Determining best dressing parameters for internal grinding SKD11 steel using EAMR technique

Truong Thi Thu Huong[1], Vu Duong[2], Le Thi Phuong Thao[1], Le Xuan Hung[1*]

[1]Thai Nguyen University of Technology, 666 3/2 Road, Thai Nguyen City, Thai Nguyen, Vietnam;
[2]Duy Tan University, 254 Nguyen Van Linh, Thanh Khe, Da Nang, Vietnam.
[*]Corresponding author: lexuanhung@tnut.edu.vn

Received 17 Aug. 2024; Revised 10 Nov. 2024; Accepted 15 Nov. 2024; Published 6 Dec. 2024.
DOI: https://doi.org/10.54939/1859-1043.j.mst.FEE.2024.171-176

ABSTRACT

The article conducts a research study on the use of Multi-Criteria Decision-Making (MCDM) in the internal grinding process of SKD11 tool steel. The aim is to identify the optimal input process parameters for the dressing process in order to minimize surface roughness (SR) and maximize wheel life (Lw). The EAMR strategy was employed to address the MCDM task, whereas the Entropy method was utilized to determine the weights of the criterion. The experiment also included the analysis of six input process parameters: coarse dressing depth, coarse dressing passes, fine dressing depth, fine dressing passes, non-feeding dressing, and dressing feed rate. The experiment was performed using an L16 orthogonal array and the Taguchi method. The wheel's durability and the roughness of the sample's surface were quantified and recorded for analysis in the MCDM problem. The research findings have identified the optimal dressing solutions for internal cylindrical grinding.).

Keywords: Internal grinding; EAMR method; Entropy method; Surface roughness; Wheel life; SKD11 tool steel.

1. INTRODUCTION

Grinding is a form of machining that employs an abrasive wheel as a tool for cutting. It is extensively employed in the process of finishing and semi-finishing grinding due to its ability to achieve high precision and minimal surface roughness. Consequently, scientists are interested in conducting studies on the grinding process.

Thus far, numerous studies have been conducted to investigate the grinding process. In their study, Yueming Liu et al. [1] employed kinematic simulations to forecast the level of surface roughness that would occur during grinding. The study examined three distinct shapes of abrasive grains (sphere, truncated cone, and cone) and a model of single-point diamond dressing. Furthermore, the suggested surface roughness model was empirically verified, demonstrating a discrepancy of 7 - 11 percent. Tran T.H. et al. [2] conducted a study on the multi-criteria optimization of dressing parameters in surface grinding for 90CrSi tool steel. Furthermore, the validity of the projected model has been confirmed through experimentation. In their study, Le-H.A. et al. [3] conducted research to identify the optimal dressing mode for external grinding of SKD11 tool steel. The objective of the research is to identify the optimal dressing method that simultaneously achieves the lowest surface roughness (RS), the longest wheel life (T), and the highest roundness (R).

In their study, L.M. Kozuro et al. [4] proposed a dressing method for external grinding that may achieve a surface roughness of Ra = 0.32 - 1.25 (μm). This method involves a longitudinal feed rate of 0.4 (m/min), four passes of dressing with a dressing depth of 0.03 (mm), and four runs of non-feeding dressing. The study conducted by Nguyen H.Q. et al. [5] focuses on the MCDM problem in the dressing process for internal grinding. A study was done in which an experiment was carried out using six input parameters. The optimal solution for the multi-criteria problem in the dressing process of internal grinding has been given based on the obtained results. Tran T.H. et al. [6] conducted a study to investigate the impact of dressing factors on the flatness tolerance during the grinding of SKD11 steel using a HaiDuong grinding wheel. This research investigates the impact of six input parameters on the flatness tolerance. These parameters include feed rate (S), depth of rough dressing cut (ar), rough dressing times (nr), depth of finish dressing cut (af), finish dressing times (nf), and non-feeding dressing (non). Based on the analyzed experimental data, it was observed that the proposed model yielded an average flatness tolerance of 4.05 µm. Furthermore, the deviation of this value from the projected value was found to be 11.38%.

