A Gower TOPSIS Method for Optimization of Machining Parameters of Nimonic 80A under Cryogenic Cooling and Minimum Quantity Lubrication

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DOI: 10.5185/amp.2020.010390

The conventional flood cooling method fails to minimize the heat generation in the cutting areas and make adverse effect on the environment during machining process. Hence CMQL (Cryogenic Minimum Quantity Lubrication) is used as coolant in this work, which gives lubrication and reduces the temperature to greater extend and also it is environment friendly. The selection of cutting conditions and appropriate tools for efficient machining process is a challenging process, hence it is necessary to optimize the machining parameters. A modified TOPSIS method using Gower distance has been proposed in this paper for the optimization of Nimonic 80A alloy. The machining parameters such as Surface Roughness (Ra) and Temperature (T) under 3 different environments namely (i) dry, (ii) wet and (iii) cryogenic MQL with different feed rate & cutting speed are examined in the optimization of Nimonic 80A alloy. Optimized results confirm that environment and feed rate are dominant factors and the environment influence is about 84.6%, followed by feed rate at 10.1%. Cryogenic MQL has better effectiveness compared to conventional cooling. The modified TOPSIS method is found to be more effective in machining problems.

Introduction

All machining process aims to improve the material's surface quality and removal rate [**1-3**]. High cutting temperatures developed during the machining process creates a dimensional deviation to the material and damage to the cutting tool [**4-6**]. The environmental effects of the conventional coolants possess serious threat and there is a need for alternative coolant [**7-10**]. The cryogenic MQL is considered in this work because of its ability to regulate the temperature produced at the tool and work piece interaction and provide necessary lubrication [**11-12**]. The machining parameters such as feed rate and environment certainly influence surface roughness. Hence there is a need to optimize the parameters by a suitable optimization technique.

Hwang and Yoon [**13, 14**] introduced TOPSIS by defining the positive and negative ideal solution. Two solution sets namely positive and negative ideal solution are formed using the possible best and worst solution respectively. The values of positive ideal solution (PIS) improve the benefit criteria whereas the values of negative ideal solution (NIS) minimize the benefit criteria. The ideal solution is said to be optimal, if it is very close to the positive ideal solution and far away from the negative ideal solution. The traditional TOPSIS approach used Euclidean distance measure (1) to determine the separation measure between PIS and NIS.

$$d(a,b) = \sqrt{\sum_{i=1}^{m}\sum_{j=1}^{n}\left|a_{ij} - b_{ij}\right|^2} \tag{1}$$

In this paper, the TOPSIS method is modified by using Gower distance [**15, 16**].

$$\boldsymbol{d(a,b) = \frac{1}{m}\sum_{i=1}^{m}\sum_{j=1}^{n}\left|a_{ij} - b_{ij}\right|} \tag{2}$$

Experimental setup

The MQL setup inject oil using pneumatic pump and reservoir. The flow is controlled by a filter regulator attached in airline. Vegetable oil is sprayed (pressure - 2 bar; flow rate - 60ml/min). Castor oil (viscosity - 0.535 pa.s) is used as a lubricant. The tool work interface and nozzle are maintained at a distance of 25mm and inclined at 45°. The cryogenic CO_2 will be sprayed in the cutting area (2mm dia nozzle / at 2.5 bar) as shown in **Fig. 1**. The factors and levels of machining parameters for the optimization are presented in **Table 1**.

Table 1. Factors and levels.

	Factors	Level 1	Level 2	Level 3
E	Environments	Dry Cooling	Wet Cooling	Cryogenic Cooling
S	Cutting Speed (M/min)	45	60	75
R	Feed Rate (mm/rev)	0.04	0.06	0.08

Fig. 1. Experimental setup.

The machining parameters are cooling techniques, feed rate and cutting speed. The response variables are surface roughness (Ra) (to be lowered) and temperature (T) (to be lowered) are shown in **Table 2**.

Table 2. Responses and Output.

		Responses				Output	
Exp	Env.	Cutting Speed (m/min)	Feed Rate (mm/rev)	R_a (µm)	T (°C)	TOPSIS Grade	Rank
1	Dry	45	0.04	1.7	251.4	0.2936	21
2	Dry	45	0.06	1.94	256	0.2178	24
3	Dry	45	0.08	2.37	267	0.0767	25
4	Dry	60	0.04	1.48	273.9	0.3125	20
5	Dry	60	0.06	1.71	278.5	0.2395	23
6	Dry	60	0.08	2.28	289.5	0.0593	26
7	Dry	75	0.04	1.31	291.9	0.3259	19
8	Dry	75	0.06	1.53	296.5	0.2557	22
9	Dry	75	0.08	2.2	307.5	0.0475	27
10	Wet	45	0.04	1.2	170.4	0.5869	12
11	Wet	45	0.06	1.44	175	0.5111	15
12	Wet	45	0.08	1.87	186	0.3700	16
13	Wet	60	0.04	0.98	192.9	0.6057	11
14	Wet	60	0.06	1.21	197.5	0.5327	14
15	Wet	60	0.08	1.78	208.5	0.3525	17
16	Wet	75	0.04	0.81	210.9	0.6192	10
17	Wet	75	0.06	1.03	215.5	0.5489	13
18	Wet	75	0.08	1.7	226.5	0.3408	21
19	CMQL	45	0.04	0.7	70.4	0.9161	3
20	CMQL	45	0.06	0.94	75	0.8403	6
21	CMQL	45	0.08	1.12	86	0.7691	9
22	CMQL	60	0.04	0.48	92.9	0.9350	1
23	CMQL	60	0.06	0.71	97.5	0.8620	5
24	CMQL	60	0.08	0.9	108.5	0.7880	7
25	CMQL	75	0.04	0.4	110.9	0.9233	2
26	CMQL	75	0.06	0.53	115.5	0.8782	4
27	CMQL	75	0.08	0.83	126.5	0.7735	8

