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PARAMETRIC OPTIMIZATION DURING ABRASIVE WATER JET MACHINING OF INCONEL-725 USING TAGUCHI INTEGRATED WITH GREY RELATIONAL ANALYSIS

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ABSTRACT

In the present day scenario, the trend of multi-objective optimization towards the improvement of response characteristics in abrasive water jet machining of Inconel 725 has become increasingly widespread in various industrial sectors viz., aircraft and automobile industries. The present paper attempts to select the optimal AWJM process parameters by implementing a popular multi- objective optimization technique i.e., Grey relational analysis. The experiments were performed as per Taguchi L9 orthogonal array on Inconel 725 by considering transverse speed, abrasive flow rate and stand-off distance as the input parameters. Then, the influence of process parameters on surface roughness, material removal rate and Kerf width has been performed by means of Grey relational analysis and ANOVA.

Keywords: *Abrasive water Jet machining, Inconel 725, Transverse speed, Abrasive flow rate, Stand-off distance, Surface roughness, Material removal rate, Taguchi orthogonal array, ANOVA, Grey relational analysis.*

I. INTRODUCTION

Worldwide rapid increased in industrialization generated a demand for an advanced material which should be compatible in the area of nuclear, aerospace and power generation. Because of having high yield strength, hardness, melting point and good thermal conductivity, currently, Inconel 725 is being viewed as a future advanced material in the aforementioned area. Presently, Inconel 725 material is used in the manufacturing of aircraft engine parts.[1,2] In view of all these properties, the Inconel 725 has been chosen as an advanced material in the present study.

The common principle and the procedure in abrasive water jet machining (AWJM) is (i) the hard abrasive/erodent being premixed with water and (ii) the premixed slurry forced through the orifice of the nozzle at high pressure [3]. While machining, the removal of material is carried out by the action of micro cutting [4]. The quality of AWJM depends upon the influence of machining parameters such as water pressure, traverse speed, abrasive flow rate, and standoff distance [5]. Kiran kumar et. al[6] analyzed the effect of input process parameters and to optimize process parameters for achieving optimizing Processes responses such as Metal Removal Rate, Surface roughness and Dimensional deviation simultaneously while machining on the Austenite-Ferrite based alloy duplex stainless steel 2205 using AWJM process. John Basha et. al[7] performed drilling on Ti-6Al-4V work-material using Abrasive jet machining with air pressure, nozzle diameter and stand-off distance as input parameters and MRR and kerf as output characteristics. The technique used towards optimization is GRA and PCA. Azmir et.al., [8] explained the influence of six machining parameters on surface roughness (Ra) and kerf taper ratio (TR) characteristics during an abrasive water jet machining of glass/epoxy laminated composite. Taguchi's design of experiments and analysis of variance were used to determine the effect of machining parameters on Ra and TR . In this case, six machining parameters abrasive types, hydraulic pressure, standoff distance, abrasive mass flow rate, traverse rate and cutting orientation were selected as control factors. Rajamanickam et. al [9] made a comparative analysis on difficult to cut aerospace alloys: Ti-6Al-4V and Inconel 825 using Abrasive Water Jet Machininig.

In this paper, an attempt is made to machine super-alloy Inconel 725 using AWJM process with different cutting parameters. The influence of machining parameters is evaluated based on Surface roughness, material removal rate and kerf width.

II. EXPERIMENTATION

An Abrasive water jet machine is used for conducting the experiments. Inconel 725 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 2.1 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 an Abrasive water jet machine using three input cutting parameters, traverse speed, abrasive flow rate and standoff.
The chemical composition of Inconel 725 and metal abrasive Garnet 80 are shown in Tables 2.2 and 2.3

Table 2.1 Process parameters and their levels

Process parameters	**Notation**	**Level -1**	**Level -2**	**Level -3**
Transverse speed (mm/min)	TS	35.5	44.2	53.04
Abrasive flow rate (gm/sec)	AR	200	250	300
Standoff distance (mm)	SD	2.0	3.0	4.0

Table 2.2 Chemical composition of INCONEL-725 metal

Elements	**Nickel**	**Carbon**	**Manganese**	**Iron**	**Sulphur**	**Silicon**	**Molybdenum**	**Titanium**
%	55-59	0.030	0.35	9	0.010	0.20	7-9.50	1-1.70

Table 2.3 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

Abrasive water jet machine and surface roughness measuring instrument are presented in Figures 2.1 and 2.2 respectively

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Figure 2.1 Abrasive water jet machine

Fig. 2.2 Surface Roughness Measuring Instrument

III. METHODOLOGY

Grey relational analysis

In the procedure of GRA, the experimental result of SR, MRR and Kerf width 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,

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

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 for responses.

