives. Some of the advantages of AWJC are no thermal distortion, high machining versatility, minimum stresses on the work piece, high flexibility and small cutting forces. It is of better-quality when compared to other cutting techniques in processing variety of materials and widely used in industry. Some of the limitations of AWJC are, it generates loud noise, messy functioning surroundings, creates tapered edges on the kerf, when cutting at high cutting speeds.

II. LITERATURE REVIEW

John kechagias et al.,**[1],** presented his research on application of Taguchi design for quality characterization of abrasive water jet machining of TRIP sheet steels. The input parameters taken are nozzle diameter, standoff distance and traverse speed. The outputs obtained are kerf width and surface roughness. In present work ANOVA method is taken for analysis.

Mukul Shukla et al., [2], conducted his work on Predictive modeling of surface roughness and kerf widths in abrasive water jet cutting of Kelvar composites using Neural Networks. The process parameters taken are standoff distance, jet impact angle, orifice diameter and abrasive factor. The output parameters are surface roughness and kerf width.

Azmir et al., [3] had studied Abrasive water jet machining process on glass/epoxy composite laminate and aluminium oxide is taken as abrasive. Taguchi analysis is used for finding minimum surface roughness by taking standoff distance and nozzle diameter as process parameters.

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Manu et al., [4] studied influence of jet impact angle on part geometry in abrasive water jet machining of aluminium alloys using Taguchi analysis. It was confirmed that increasing the kinetic energy of Abrasive Water Jet Machining (AWJM) process may produce a better quality of cuts.

Ma et al., [5] investigated that abrasive water jet cutting can produce tapered edges on the kerf of work piece being cut, a simple empirical correlation for the kerf profile shape under different traverse speed has been developed that fits the kerf shape well. The mechanisms underlying the formation of the kerf profile are discussed and the optimum speed for achieving the straightest cutting edge is presented.

Pratik J. Parikh et al., [6], made an approach towards the abrasive water jet machining process parameters using Neural Networks. The process parameters taken are orifice diameter, depth of cut, work piece – abrasive material combination factor.

Pradeep kumar Sharma et al., [7], studied on comparison of process parameters during machining of Glass Fiber Reinforced Plastic by abrasive jet machining using silicon carbide as abrasives. ANOVA analysis and Taguchi method is used for comparing MRR, over cut and taper cut.

Ahsan et al., [8], had concluded from ANOVA analysis that type of abrasive particles is the most significant factor on surface roughness during abrasive water jet machining on glass/epoxy composites using aluminium oxide as abrasive. For noise factors effect, the forms of glass fibers and thickness of composite laminates showed the greatest influence on Ra.

Manabu Wakuda, *et al* [9], performed micro abrasive jet machining on alumina ceramics using three kinds of commercial abrasive particles WA grits, GC abrasives and SD abrasives compares the surface roughness from all. Three kinds of commercial abrasive particles were utilized to dimple the sintered alumina samples, and it was found that the material response to particle impact depends drastically on the employed abrasives.

Paul et al [10], made an investigation on Abrasive water jet machining of glass fiber metal laminates using olivine as abrasive that taper quality parameter increases with cutting ability. The quality parameters associated with kerf, the taper quality parameter, the amount of burr formation, the straightness of the edge at the exit side, etc. correlate quite well with the cutting ability parameter.

Chen et al [11], studied the characteristics and zones of kerf during the abrasive water jet cutting of hard ceramic materials. Its low cutting speed needs to be increased without compromising the quality of the surface finish. It involves multi-dimensional cutting to examine the effect of jet impact angles on cutting quality.

Bala Murugan Gopalsamy etal [12] deals with experimental investigations carried out for machinability study of hardened steel and to obtain optimum process parameters by Grey relational analysis. An orthogonal array, grey relations, grey relational coefficients and analysis of variance are applied to study the performance characteristics of machining process parameters such as cutting speed, feed, depth of cut and width of cut with consideration of multiple responses i.e., volume of material removed, tool wear and tool life.

Wang et al., [13] presents Orthogonal array of Taguchi experiment where in four parameters like cutting speed, feed rate, tool nose run off with three levels in optimizing the multi-objective such as surface roughness, tool wear and material removal rate in precision turning on CNC lathe. For the purpose of multi response optimization, Grey relational analysis was employed.

