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SERVICES FOR SCIENCE AND EDUCATION

Determining Best Dressing Factors in Surface Grinding Hardox 500 Using MABAC Technique

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ABSTRACT

This paper presents the results on the application of the multi-criteria decision-making (MCDM) method for selecting the optimal dressing mode for surface grinding of Hardox 500. The study addressed the MCDM problem through the application of the Multi-Attributive Border Approximation Area Comparison (MABAC) method, with criterion weights established via Method Based on the Removal Effects of Criteria (MEREC) method. Additionally, surface roughness (RS) and material removal rate (MRR) were selected as the two criteria for the current study. Also, five dressing variables were analyzed: non-feeding dressing n_n, fine dressing depth d_f, fine dressing times n_f, rough dressing depth d_r, and rough dressing times n_r. Moreover, 16 experimental runs (design's type L16 (4^4x2^1)) were designed and executed. The problem concerning MCDM has been addressed. The investigation's findings suggest that option No. 5, characterized by the input parameters d_r = 0.02 mm, n_r = 1, n_f = 1, d_f = 0.01 mm, and n_n = 2, represents the optimal dressing mode.

Keywords: Surface grinding, Hardox 500, MABAC method, MEREC method, Surface Roughness, Material removal rate.

INTRODUCTION

Until now, several studies have been undertaken to optimize the grinding process. M. S. Rodrigues et al. [1] conducted a study to improve alternative ways by examining the grinding of hardened AISI 4340 steel with four lubricooling fluids: Base fluid, Volatile Corrosion Inhibitor (VCI), VCI Low Cost (VCI LC), and VCI Extreme Pressure (VCI EP). The parameters obtained in the study comprise surface roughness, roundness error, wheel wear, grinding power, pollution, and cost. Corrosion inhibitors can enhance workpiece quality but yield varying results across different parameters. Hoang X.T. et al. [2] presented a study on the computation of the optimal exchanged grinding wheel diameter in the external grinding of 9CrSi tool steel. This study examined the impact of grinding process factors, including starting grinding wheel diameter, total dressing depth, radial grinding wheel wear per dress, and wheel life on the exchanged grinding wheel diameter. Additionally, the influence of cost components such as the machine tool hourly rate and the grinding wheel expense was examined. A model was presented to determine the optimal swapped grinding wheel diameter based on the data. Luu A. T. et al. [3]

performed a study to improve the dressing parameters of grinding wheels for 9CrSi tool steel, aiming to decrease average roughness and flatness tolerance by the Taguchi technique and Grey Relational Analysis (GRA). The results indicate that the optimal dressing parameters for achieving minimal average roughness and flatness tolerance are a coarse dressing depth of 0.025 mm, three coarse dressing cycles, a fine dressing depth of 0.005 mm, two fine dressing cycles, three non-feeding dressings, and a dressing feed rate of 1.6 m/min. Experiments with the optimized dressing parameters have been conducted to validate the predictive model. Tran T.H. et al. [4] performed a study to determine the ideal dressing conditions for grinding SKD11 tool steel utilizing a HaiDuong grinding wheel. This study examined the impacts of six input parameters: feed rate, depth of rough dressing cut, rough dressing duration, depth of finish dressing cut, finish dressing duration, and non-feeding dressing.

H. Liu et al. [5] investigated the impact of speed on the creation of machined surfaces during ultrahigh-speed grinding of IN718 superalloy at velocities reaching 240 m/s. This study meticulously analyzes the grinding forces and surface integrity across several speed ranges. Various methodologies are utilized to characterize and investigate the subsurface microstructure. The findings indicate that brittle-mode removal of IN718 superalloy transpires at a grinding speed surpassing 190 m/s, significantly reducing work hardening and heat production caused by increased plastic deformation. Moreover, the machining speed affects the formation mechanism of the recrystallization layer, progressively shifting from dominance of discontinuous dynamic recrystallization (dDRX) to that of continuous dynamic recrystallization (cDRX) as grinding speed increases. Le X.H. et al. [6] conducted a study to analyze the impact of coolant parameters on surface roughness during the internal cylindrical grinding of annealed 9CrSi steel. Thirteen tests utilizing central composite design and response surface methodology examine the concentration and flow rate of the coolant. The impact of each parameter and their interaction on surface roughness is examined by their regression model. Optimal parameters are derived from that model to achieve the least surface roughness. Tran T.H. et al. [7] performed a study to identify the optimal dressing parameters for achieving the minimal flatness tolerance in the grinding of SKD11 steel with a HaiDuong grinding wheel. This research examines the impact of six input parameters—feed rate (S), depth of rough dressing cut (a_r), rough dressing times (nr), depth of finish dressing cut (a_f), finish dressing times (n_f), and non-feeding dressing (n_{non}) — on flatness tolerance. Tran T.H. et al. [8] conducted a study to examine the influence of process factors on the surface roughness in surface grinding of 90CrSi tool steel. This study considered process characteristics such as coolant concentration, coolant flow, cross feed, table speed, and depth of cut. The impact of the process parameters on surface roughness was assessed. A predictive methodology for calculating surface roughness was proposed.