Luu A.T. et al. [7] performed a study to enhance the dressing characteristics of a grinding wheel for 9CrSi tool steel. The study's results suggest the ideal treatment settings for achieving the lowest roughness average and flatness tolerance. The study conducted by Le X.H. et al. [8] aimed to optimize the dressing parameters in the internal cylindrical grinding process for 9CrSi tool steel. The objective of the study is to reduce surface roughness and optimize material removal rate (MRR). Multiple investigations have been carried out to ascertain the most effective dressing method. Furthermore, numerous investigations have been carried out to optimize the grinding process in order to achieve the lowest possible surface roughness [9], the highest material removal rate [10], or the longest wheel lifetime [2].

The primary objective of this study is to utilize the MCDM technique in order to identify the best dressing parameters for the internal grinding process of SKD11 steel. The study investigated two variables: the durability of the wheel and the degree of surface roughness. Furthermore, the MCDM problem was addressed utilizing the EAMR methodology, and the criteria weights were established employing the entropy approach. The EAMR method has successfully been used to identify the best dressing parameters for internal cylindrical grinding.

2. METHODOLOGY

2.1. Method to solve MCDM problem

This study utilized the EAMR technique to address the issue of Multiple Criteria Decision Making (MCDM). The following steps are essential for executing this approach [11]:

- Step 1: Create the decision-making matrix:

$$X_d = \begin{bmatrix} x_{11}^d & \cdots & x_{1n}^d \\ x_{21}^d & \cdots & x_{21}^d \\ \vdots & \cdots & \vdots \\ x_{m1}^d & \cdots & x_{mn}^d \end{bmatrix} \tag{1}$$

In which, 1 ≤d ≤ k; k denotes the decision maker’s number; d is the decision maker's indication.

- Step 2: Calculate the mean value of each option by:

$$\bar{x}_{ij} = \frac{1}{k}\left(x_{ij}^1 + x_{ij}^2 + \cdots + x_{ij}^k\right) \tag{2}$$

- Step 3: Find the creation weights;

- Step 4: Determine each criterion's weighted average by:

$$\bar{w}_j = \frac{1}{k}\left(w_j^1 + w_j^2 + \cdots + w_j^k\right) \tag{3}$$

- Step 5: Compute n_{ij} by:

$$n_{ij} = \frac{\bar{x}_{ij}}{e_j} \tag{4}$$

Where, e_j is determined by:

$$e_j = max_{i\in\{1,\ldots,m\}}\left(\bar{x}_{ij}\right) n_{ij} = \frac{\bar{x}_{ij}}{e_j} \tag{5}$$

- Step 6: Calculate the normalized weight by:

$$v_{ij} = n_{ij} \cdot \overline{w}_j \tag{6}$$

- Step 7: Find the criteria's normalized score.

+) For MRR target:

$$G_i^{+} = v_{i1}^{+} + v_{i2}^{+} + \cdots + v_{im}^{+} \tag{7}$$

+) For EWR target:

$$G_i^{-} = v_{i1}^{-} + v_{i2}^{-} + \cdots + v_{im}^{-+} \tag{8}$$

- Step 8: Calculate the ranking's (RV) values from Gi+ and Gi-.
- Step 9: Determine the options' evaluation score by:

$$S_i = \frac{G_i^{+}}{G_i^{-}} \tag{9}$$

- Rank the order of alternatives by maximizing Si.

2.2. Method for determining criteria weights

The inquiry adopted the ENTROPY methodology to determine the weights of the criteria. The procedure for implementing this strategy is thoroughly explained in reference [12].

+) Build the first matrix using the same method used at the start of the EAMR method.