R.K .Suresh et al., [14] focussed on an approach based on Grey relational analysis and Desirability function analysis for optimizing the process parameters during turning of AISI 8620 alloy steel with CVD coated tool with multiple performance characteristics. Experimentation were carried out on a CNC lathe using L9 orthogonal array based on Taguchi design of experiments. The influence of spindle speed, feed and depth of cut were analyzed on the performance of surface roughness and material removal rate. The optimal turning parameters are determined by composite desirability index and grey relational grade. Analysis of variance (ANOVA) is used to determine the influence of parameters which significantly affect the responses. From the study, it is concluded that machining performance is significantly improved

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From the literature review, it is evident that little work has been reported on Abrasive water jet machining of Monel-400 as workmaterial and hence the present work has been conducted on Monel-400 as workmaterial with Garnet-80 as abrasive particles

III. EXPERIMENTATION

An Abrasive water jet machine is used for conducting the experiments. Monel-400 metal was used as the work material and Garnet 80 mesh is used as the abrasive particles. The average surface roughness on the work piece was measured using SEF 3500D surface roughness measuring instrument. Experimentation is carried-out using Taguchi design of experiments. In this work, three parameters namely, traverse speed, abrasive flow rate and standoff distance were considered for experimentation. Accordingly there are three input parameters and for each parameter three levels are assumed. For three factors, three levels, Taguchi specified L9 orthogonal array experimentation and based on this data was recorded and further analyzed. Table 3.1 shows the parameters and their levels considered for experimentation. The tests are carried on a work piece of 100mm length, 100mm breadth and 10mm thickness in a Abrasive water jet machine using three input cutting parameters, traverse speed, abrasive flow rate and standoff.

The chemical composition and properties of Monel – 400 metal are shown in Tables 3.2 and 3.3

The chemical composition and properties of Garnet 80 Mesh is shown in Tables 3.4 and 3.5

Table 3.1 Process parameters and their levels

Process parameters	Notation	Level -1	Level -2	Level -3
Transverse speed(mm/min)	TS	60	70	80
Abrasive flow rate (gm/sec)	AR	100	150	200
Standoff distance (mm)	SD	1.0	2.0	3.0

Table 3.2: Chemical composition of MONEL-400 metal

Elements	Nickel	Carbon	Manganese	Iron	Sulphur	silicon	Copper
Percentage	63.0	0.3	2.0	2.5	0.024	0.5	28.0-34.0

Table 3.3: Properties of MONEL-400 metal

Property	Metric	Imperial
Modulus of Elasticity	179 GPa	26000 psi
Electrical resistivity	54.7 x 10-8 Ohm-m	54.7*10-6 Ohm-cm
Tensile strength(annealed)	550 MPa	79800 psi
Yield strength (annealed)	240 MPa	34800 psi
Density	8.80 x103 kg/m3	549 lb./ft3
Melting point	1350°C	2460°F

Table 3.4: chemical composition of GARNET 80 MESH

Element	SiO_2	Al_2O_3	FeO	MgO	TiO_2	MnO	CaO	Cr_2O_3	P_2O
Percentage	31.00	21.60	37.00	7.40	0.55	0.53	1.84	0.05	0.05

Table 3.5: Physical properties of GARNET 80 MESH

Property	Bulk density	Specific Gravity	Hardness	Melting point	Grain Shape
Value	2.34 g/cm^3	4.10 kg/m^3	7.5 - 8	1250^{0}C	Sharp angular

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Figure 3.1 Abrasive water jet machine

Fig. 3.2 Surface Roughness Measuring Instrument

IV. METHODOLOGY

Grey relational analysis

In the procedure of GRA, the experimental result of SR and MRR are normalized at first in the range between zeros to one due to different measurement units. This data pre-processing step is termed as 'grey relational generating'. Based on the normalized experimental data, grey relational coefficient is calculated to correlate the desired and actual experimental data. The overall Grey Relational Grade (GRG) is determined by averaging the grey relational coefficient corresponding to selected responses. This approach converts a multiple response process optimization problem into a single response optimization by calculating overall grey relational grade.

The normalized experimental results can be expressed as follows.

For larger is better,

$$x_i = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

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For smaller is better,

$$x_i = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - min\, y_i(k)}$$

Where, $\max y_i(k)$ and $min\, y_i(k)$ are the larger and smaller values of $y_i(k)$ respectively

The Grey relational coefficient $\xi(k)$ for $y_i(k)$ is calculated

$$\xi(k) = \frac{\Delta \min + \zeta\, \Delta\, max}{\Delta 0i\,(k) + \zeta\, \Delta\, max}$$

Where $\Delta 0i\,(k)$ is reference sequence deviation which is equal to $mod\,(\max y_i(k) - \min y_i(k))$
ζ is distinguishing coefficient which varies from 0 to1 the value of ζ is set as 0.5 to maintain equal weightage of surface roughness and material removal rate.