Le X.H. et al. [9] performed a study on the adjustment of dressing parameters in internal cylindrical grinding to achieve maximum material removal rate. This study examined the effects of dressing parameters, including dressing feed rate, coarse dressing depth, coarse dressing frequency, fine dressing depth, fine dressing frequency, and dressing count without depth of cut, on the material removal rate. Yueming Liu et al. [10] utilized kinematic simulations to predict the extent of surface roughness resulting from grinding. The research investigated three unique configurations of abrasive grains (sphere, truncated cone, and cone) with a model of single-point diamond dressing. The proposed surface roughness model was empirically validated, revealing a deviation of 7-11 percent. Tran T.H. et al. [11] conducted a study to determine the optimal exchanged grinding wheel diameter to minimize grinding costs in the surface grinding process for stainless steel. The relationship between grinding costs and the optimal swapped grinding wheel diameter has been investigated and expressed in mathematical formulas. The optimal exchanged grinding wheel diameter, which minimizes grinding costs, has been established as a function of various parameters, including initial grinding wheel diameter, total dressing depth, radial grinding wheel wear per dress, wheel life, machine tool hours, and grinding wheel cost. Le X.H. et al. [12] performed a study on the optimal computation of the exchanged diameter of grinding wheels in the internal grinding of stainless steel. This study examined the impact of grinding process parameters, including initial diameter, total depth of dressing cut, wheel life, radial grinding wheel wear per dress, and the ratio of length to diameter of workpieces on the exchanged grinding wheel diameter. The effects of cost parameters, including the machine tool hourly rate and the grinding wheel expense, were examined. A proposed model for determining the optimal swapped grinding wheel diameter was presented based on the study's findings.

L.M. Kozuro et al. [13] proposed a dressing strategy for external grinding able to attaining a surface roughness of Ra = 0.32-1.25 (μm). This technique involves a longitudinal feed rate of 0.4 m/min, four dressing passes with a dressing depth of 0.03 mm, and four non-feeding dressing operations. Tran T.H. et al. [14] performed an optimization analysis to ascertain the ideal swapped grinding wheel diameter for external grinding. This study explored seven input grinding parameters: initially grinding wheel diameter, grinding wheel width, wheel life, radial grinding wheel wear per dressing, total depth of dressing cut, machine tool hourly rate, and grinding wheel cost. The impact of grinding parameters on the optimal exchanged grinding wheel diameter for the external cylindrical grinding process was analyzed in connection with the screening trials. The impact of the interactions among the input grinding parameters was also assessed. The regression equation for calculating the optimal exchanged grinding wheel diameter was provided. Tran T.H. et al. [15] performed a study on the multi-criteria optimization of dressing parameters in surface grinding of 90CrSi tool steel. The aim of the study is to reduce surface roughness and normal shear force while enhancing the useful lifetime of the grinding wheel through the application of the Taguchi method and Grey Relational Analysis (GRA). The study's results enabled the suggestion of the ideal dressing parameters. The predicted model's validity has been corroborated by experimentation.

This paper provides the outcomes of an MCDM assessment aimed at selecting the best dressing mode for surface grinding of Hardox 500. The study employed the MCDM approach utilizing the MABAC method, with the weights of the criteria established through the MEREC method. After addressing the MCDM problem with two criteria (SR and MRR), the optimal dressing factors have been proposed.

METHODOLOGY

Method to Solve MCDM

This study addressed the MCDM problem via the MABAC methodology. The subsequent actions must be adhered to in order to utilize this strategy [16]:

Step 1: Create initial decision-making matrix:

$$\begin{bmatrix} r_{11} & \cdots & r_{1j} & \dots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_1 & \dots & r_{ij} & \dots & r_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mj} & \dots & r_{mn} \end{bmatrix}_{m\times n} \quad (1)$$

Where m and n are the number of options and criteria.

