ABRASIVE WATERJET CUTTING OF INCONEL 718 ALLOY AND DESIRABILITY ANALYSIS

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Abstract

Abrasive waterjet cutting (AWJC) is a non-traditional machining process employed to handle stronger materials. Inconel 718 alloy is a material which is difficult to handle by traditional machining process. The present work is focused towards studying the surface roughness and kerf width obtained in AWJC of Inconel 718 alloy. The abrasive waterjet parameters like the water pressure, feed rate and abrasive flow rate are included in experimentation. The quality characteristics are observed for the various combinations of the cutting parameters designed by Taguchi's L_9 orthogonal array. Desirability analysis is employed for predicting the optimal setting of AWJC parameters and analysis of variance (ANOVA) is performed to identify the contribution of various parameters in affecting the responses. The confirmation experiment is also conducted to validate the proposed approach.

Key words: Abrasive waterjet cutting; Inconel 718; Surface roughness; Kerf width; Desirability analysis; ANOVA.

I. INTRODUCTION

Waterjet technology is used to cut materials in pure form or in a combined form along with abrasives. Abrasive waterjet cutting (AWJC) has wide industrial applications because of its merits including zero thermal distortion and environmental friendliness. The process limitation includes an unwanted noise and a messy workplace. The process involves focusing of an abrasive waterjet through a small orifice at supersonic speeds to perform the required operation [1]. The process responses depend on the values of cutting parameters and the cost of the abrasives constitute nearly 50% of the total operating cost [2]. Inconel 718 alloy having typical applications in gas turbines, pumps, rocket motors and space crafts is chosen to be machined using AWJC process. The input parameters like water pressure, feed rate and abrasive flow rate are observed to influence the process responses. Hence selecting an optimal combination of AWJC parameters is important for better responses. Parameter design can be sorted out using methods like the technique for order of preference by similarity to ideal solution (TOPSIS), genetic algorithm (GA), principal component analysis (PCA), grey relational analysis (GRA), response surface methodology (RSM), simulated annealing (SA), fuzzy logic and desirability analysis [3,4,5,6,7].

The RSM is a statistical method which generates a polynomial equation to relate the responses with the process inputs [8]. The technique is observed to lose its vigour away from the experimental domain [9,10]. However the experimentations using orthogonal array rather than the central composite design is found to be economical because of a reduced number of experimental trials [11,12]. Taguchi technique is found to be effective in optimization of single response, however Taguchi based desirability analysis which involves calculation of composite desirability index is effective in predicting the optimal operating condition [13,14,15]. Generally the methodology of RSM is supplemented by desirability analysis [16,17]. The Taguchi based PCA is found to perform well and forecast the optimal parameter setting as well [18,19].

From the literature review, it is understood that desirability analysis involves simple computational procedure for multi response optimization. Further limited work is addressed in the area of parameter design in AWJC of Inconel 718 alloy. Hence an attempt has been made to identify the optimal setting of AWJC parameters for the Inconel 718 alloy.

II. EXPERIMENTAL SETUP AND OBSERVATIONS

The material chosen for machining trials is Inconel 718 alloy widely used in turbines and spacecraft applications. The cutting trials are performed using waterjet Germany cutter (model: S3015, SL-V 50 HP), inbuilt with a dual intensifier pump to produce a maximum possible pressure of 4000 bar. The waterjet is focused via a sapphire nozzle (diameter 0.76 mm), controlled by a PLC system. The experimental setup is shown in Fig. 1. The dominant AWJC parameters chosen for experimentation include the water pressure (W), feed rate (F) and abrasive flow rate (A). The range and levels are selected based on literature and pilot trials. Taguchi's L_9 orthogonal array is used to conduct the trials for various combinations of AWJC parameters during which the jet impact angle is maintained at 90°. Three levels are chosen for various parameters and surface roughness (SR) and kerf width (KW) are measured as the responses. The SR values are measured using contact type roughness tester at all sides of cut and the average values are listed in Table 1. The KW is measured as mean of the top and bottom kerf.

Fig. 1. Experimental setup

Table 1. SR and KW values for various trials

Trial	Parameters			Responses	
	W (bar)	F (mm/min)	A (g/min)	SR (µm)	KW (mm)
1	2000	150	350	5.436	0.375
2	2000	180	450	5.523	0.358
3	2000	210	550	5.223	0.422
4	2700	150	450	5.731	0.254
5	2700	180	550	5.046	0.231
6	2700	210	350	4.864	0.276
7	3300	150	550	4.092	0.325
8	3300	180	350	4.962	0.333
9	3300	210	450	4.353	0.364

III. SELECTION OF OPTIMAL AWJC PARAMETERS THROUGH DESIRABILITY ANALYSIS

Selection of optimal AWJC parameters for Inconel 718 alloy is utmost essential to obtain the best cut surface characteristics and avoid further processing. This is bound to reduce the cost in the long run. The desirability function approach is a ranking technique employed to convert the responses into scale free values. The overall desirability index is calculated to predict the optimal condition using the following steps.

Step 1: Find the individual desirability (d_{ij}) values for all the responses using the *smaller-the-better-type* function (Eq. 1).

$$d_{ij} = \left(\frac{y_{ij} - L_i}{T_i - L_i}\right)^s, if L_i \leq y_{ij} \leq T_i \qquad (1)$$

Where n is the number of variables, m is the number of trials, i=1, 2… n and j= 1, 2… m, L_i and T_i are the lower and target values of the responses respectively.