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

IV. RESULT

A series of tests were conducted to assess the effect of process parameters on surface roughness material removal rate, Kerf width and the results of experimental data are shown in Table 4.1. Calculation of Grey relational coefficient, response table for GRG, ANOVA for GRG are presented in Tables 4.2, 4.3 and 4.4 respectively

Table 4.1 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)	Kerf width (mm)
1	35.5	200	2	3.10	5.359	1.004
2	35.5	250	3	2.32	5.597	1.051
3	35.5	300	4	2.78	5.989	1.125
4	44.2	200	3	3.20	6.244	0.943
5	44.2	250	4	2.98	6.852	1.030
6	44.2	300	2	2.65	6.921	1.040
7	53.04	200	4	3.52	6.799	0.858
8	53.04	250	2	3.03	7.110	0.893
9	53.04	300	3	3.13	7.803	0.978

Table 4.2 Grey relational analysis for surface roughness (SR) and material removal rate (MRR), Kerf width (KW)

Expt No	Experimental data			Normalized values			Grey relational Coefficient			Grey relational coefficient
	SR	MRR	KW	SR	MRR	KW	SR	MRR	KW	
1	3.10	5.359	1.004	0.3500	0	0.4532	0.4348	0.3333	0.4776	0.4153
2	2.32	5.597	1.051	1.0000	0.0974	0.2772	1.0000	0.3565	0.4089	0.5885
3	2.78	5.989	1.125	0.6167	0.2578	0	0.5660	0.4025	0.3333	0.4339
4	3.20	6.244	0.943	0.2667	0.3621	0.6816	0.4054	0.4394	0.6109	0.4853
5	2.98	6.852	1.030	0.4500	0.6109	0.3558	0.4761	0.5624	0.4369	0.4918
6	2.65	6.921	1.040	0.7250	0.6391	0.3184	0.6452	0.5808	0.4231	0.5497
7	3.52	6.799	0.858	0	0.5892	1.0000	0.3333	0.548967	1.0000	0.6274
8	3.03	7.110	0.893	0.4083	0.7164	0.8689	0.4580	0.63812	0.7923	0.6295
9	3.13	7.803	0.978	0.3250	1.0000	0.5506	0.4255	1	0.5266	0.6507

Table 4.3 Response table for Grey relational grade

Process parameters	Average relational grade				
	Level 1	Level2	Level3	Max-Min	Rank
Transverse speed (mm/min)	0.4792	0.5089	*0.6359	0.1567	1
Abrasive flow rate (gm/sec)	0.5093	*0.5699	0.5448	0.0610	2
Stand-off Distance(mm)	0.5315	0.5177	*0.5748	0.0571	3
*Optimum levels					

Table 4.4 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	0.04154	0.020768	4.14032	66.506
Abrasive flow rate (gm/sec)	2	0.00556	0.002782	0.55453	8.907
Stand-off Distance(mm)	2	0.00532	0.002662	0.53064	8.524
Error	2	0.01003	0.00502		16.063
`	8				100.000

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 4.5

Table 4.5 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-AR2-SD3	TS3-AR2-SD3
Surface roughness (µm)	3.10	3.161	3.031
MRR (mm^3/sec)	5.359	7.105	7.532
Kerf width (mm)	1.004	0.923	0.895
Grey relational grade	0.4153	0.6409	0.6557

V. CONCLUSIONS

1. The optimal parameters setting with Grey relational analysis lies at 53.04 mm/min transverse speed, 250 gm/sec abrasive flow rate and 4.0 mm stand-off distance. The optimum predicted value for surface roughness is 3.161 µm, MRR 7.105 mm^3/sec, Kerf width 0.923 mm and grey relational grade is 0.6409.

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Also the experimental value for surface roughness is 3.031 µm, MRR is 7.532 mm^3/sec, Kerf width 0.895 mm and grey relational grade is 0.6557.

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 experimental surface roughness (3.031 µm) is lower than surface roughness at initial setting level. Also predicted MRR (7.105 mm^3/sec) and experimental MRR(7.532 mm^3/sec) are much higher as compared to MRR at initial setting level. Likewise predicted kerf width (0.923 mm) and experimental kerf width (0.895 mm) are much lower than that at initial setting level. It may be noted that there is a good agreement between the predicted GRG (0.6409) and experimental GRG (0.6557) and therefore the condition **TS_3-AR_2-SD_3** of process parameters combination was tested as optimal. Further significant improvement in machinability is observed and measured that there is improvement in surface roughness(experimental 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 as also with kerf width. 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 66.506 %, abrasive flow rate 8.907 % and stand-off distance 8.524 % respectively

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