+) Determine the normalized values of the elements in the matrix as follows:

- For Lw objective:

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

- For SR objective:

$$h_{ij} = \frac{x_{ij}}{maxx_{ij}} \tag{11}$$

+) Calculate the effectiveness of the options Si by:

$$S_i = ln\left[1 + \left(\frac{1}{n}\sum_{j}\left|ln\left(h_{ij}\right)\right|\right)\right] \tag{12}$$

+) Find the efficiency of the ith option S'_{ij} by:

$$S'_{ij} = Ln\left[1 + \left(\frac{1}{n}\sum_{k,k\neq j}\left|ln\left(h_{ij}\right)\right|\right)\right] \tag{13}$$

+) Determine the removal effect of the jth criterion E_j:

$$E_j = \sum_{i}\left|S'_{ij} - S_i\right| \tag{14}$$

+) Compute the criteria's weight by:

$$w_j = \frac{E_j}{\sum_k E_k} \tag{15}$$

3. EXPERIMENTAL SETUP

In order to fulfill this paper, an experiment was conducted. The experimental setup for internal grinding is displayed in figure 1 and comprises the following equipment: The grinding machine used is the Minakuchi MGU-65-26T, which was produced in Japan. The grinding wheel (ϕ23xϕ25x8 (mm)) is a model 19A 120L 8 ASI T S 1A (Japan). The diamond dresser used is the DKB3E002110. The surface roughness tester used is the Mitutoyo.

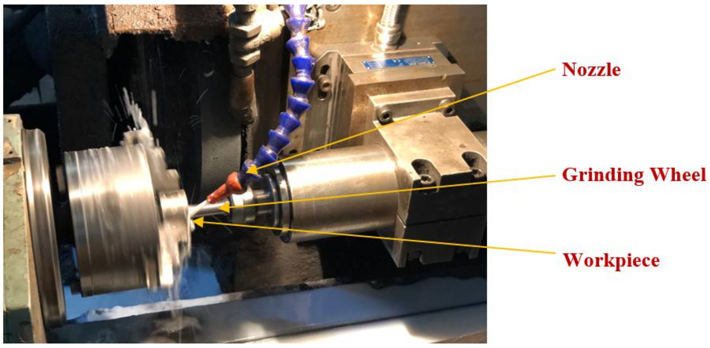

Figure 1. *Experimental setup.*

Table 1. *Input dressing parameters.*

No.	**Input factors**	**levels**			
		1	**2**	**3**	**4**
1	Coarse dressing depth a_r (mm)	0.025	0.03	-	-
2	Coarse dressing passes n_r (times)	1	2	3	4
3	Fine dressing depth a_f (mm)	0.005	0.01	0.015	0.02
4	Fine dressing passes n_f (times)	0	1	2	3
5	Non-feeding dressing n_0 (times)	0	1	2	3
6	Dressing feed rate S_d (m/min)	1	1.2	-	-

The experiment was executed using the following procedures: The dressing approach was performed following the experimental protocols specified in table 2. The test specimens required grinding using the grinding wheel after the process of dressing. The grinding wheel and the workpiece rotated at speeds of 12000 rpm and 150 rpm, respectively. The radial wheel speed was 0.0025 (mm/stroke), and the axial feed speed was 1 (m/min.). Following each test run, the surface roughness and grinding time of each sample are assessed. This process continues until the SR exceeds the designated threshold, which is 0.4 (µm) in this specific instance. Currently, Lw reflects the total length of grinding for all samples. The results, specifically the SR and Lw values, are displayed in table 2.

Table 2. *Experimental plan and output results.*

No.	a_r	n_r	a_f	n_f	n_0	S_d	Ra (mm)	Lw (min.)
1	0.025	1	0.01	0	0	1	0.365	11.267
2	0.03	1	0.01	1	1	1	0.214	12.733
3	0.025	1	0.02	2	2	1.2	0.195	12.697
…	…	…	…	…	…	…	…	…
16	0.03	4	0.02	0	2	1	0.363	12.230

