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Using MOORA Method for Finding Best Dressing Parameters for Surface Grinding Hardox 500

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ABSTRACT

This study reports the findings on the use of the multi-criteria decision-making (MCDM) method to determine the optimal dressing mode for surface grinding of Hardox 500. The research examined the MCDM issue utilizing the Multi-Objective Optimization based on Ratio Analysis (MOORA) method, with criterion weights determined through the Entropy method. Furthermore, surface roughness (RS) and material removal rate (MRR) were identified as the two criteria for this study. Additionally, five dressing variables were investigated: non-feeding dressing nn, fine dressing depth df, fine dressing times nf, rough dressing depth dr, and rough dressing times nr. Additionally, 16 experimental runs were designed and conducted using the L16 (4^4 x 2^1) design type. The issue related to MCDM has been assessed. The investigation's findings indicate that option No. 5, defined by the input parameters d_r = 0.02 (mm), n_r = 1, nf = 1, d_f = 0.01 (mm), and n_n = 2, represents the optimal dressing mode.

Keywords: Surface grinding, Hardox 500, MOORA method, ENTROPY method, Surface Roughness, Material Removal Rate.

INTRODUCTION

So far, different studies have been performed to explore the grinding process. E. Irazu et al. [1] carried an examination into the impact of grinding wheel wear on cutting forces, analyzing grinding wheel topography to find a measure that quantifies grinding wheel wear non-destructively. It was reported that, following a brief conditioning phase, cutting forces rise in an essentially linear manner with the machined length. During this second phase, the force ratio tends toward a constant value, and the primary wear process is the formation of flat surfaces on the diamond grains. In these circumstances, the 3D surface roughness metrics Sa, Sq, Spk, and Sku have demonstrated efficacy in monitoring wheel wear. Le X.H. et al. [2] 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 impact of cost considerations, including the hourly rate of machine tools and the expense of grinding wheels, was also examined. A proposed model for determining the optimal swapped grinding wheel diameter was presented based on the study's findings. Tran T.H. et al. [3] 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. L.M. Kozuro et al. [4] suggested a dressing process for external grinding that can obtaining a surface roughness of Ra=0.32-1.25 (μm). This technique includes 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 runs. Hoang X.T. et al. [5] 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 factors such as the machine tool hourly rate and the grinding wheel expense was examined. A model has been given to figure out the optimal replaced grinding wheel diameter based on the data. Le X.H. et al. [6] accomplished a study on the optimization of dressing parameters in internal cylindrical grinding to achieve the 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. 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 (ar), rough dressing frequency (nr), depth of finish dressing cut (af), finish dressing frequency (nf), and non-feeding dressing (nnon)—on flatness tolerance. Nguyen H.Q. et al. [8] carried out a study addressing the MCDM problem in the dressing process for internal grinding. This study employed four Multiple Criteria Decision Making (MCDM) methodologies: TOPSIS, MARCOS, EAMR, and MAIRCA, to tackle the MCDM issue and fulfill the dual aims of lowering SR and maximizing MRR. The ideal solution for the multi-criteria issue in the internal grinding dressing process has been presented based on the data obtained. S. Zhang et al. [9] proposed a novel approach for preparing diamond grinding wheels utilizing abrasive waterjet (AWJ) technology to mitigate workpiece damage and wheel clogging associated with grinding challenging materials using traditional diamond grinding wheels. The primary process parameters were established according to the theoretical model for treating diamond grinding wheels utilizing AWJ. Response surface methodology (RSM) and backpropagation artificial neural networks (BP-ANN) were utilized to develop regression models correlating process factors with microgroove features. A comparative analysis was conducted to assess the predictive efficacy of both RSM and BP-ANN. The findings demonstrated that both BP-ANN and RSM are effective methodologies for forecasting microgroove attributes. Tran T.H. et al. [10] performed a study to determine the optimal exchanged grinding wheel diameter to reduce 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, necessary for minimizing grinding costs, has been established as a function of various parameters, including the initial grinding wheel diameter, total dressing depth, radial grinding wheel wear per dress, wheel life, machine tool hours, and grinding wheel cost. Nguyen T.T. et al. [11] evaluated the impact of dressing regime factors on roundness tolerance in the external grinding of SKD11 steel. This study assessed the impact of rough dressing depth, dressing feed rate, fine dressing depth, rough dressing frequency, fine dressing frequency, and non-feeding dressing frequency on roundness tolerance. The recommended optimum dressing parameters are as follows: fine dressing times (nf) of 3, non-feeding dressing times (no) of 3, fine dressing depth (af) of 0.01 mm, rough dressing times (nr) of 3, rough dressing depth (ar) of 0.03 mm, and dressing feed rate (Sd) of 1.0 m/min. Tran T.H. et al. [12] performed an optimization analysis to ascertain the ideal swapped grinding wheel diameter for external grinding. This study examined seven input grinding parameters: starting 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 conjunction with the screening trials. The impact of the interactions among the input grinding parameters was also assessed. The regression equation for determining the optimal swapped grinding wheel diameter was presented. Tran T.H. et al. [13] undertook a study to find the ideal dressing conditions for grinding SKD11 tool steel using 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. Tran N.G. et al. [14] reported the findings of a multi-objective optimization study on internal cylindrical grinding of SKD11 steel aimed at minimizing surface roughness. This study examined six dressing parameters: coarse dressing depth, number of coarse dressings, fine dressing depth, number of fine dressings, non-feeding dressing, and dressing feed speed. The findings indicate that the ideal surface roughness is 0.111 µm, achieved with optimal dressing parameters: fine dressing depth at level 2, number of fine dressings at level 3, number of non-feeding dressings at level 4, number of coarse dressings at level 3, coarse dressing depth at level 2, and dressing feed rate at level 1. Hoang X.T. et al. [15] proposed an optimization for external grinding of 9XC steel to achieve lowest surface roughness.