Optimization steps using Modified Gower TOPSIS method

1. The decision matrix is constructed by evaluating the alternatives in terms of criteria.
2. Normalized decision matrix is calculated by

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \text{ i = 1 to m; j = 1 ton.} \quad (3)$$

3. Weighted normalized decision matrix are obtained by $v_{ij} = w_j n_{ij}$, i = 1 to m; j = 1 to n. where w_j indicates the weight of criterion 'j' and $\sum_{j=1}^{n} w_j = 1$.
4. The positive ideal solution (PIS) and negative ideal solution (NIS) are obtained using

$$A^+ = \{v_1^+, \ldots\ldots, v_n^+\} = \left\{\max_i v_{ij},\ j = 1, \ldots\ldots, n\right\},$$

$$A^- = \{v_1^-, \ldots\ldots, v_n^-\} = \left\{\min_i v_{ij},\ j = 1, \ldots\ldots, n\right\},$$

5. The separation measures are calculated using Gower distance measure.

Positive ideal solution:

$$d_i^+ = \frac{1}{m}\sum_{j=1}^{n}\sum_{i=1}^{m}\left|a_{ij} - {b_{1j}}^+\right| \quad (4)$$

Negative ideal solution:

$$d_i^- = \frac{1}{m}\sum_{j=1}^{n}\sum_{i=1}^{m}\left|a_{ij} - {b_{1j}}^-\right| \quad (5)$$

6. **Relative closeness:** $C_i = \frac{d_i^-}{d_i^+ + d_i^-}$, i = 1 to m. (6)
7. Rank preference are given according to the TOPSIS grade C_i.
8. The multi-response characteristic depends on TOPSIS grade and it is computed by

$$\overline{C_j} = \frac{1}{k}\sum_{i=1}^{k} C_{ij}, \quad (7)$$

where $\overline{C_j}$ represents TOPSIS grade for jth experiment and 'k' indicates the no of performance characteristics. The higher the TOPSIS grade, the parameter is closer to the ideal solution.

9. The significant factors are determined using (ANOVA) Analysis of variance.

Results and discussion

TOPSIS grade and ranking are obtained for all 27 experiments using (3) to (6) and presented in **Table 2**. The TOPSIS relational grade of every parameter at that level are computed by (7) and shown in **Table 3**. The alternative which has highest TOPSIS grade will be considered as the best alternative. The TOPSIS grade of Experiment No. 22 is high, hence the corresponding parameter setting (Environment - **CMQL**, Cutting Speed - **60 m/min**, Feed Rate - **0.04 mm/rev**) are optimal parameter values.

Table 3. Response Table of Average TOPSIS Grade.

Factors	Level 1	Level 2	Level 3	Max-Min	Rank
Environment	0.203	0.496	0.854	0.651	1
Cutting Speed	0.509	0.521	0.583	0.074	3
Feed Rate	0.613	0.543	0.397	0.216	2

The cryogenic MQL is found to be favorable cooling condition which is evident from the optimization results. The study confirms the effectiveness of cryogenic cooling by controlling the temperature and MQL provide necessary lubrication.

Table 4 shows the significance and contribution of the parameters which was determined using analysis of Variance (ANOVA). The variance ratio with respect to the effect of a factor and error respectively is called F value. F value indicates the significance of the given parameter. Table 4 exhibits the ANOVA values with the following observations: the environment is the most influential factor with 84.6% in the optimization of Nimonic 80A, followed by feed rate 10.1% and cutting speed 1.3%.

Table 4. ANOVA (Analysis of Variance).

Factors	SOS	dof	Mean Square	F Value	% Contribution
Environment	16.500	2	8.250	0.886	84.6
Cutting Speed	0.257	2	0.129	0.013	1.3
Feed Rate	1.969	2	0.985	0.101	10.1
Error	0.773	20	9.713	0.000	4.0

Total	19.499	26	0.000	0.000	100

@Significant at 95% confidence level

The proposed modified TOPSIS method grades and ranks the alternative using the distances created by the positive and negative ideal solution. The determination of separation distance measures between PIS and NIS using Gower distance is very simple and effective.

Summary

The modified TOPSIS method has been developed using Gower distance measure and adopted for the optimization of Nimonic 80A. The modified Gower TOPSIS is a very effective tool for multi response optimization problems which intends to choose simultaneously the alternatives. The values of positive ideal solution (PIS) improve the benefit criteria whereas the values of negative ideal solution (NIS) minimize the benefit criteria which have the shortest distance from the positive ideal solution and the farthest distance from the negative-ideal solution. The order of ranking of all the alternatives is determined using closeness coefficient. The experiment was conducted under 3 different cutting speed and feed rates. It is evident from the results that environment and feed rate are dominant factors. The environments influence is 84.6%, followed by feed rate 10.1% and cutting speed 1.3%. Cryogenic MQL has better effectiveness compared to conventional cooling. Optimal results suggest that the modified TOPSIS approach can be employed successfully in manufacturing engineering.

Keywords

Optimization, cryogenic, MQL, nimonic 80A, TOPSIS, MCDM.

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