Grey relational grade, $\Upsilon_i = \frac{1}{n}\sum_{i=1}^{n} \xi_i\,(k)$

V. RESULT

A series of tests were conducted to assess the effect of process parameters on surface roughness and material removal rate and the results of experimental data are shown in Table 5.1. GRG, response table for GRG, ANOVA for GRG are presented in Tables 5.2, 5.3 and 5.4 respectively

Table 5.1 Experimental data

Expt No	Transverse speed (mm/min)	Abrasive flow rate (gm/sec)	Stand-off Distance(mm)	Surface roughness(μm)	Material removal rate(mm^3/sec)
1	60	100	1	8.54	6.217
2	60	150	2	9.92	4.968
3	60	200	3	9.63	5.179
4	70	100	2	9.12	8.781
5	70	150	3	8.54	3.625
6	70	200	1	9.41	7.690
7	80	100	3	7.65	4.214
8	80	150	1	9.23	7.226
9	80	200	2	9.14	11.635

Table 5.2 Grey relational analysis for surface roughness (SR) and material removal rate (MRR)

Expt No	Experimental data		Normalized values		Grey relational coefficient		GRG	Rank
	SR	MRR	SR	MRR	SR	MRR		
1	8.54	6.217	0.60793	0.323596	0.560494	0.425024	0.492759	4
2	9.92	4.968	0	0.167665	0.333333	0.375281	0.354307	9
3	9.63	5.179	0.127753	0.194007	0.364366	0.382851	0.373608	8
4	9.12	8.781	0.352423	0.643695	0.435701	0.583904	0.509802	3
5	8.54	3.625	0.60793	0	0.560494	0.333333	0.446914	7
6	9.41	7.690	0.22467	0.507491	0.392055	0.503774	0.447914	5
7	7.65	4.214	1	0.073533	1	0.350516	0.675258	2
8	9.23	7.226	0.303965	0.449563	0.418048	0.475992	0.44702	6
9	9.14	11.635	0.343612	1	0.432381	1	0.71619	1

Table 5.3 Response table for Grey relational grade

Process parameters	Average relational grade				
	Level 1	Level2	Level3	Max-Min	Rank
Transverse speed (mm/min)	0.4069	0.4682	*0.6128	0.2059	1
Abrasive flow rate (gm/sec)	*0.5593	0.4161	0.5126	0.1432	2
Stand-off Distance(mm)	0.4626	*0.5268	0.4986	0.0642	3
Total mean value of the Grey relational grade *Optimum levels					

Table 5.4 ANOVA based on Grey relational grade

Source of variation	Degrees of freedom	Sum of squares	Mean sum of squares	F-ratio	Percent contribution
Transverse speed (mm/min)	2	0.067081	0.03354	3.788649	54.539
Abrasive flow rate (gm/sec)	2	0.031996	0.015998	1.807085	26.014
Stand-off Distance(mm)	2	0.006214	0.003107	0.35095	5.052
Error	2	0.017706	0.008853		14.395
`	8				100.00

Confirmation test

The objective of the confirmation at optimum levels is to validate the conclusions drawn during the analysis phase. Once the optimal level of process parameters is selected, the next step is to verify the improvement in response characteristics using optimum level of parameters. A conformity test is conducted using the following equation:

$\gamma = \gamma_m + \sum_{i=1}^{n} \gamma i - \gamma m$, where γ_m is total mean of the required responses

γ_j is the mean of the required responses at optimum level

n is the number of process parameters that significantly affects the multiple performance characteristics

A clear comparison between predicted and experimental values are presented in Table 5.5

***Table 5.5* Comparison of predicted and Experimental results using GRA**

GRA	Optimum process parameters		
	Initial process parameters	Predicted values	Experimental values
Level of parameters setting	TS1-AR1-SD1	TS3-AR1-SD2	TS3-AR1-SD2
Surface roughness (µm)	8.54	8.463	8.325
MRR (mm^3/min)	8.217	9.327	9.746
Grey relational grade	0.49276	0.7069	0.7317

VI. CONCLUSIONS

1. The optimal parameters setting with Grey relational analysis lies at 80 mm/min transverse speed, 100 gm/sec abrasive flow rate and 2.0 mm stand-off distance. The optimum predicted value for surface roughness is 8.463 µm, MRR 9.327 mm^3/min and grey relational grade is 0.7069. Also the experimental value for surface roughness is 8.325 µm, MRR is 9.746 mm^3/min and grey relational grade is 0.7317.
2. In case of Grey relational analysis, it is found that both predicted and experimental response characteristics are better as compared to initial machining parameters. To be specific predicted surface roughness(8.463 µm) and experimental surface roughness (8.325 µm) are very much lower than surface roughness at initial setting level. Also predicted MRR (9.327 mm^3/min) and experimental

MRR(9.746 mm^3/min) are much higher as compared to MRR at initial setting level. It may be noted that there is a good agreement between the predicted GRG (0.7069) and experimental GRG(0.7317) and therefore the condition **TS_3-AR_1-SD_2** of process parameters combination was tested as optimal. Further significant improvement in machinability is observed and measured that there is improvement in surface roughness(both experimental and predicted value), as compared with initial machining parameters and at the same time there is a substantial increase in MRR (both experimental and predicted) as compared with initial setting. This encourages applying Grey relational analysis for optimizing multi response problems.

3. Further, from Analysis of variance (ANOVA) depicts that transverse speed is the most significant parameter followed by abrasive flow rate affecting multi response characteristics with transverse speed 54.539 %, abrasive flow rate 26.014 % and stand-off distance 5.052 % respectively

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