This study examined three dressing modes: coarse dressing, fine dressing, and non-feeding dressing. The subsequent optimal dressing parameters were recommended: The coarse dressing depth is 0.07 mm, the fine dressing depth is 0.02 mm, and the number of non-feeding dressing cycles is 3. Le X.H. et al. [16] executed an investigation to optimize dressing parameters to achieve minimal surface roughness in internal grinding of SKD11 steel via the Taguchi method. The utilized input parameters include coarse dressing depth, quantity of coarse dressings, fine dressing depth, quantity of fine dressings, non-feeding dressing, and dressing feed velocity. The quantity of coarse dressing exerts the most significant influence on Ra (88.28%). The difference between the experimental roughness average and the predicted value is negligible. Hoang A.L. et al. [17] handled a study to determine the most effective dressing method for the external grinding of SKD11 tool steel. They applied the MABAC (multi-attributive border approximation area comparison) technique for this objective. The aim of the research is to determine the ideal dressing technique that concurrently attains the minimal surface roughness (RS), maximal wheel longevity (T), and superior roundness (R). An experiment was performed to accomplish this job, employing six input parameters: the depth of fine dressing, the number of fine dressing passes, the depth of coarse dressing, the number of coarse dressing passes, the non-feeding dressing, and the rate of dressing feed. An ideal dressing method for external cylindrical grinding has been proposed based on the results obtained.

This study presents the results of a MCDM assessment focused on identifying the optimal dressing method for surface grinding of Hardox 500. The research utilized the MCDM approach, specifically the MOORA method, with criteria weights determined by the ENTROPY method. Following the resolution of the MCDM problem utilizing two criteria (SR and MRR), the optimal dressing factors have been suggested.

METHODOLOGY

Method for solving MCDM

This research examined the MCDM issue using the MOORA methodology. To implement this strategy, the following actions must be followed [18]:

Step 1: Build the initial decision-making matrix:

$$X = \begin{bmatrix} r_{11} & \cdots & r_{1j} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{1} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mj} & \cdots & r_{mn} \end{bmatrix} \quad (1)$$

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

Step 2: Compute the normalized matrix by:

$$n_{\mathrm{ij}} = \frac{r_{ij}}{max r_{ij}} \quad (2)$$

$$n_{\mathrm{ij}} = \frac{min r_{ij}}{r_{ij}} \quad (3)$$

Equation (2) is applied for SR target and (3) for MRR.

Step 3: Find $\left[X_{ij}\right]_{m\times n}$:

$$X_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{m} y_{ij}^2}} \quad (4)$$

Step 4: Determine the decision-making matrices after normalizing the weights by:

$$W_{ij} = w_j \times y_{ij} \quad (5)$$

Step 5: Calculate Pi and Ri by:

$$P_i = \frac{1}{|B|}\sum_{j\in B} W_{ij} \quad (6)$$

$$R_i = \frac{1}{|NB|}\sum_{j\in NB} W_{ij} \quad (7)$$

Where B and NB are the criteria number as large as better and the criterion number as small as better, correspondingly.

Step 6: Compute Qi by:

$$Q_i = P_i - R_i \quad (8)$$

Step 7: Rank the alternatives by maximizing Qi.

Method for Determining Criterion Weights

The criterion weights were computed using the Entropy technique. This approach is conducted using the following steps [19].