Step 2: Compute the overall desirability index (ODI) by taking the average of individual desirability values using Eq. 2. The ODI values lie between 0 and 1.

$$\mathrm{ODI_j} = \{\Pi_{i=1}^{n} \mathrm{d_{ij}}\}^{\frac{1}{n}}. \qquad (2)$$

Step 3: Identify the optimal level of the parameters based on the ODI value. The quality of product is better at higher value of ODI avoiding further cost.

Step 4: Perform the analysis of variance (ANOVA) to identify the contribution of various parameters in affecting the desired responses.

Step 5: Conduct the validation test to approve the followed methodology.

IV. RESULTS AND DISCUSSION

A. Application of the Methodology of Desirability analysis

The technique of desirability analysis is applied to the multi-input multi-output process of AWJC. The individual desirability values and ODI are calculated for both the responses and listed in Table 2. The ODI values offer the single representation for both the responses. Cutting trials with higher values of ODI represent a machining condition close to the optimal setting of parameters. The ODI values plotted for various trials are shown in Fig. 2.

Table 2. Individual desirability and ODI values

Trial	Individual Desirability		ODI
	SR	KW	
1	0.1800	0.2461	0.2105
2	0.1269	0.3351	0.2062
3	0.3099	0.0000	0.0000
4	0.0000	0.8796	0.0000
5	0.4179	1.0000	0.6465
6	0.5290	0.7644	0.6359
7	1.0000	0.5079	0.7126
8	0.4692	0.4660	0.4676
9	0.8408	0.3037	0.5053

B. Optimal Cutting Condition and ANOVA.

The main effect of the parameters on the ODI is calculated for each level and listed in Table 3. The best level of each parameter is identified as one with the maximum value of ODI. The optimal parameter level is predicted $W_3F_2A_3$. The ANOVA table can be used to study the parameter contribution on responses. The results of ANOVA on ODI are shown in Table 4. The contribution chart is shown in Fig. 3. It gives an account of the share of each parameter in affecting the responses.

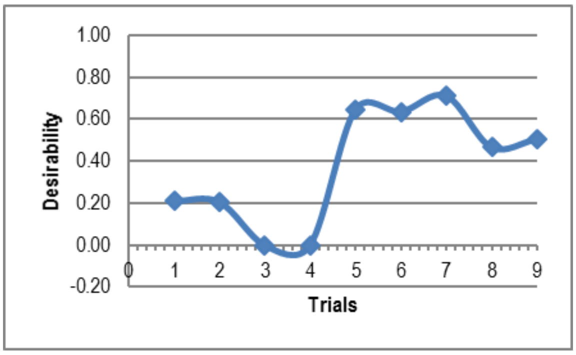

Fig. 2 Plot of ODI values for various cutting trials

Table 3. Parameter effects on CDI

Parameters	Level 1	Level 2	Max-Min
W	0.1389	0.4275	0.5618
F	0.3077	0.4401	0.3804
A	0.4380	0.2372	0.4530

Table 4. ANOVA results

Source of variance	Sum of squares	Degrees of freedom	Mean sum of square	F-ratio	% Contribution
W	0.2802	2	0.1401	1.2488	45.33
F	0.0872	2	0.0436	0.1176	14.10
A	0.2244	2	0.1122	0.3884	36.30
Error	0.0264	2	0.0132		4.27
Total	0.6181	8			100

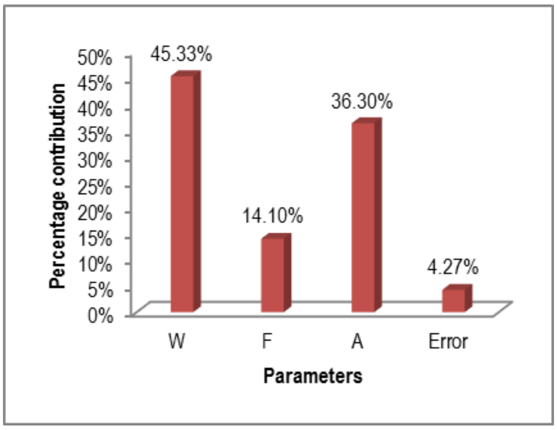

Fig. 3 Factor contribution chart

C. Validation Experiment

After obtaining the optimal level of AWJC parameters using the approach of desirability analysis, the confirmation test is conducted to verify the improvement in the performance characteristics. The results of the confirmation experiment conducted with the desirable setting are compared with those obtained with initial setting of parameters (Table 5). A significant change in the response values is observed with the optimal design parameters.

Table 5. Validation test results

Responses	Initial parameter setting		Optimal setting using desirability analysis		Improvement	
	Calculated S/N ratio	Response Value	Predicted S/N ratio	Response Value	S/N ratio	Response Value
SR (um)	-12.609	4.104	-12.231	3.814	0.3775	0.2900
KW (mm)	9.678	0.328	10.017	0.265	0.3387	0.0630
Parameter settings	$W_3F_1A_3$		$W_3F_2A_3$			

V. CONCLUSION

This paper has revealed the implementation of desirability analysis to forecast the near optimal AWJC parameters for Inconel 718 alloy. The following conclusions can be drawn.

•The simple computational efforts of desirability analysis is employed to predict the optimal AWJC parameters for Inconel 718 alloy as water pressure: 3300 bar, feed rate: 180 mm/min and abrasive flow rate: 550 g/min.

•The ANOVA result has shown that water pressure is an important parameter influencing the responses with a contribution of 45.33 %.

•The confirmation test has validated the application of desirability analysis in selecting the best design parameters.

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