Step 2: Compute the normalized values r_{ij} by:

$$r_{ij}^* = \frac{r_{ij}-r_i^-}{r_i^+-r_i^-} \quad (2)$$

$$r_{ij}^* = \frac{r_{ij}-r_i^+}{r_i^+-r_i^-} \quad (3)$$

In which i=1,2, ...,m and j=1,2, ...,n. Equation (2) is used for criteria MRR, and (3) is used for creation SR. In addition, $r_i^+ = max\ (r, r, \dots, r)$ and $r_i^- = min\ (r, r, \dots, r)$.

Step 3: Determine the weighted matrix elements by:

$$v_{ij} = w_j + w_j \times r_{ij}^* \quad (4)$$

Step 4: Calculate the border approximation area matrix:

$$g_j = \left(\prod_{i=1}^{m} v_{ij}\right)^{1/m} \quad (5)$$

In which j=1,2, ...,n.

Step 5: Find the distance between the options and the border approximation area by:

$$q_{ij} = v_{ij} - g_i \quad (6)$$

With i=1,2, ...,m and j=1,2, ...,n.

Step 6: Determine the total distances of each option from the approximate border area:

$$S_i = \sum_{j=1}^{n} q_{ij}\, , i = 1,2, \dots , m \quad (7)$$

Step 7: Rank the options by maximizing S

Method to Find Criterion Weights

The criterion weights were computed using the MEREC technique. This approach is conducted using the following steps [17].

+) Build the first decision-making matrix:

$$X=\begin{matrix} x_{11} & \dots & x_{1n} \\ x_{21} & \dots & x_{2n} \\ \vdots & \dots & \vdots \\ x_{mn} & \dots & x_{mn} \end{matrix} \tag{8}$$

In which, m and n are the number of options and criteria.

+) Compute the value of the normalized matrix by:

- For MRR target:

$$h_{ij} = \frac{minx_{ij}}{x_{ij}} \tag{9}$$

- For SR objective:

$$h_{ij} = \frac{x_{ij}}{maxx_{ij}} \tag{10}$$

+) Determine the effectiveness of the options Si by:

$$S_i = ln\left[1 + \left(\frac{1}{n}\Sigma_j, \left|ln\left(h_{ij}\right)\right|\right)\right] \tag{11}$$

+) Determine the efficiency of the i^th option S'_{ij} by:

$$S'_{ij} = Ln\left[1 + \left(\frac{1}{n}\Sigma_k, k \neq j\left|ln\left(h_{ij}\right)\right|\right)\right] \tag{12}$$

+) Find the removal effect of the j^th criterion E_j:

$$E_j = \Sigma_i\left|S'_{ij} - S_i\right| \tag{13}$$

+) Compute the criteria's weight by:

$$w_j = \frac{E_j}{\Sigma_k \mathrm{E}_k} \tag{14}$$

EXPERIMENTAL SETUP

Table 1: Input dressing parameters

No.	Parameters	Symbol	Level			
			1	2	3	4
1	Rough dressing depth (mm)	d_r	0.015	0.02	0.025	0.03
2	Rough dressing times	n_r	1	2	3	4
3	Fine dressing depth (mm)	d_f	0.005	0.01	-	-
4	Fine dressing times	n_f	0	1	2	3

5	Non-feeding dressing	nn	0	1	2	3

Table 2: Experimental matrix and output results

No.	d_r	n_r	n_f	nn	d_f	SR (μm)	MRR (mm^3/s)
1	0.015	1	0	0	0.005	0.674	5.732
2	0.015	2	1	1	0.005	0.590	5.709
3	0.015	3	2	2	0.010	0.594	5.505
4	0.015	4	3	3	0.010	0.647	6.431
5	0.020	1	1	2	0.010	0.436	8.494
6	0.020	2	0	3	0.010	0.480	5.222
7	0.020	3	3	0	0.005	0.617	3.356
8	0.020	4	2	1	0.005	0.785	11.774
9	0.025	1	2	3	0.005	0.452	5.645
10	0.025	2	3	2	0.005	0.812	6.529
11	0.025	3	0	1	0.010	1.216	3.973
12	0.025	4	1	0	0.010	0.875	6.007
13	0.030	1	3	1	0.010	0.943	7.404
14	0.030	2	2	0	0.010	0.693	6.650
15	0.030	3	1	3	0.005	1.384	5.603
16	0.030	4	0	2	0.005	0.774	11.103

An experiment was conducted to find the best dressing element for surface grinding Hardox 500. Table 1 presents the levels of the input factors. The experiment was designed using an L16 (4^4x2^1) configuration with 16 experimental runs, applying the Minitab R19 software.