Step 1: Finding indicator normalized values:

$$p_{\mathrm{ij}} = \frac{x_{\mathrm{ij}}}{m+\sum_{i=1}^{m} x_{\mathrm{ij}}^2} \quad (9)$$

Step 2: Computing the Entropy for each indicator:

$$me_j = -\sum_{i=1}^{m}\left[p_{ij} \times ln(p_{ij})\right] - \left(1-\sum_{i=1}^{m} p_{ij}\right) \times ln\left(1-\sum_{i=1}^{m} p_{ij}\right) \quad (10)$$

Step 3: Calculating the weight of each indicator:

$$w_j = \frac{1-me_j}{\sum_{j=1}^{m}(1-me_j)} \quad (11)$$

EXPERIMENTS AND ANALYSIS

This study involved an experiment to identify the optimal dressing element for surface grinding Hardox 500. Table 1 displays the levels of the input factors. The experiment utilized an L16 (44x21) configuration comprising 16 experimental runs, implemented through Minitab R19 software. Figure 1 depicts the experimental setup. The apparatus consists 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 carried out in the following manner: Each experiment was conducted in triplicate. An SJ201 surface roughness meter was utilized to assess SR. The wheel life is influenced by the time needed to initiate grinding after dressing and the application of a standard Py spike. The wheel life and the measured total material volume were used to calculate the MRR. Table 2 shows the plan of the experiment and the output findings.

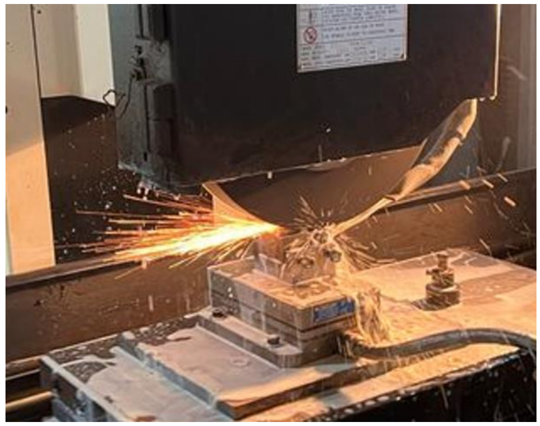

Fig. 1: Setup of experiment

Table 1: Input dressing factors

No.	Factors	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	n_n	0	1	2	3

Table 2: Experimental plan and output findings

No.	d_r	n_r	nf	n_n	d_f	SR (μm)	MRR (mm³/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

FINDING BEST DRESSING PARAMETERS

To solve the MCDM problem for determining the optimal dressing setting, the creation weights are first established using the Entropy technique, as detailed in Section 2.2 below:

First, compute the normalized values pij using Equation (8). Determine the Entropy value for each indication mej using Equation (9). Find the weight of the criteria wij using Equation (10). The weights of Ra and MRR were determined to be 0.6012 and 0.3988, respectively. The MOORA technique for MCDM is detailed in Section 2.1. Employ Equations (2) or (3) for obtaining the normalized matrix. The normalized decision-making matrix is subsequently estimated using Equation (4). Subsequently, calculate the decision-making matrices utilizing equation (5). Subsequently, calculate Pi and Ri using Equations (6) and (7). The computation of Qi is performed using formula (8). Finally, rank the options by maximizing Qi. Table 3 presents the computed parameters and the ranking of options derived from the MOORA method. Table 3 demonstrates that option 5 is the most advantageous selection. This is attributed to its peak value for Si (Si=0.0394). The following values indicate the optimal selection: dr = 0.02 (mm), nr = 1 (times), nf = 1 (times), df = 0.01 (mm), and nn = 2.

Table 3: Calculated results and ranking of options

No.	Wij		Ri	Pi	Qi	Rank
	SR	MRR				
1	0.1282	0.0826	0.1282	0.0826	-0.0457	10
2	0.1123	0.0822	0.1123	0.0822	-0.0301	6
3	0.1130	0.0793	0.1130	0.0793	-0.0337	8
4	0.1231	0.0926	0.1231	0.0926	-0.0305	7
5	0.0830	0.1224	0.0830	0.1224	0.0394	1
6	0.0913	0.0752	0.0913	0.0752	-0.0161	5
7	0.1175	0.0483	0.1175	0.0483	-0.0691	12
8	0.1494	0.1696	0.1494	0.1696	0.0202	2
9	0.0860	0.0813	0.0860	0.0813	-0.0047	4
10	0.1546	0.0941	0.1546	0.0941	-0.0605	11
11	0.2314	0.0572	0.2314	0.0572	-0.1741	15
12	0.1664	0.0865	0.1664	0.0865	-0.0799	14
13	0.1794	0.1067	0.1794	0.1067	-0.0728	13
14	0.1319	0.0958	0.1319	0.0958	-0.0361	9
15	0.2633	0.0807	0.2633	0.0807	-0.1826	16
16	0.1472	0.1599	0.1472	0.1599	0.0127	3

CONCLUSION

The present study utilized the MOORA method to optimize different dressing modes for the surface grinding of Hardox 500 steel. The findings indicate that employing option 5 results in the lowest SR and the highest MRR simultaneously. In the 16 test runs, Solution No. 5 exhibited the highest performance, attaining a maximum utility function value of Si=0.3129. The optimal dressing parameters for surface grinding, determined through MOORA 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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