4. DETERMINING BEST INPUT DRESSING PARAMETERS

Once the experiment is completed, the SR and L_w values of the outcome will be transmitted to EAMR as input variables for the execution of the MOOP. To solve the MCDM problem, the criteria weights were determined using the Entropy technique described in section 2.2, following the approach stated below: The values p_{ij} are normalized using equation (10). The Entropy value for each indicator mej was calculated using equation (11). Determine the weight of the criteria, wj, by applying equation (12). The weights allocated to SR and Lw were calculated as 0.5684 and 0.4316, respectively. Section 2.1 provides guidance on the optimal utilization of the EAMR technique for tackling the MCDM challenge. The initial matrix is formed using Formula (1). Calculate the average value of the options for each criterion using equation (2). Equation (3) can be used to calculate the average weighted values. Determine the value of n_{ij} using Equation (4), taking into account that ej is determined by equation (5). Next, apply formula (6) to compute the value of vij. Utilize equation (7) to compute the normalized score of the criterion for the Lw target, and subsequently employ equation (8) to derive the values of Gi for the SR target. Finally, determine the Si value by applying formula (9). Table 3 presents the results of the option ranking and parameter computation carried out utilizing the EAMR approach.

***Table 3.** Calculated results and rankings of options.*

Trial.	n_{ij}		v_{ij}		Gi		Si	Rank
	SR	Lw	SR	Lw	SR	Lw		
1	1.0000	0.8566	0.5684	0.3697	0.5684	0.37	0.6504	16
2	0.5850	0.9681	0.3325	0.4178	0.3325	0.418	1.2565	3
3	0.5333	0.9653	0.3031	0.4166	0.3031	0.417	1.3744	1
…	…	…	…	…	…	…	…	…
16	0.9951	0.9298	0.5656	0.4013	0.5656	0.401	0.7095	15

According to the statistics presented in table 3, it can be concluded that option 3 is the best choice. The reason for this is that the proximity coefficient has the greatest value of Si (Si = 1.4308). According to table 2, the most favorable option has the following parameters: af = 0.015 (mm); nf = 2 (times); n0 = 2 (times); Sd = 1.2 (m/min.).

5. CONCLUSIONS

This article presents the results of a study that was intended to find out the most effective dressing parameter for the internal grinding of SKD11 tool steel. To achieve this purpose, the paper stationed the EAMR strategy to address the MCDM problem and utilized the Entropy technique to calculate the criterion weights. The experiment adopted the L16 orthogonal array (4^4x2^2) and applied the Taguchi method to achieve this. The study's findings indicate that to reduce surface roughness and enhance the longevity of the wheel in the internal grinding process, the following input parameters should be configured: a_r = 0.025 (mm); n_r = 1 (times); a_f = 0.015 (mm); n_f = 2 (times); n_0 = 2 (times); S_d = 1.2 (m/min.).

Acknowledgment: *This work was supported by Thai Nguyen University of Technology.*

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TÓM TẮT

Ứng dụng kỹ thuật EAMR để xác định bộ thông số sửa đá mài tối ưu khi mài bề mặt trụ trong thép SKD11

Bài báo tiến hành nghiên cứu về việc áp dụng kỹ thuật ra quyết định đa tiêu chí (MCDM) trong quá trình gia công mài mặt trụ trong thép công cụ SKD11. Mục đích là xác định các thông số quá trình đầu vào tối ưu cho quá trình mài để giảm độ nhám bề mặt (SR) và tăng tối đa tuổi bền đá mài (Lw). Phương pháp EAMR được sử dụng để giải quyết nhiệm vụ MCDM, trong khi phương pháp Entropy được sử dụng để xác định trọng số của tiêu chí. Thực nghiệm gồm phân tích 06 thông số đầu vào của quá trình mài: chiều sâu sửa đá thô, số lượt sửa đá thô, chiều sâu sửa đá tinh, số lần sửa đá tinh, số lần sửa đá siêu tinh và lượng chạy doa khi sửa đá. Thí nghiệm được thực hiện bằng cách sử dụng ma trận L16 và phương pháp Taguchi. Tuổi bền bền của đá mài và độ nhám của bề mặt chi tiết gia công được xác định và phân tích trong bài toán MCDM. Các kết quả của nghiên cứu đã xác định bộ thông số sửa đá mài tối ưu cho quá trình mài trụ trong.

Từ khóa: Mài lỗ; Mài bề mặt trụ trong; Phương pháp EAMR; Phương pháp Entropy; Nhám bề mặt; Tuổi bền; Thép SKD11.