Figure 1 illustrates the experimental setup. The apparatus includes a surface grinding machine (PSG-CL3060AH, Taiwan), a grinding wheel (Cn60MV1G V1, 350x40x127 35 (m/s)), a dressing tool (3908-0088C type 2, Russia), and a piezoelectric dynamometer (Kistler 9257BA, Germany). The experiment was conducted as follows: Each experiment was performed three times. An SJ201 surface roughness meter was employed to measure SR. The lifespan of the wheel is determined by the duration required to commence grinding following dressing and the use of a standard Py spike. The wheel life and the measured total material volume were utilized to determine MRR.

Fig. 1: Experimental setup

FINDING BEST DRESSING PARAMETERS

Table 3: Calculated results and ranking of options

No.	gij			qij		S_i	Rank
	SR		MRR	SR	MRR		
1	0.9893		0.5424	0.0621	-0.0310	0.0311	10
2	0.9893		0.5424	0.1152	-0.0321	0.0831	6
3	0.9893		0.5424	0.1129	-0.0418	0.0711	8
4	0.9893		0.5424	0.0793	0.0021	0.0813	7
5	0.9893		0.5424	0.2131	0.0998	0.3129	1
6	0.9893		0.5424	0.1852	-0.0552	0.1299	5
7	0.9893		0.5424	0.0981	-0.1436	-0.0455	12
8	0.9893		0.5424	-0.0083	0.2552	0.2470	2
9	0.9893		0.5424	0.2029	-0.0352	0.1677	4
10	0.9893		0.5424	-0.0256	0.0067	-0.0189	11
11	0.9893		0.5424	-0.2816	-0.1144	-0.3960	15
12	0.9893		0.5424	-0.0651	-0.0180	-0.0831	14
13	0.9893		0.5424	-0.1085	0.0482	-0.0603	13
14	0.9893		0.5424	0.0499	0.0125	0.0623	9
15	0.9893		0.5424	-0.3881	-0.0371	-0.4253	16
16	0.9893		0.5424	-0.0011	0.2234	0.2224	3

To address the MCDM problem for identifying the optimal dressing setting, the creation weights are initially established using the MEREC technique (refer to Section 2.2) as outlined below: The values hj were standardized according to equations (9) and (10). The values S_i and S'_{ij} were derived from equations (11) and (12). Equation (13) was employed to determine the impact of the criterion's removal. The criterion weights were determined using Equation (14), which delineates them. Weights of 0.5190 and 0.4810 were calculated for SR and MRR, respectively. Section 2.1 outlines the process of utilizing the MABAC method. The initial matrix is generated as per Equation (1). Equations (2) for the MRR target and (3) for the SR objective are employed to calculate the normalized values of r_{ij}*. The normalized weighted values v_{ij} are calculated using formula (4). Equation (5) is utilized to calculate the border approximation area matrix. The distance between the alternatives and the border approximation area q_{ij} is calculated using formula (6). The total distances between each option and the approximate border area S_i are calculated using formula (7). To establish the ranking of options, S is optimized. Table 4 displays the calculated parameters and the ranking of options obtained through the MABAC method.

Table 3 indicates that option 5 is the most favorable choice. This is ascribed to its maximum value for S_i (S_i = 0.3129). The subsequent values represent the optimal choice: d_r = 0.02 (mm), n_r = 1 (times), n_f = 1 (times), d_f = 0.01 (mm), and n_n = 2.

CONCLUSION

This study employed the MABAC approach to optimize various dressing modes for surface grinding of Hardox 500 steel. The study's findings suggest the utilization of option 5 to achieve the lowest SR and the highest MRR concurrently. Among the 16 test runs, Solution No. 5 demonstrated the highest performance characteristic, achieving a maximum utility function value of S_i = 0.3129. The optimal dressing parameters for surface grinding, as established by MABAC technology, are d_r = 0.02 (mm), n_r = 1 (times), n_f = 1 (times), d_f = 0.01 (mm), and n_n = 2.

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