

Multi-criteria decision making in CBN grinding tool steel using TOPSIS method

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ABSTRACT

This paper introduces the results of a multi-criteria decision making (MCDM) study when CBN grinding SKD11 tool steel in a CNC milling machine. In this work, the TOPSIS method was applied to solve the MCDM problem, and the Entropy method was used to find the weight of criteria. Also, two criteria were chosen: surface roughness (SR) and material removal speed (MRS). Furthermore, an experiment with design L18 (61+33) was carried out using the Taguchi method. In the experiment, four input parameters were investigated: the dressing cut depth a_{ed} (mm), the wheel speed Rpm (rpm), the feed rate F_e (mm/min), and the wheel diameter d (mm). From the results of this work, the best experimental setup was proposed.

Keywords: CBN grinding; MCDM; TOPSIS method; Surface roughness; Material removal speed; SKD11.

1. INTRODUCTION

Choosing the best or most reasonable solution among many given options is a very common and complex problem in mechanical machining processes. This problem is especially important when the criteria set out are in disagreement. The requirement to increase the material removal rate (MMR) necessitates increasing the feed rate and the depth of cut. Surface roughness (SR) will increase as a consequence. In such words, the SR and MMR requirements or criteria are contradictory. The multi-criteria decision making (MCDM) problem is frequently used to solve the above problem.

To date, a number of studies have been conducted on the use of MCDM methods to determine the best solution in mechanical processing in general and the grinding process in specific. In [1], the MARCOS method was applied to solve the MCDM problem to find the best input parameters in the surface grinding of 90CrSi steel using a CBN wheel. The authors in [2] used the fuzzy TOPSIS method to conduct a study on grinding wheel abrasive material selection. The results of an MCDM problem in the dressing process for internal grinding were reported in [3]. In this work, the TOPSIS, MARCOS, EAMR, and MAIRCA were selected for solving the MCDM problem to get the minimum SR and maximum MRR while simultaneously time. The authors in [4] introduced the findings of a study on the best dressing factors in CNC cylindrical grinding En-31 steel using the TOPSIS method. The WASPAS and PIV methods were presented in [4] to solve the MCDM problem in the external cylindrical grinding of 65G steel. A recent study on multi-criteria decision making (MCDM) for the dressing process in internal grinding was published in [3]. For surface grinding SKD11 tool steel, the MOORA and COPRAS techniques were used to solve the MCDM problem [5].

This paper presents the findings of an MCDM study in CBN grinding on CNC milling machines. SR and MRS were chosen as study criteria. The MCDM method was TOPSIS, and the creation weights were determined using the Entropy method. The TOPSIS method was used in this study as it can be used for both quantitative and qualitative studies of the problem. Also, this method gives the best and quick decision to our real-life problems than AHP (Analytical Hierarchy Process) and FAHP (Fuzzy Analytic Hierarchy Process) methods. Furthermore, four input parameters were considered: a_{ed} , R_{pm} , F_e , and d . The MCDM problem has been solved, and the best experimental setup has been suggested.

2. METHODOLOGY

2.1. Method for multi-criteria decision making

In this work, the TOPSIS method was applied to solve MCDM problem. To use this method, the following steps must be taken [6]:

Step 1: Creating the initial decision-making matrix:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ x_{21} & \cdots & x_{2n} \\ \vdots & \cdots & \vdots \\ x_{mn} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

In which, m is the alternative number; n is the criteria number; x_{mn} is the value of the criterion n in the alternative m .

Step 2: Finding the normalized values k_{ij} :

$$k_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (2)$$

Step 3: Determining the weighted normalized decision matrix by:

$$l_{ij} = w_j \times k_{ij} \quad (3)$$

Step 4: Calculating the best alternative A^+ and the worst s alternative A^- by:

$$A^+ = \{l_1^+, l_2^+, \dots, l_j^+, \dots, l_n^+\} \quad (4)$$

$$A^- = \{l_1^-, l_2^-, \dots, l_j^-, \dots, l_n^-\} \quad (5)$$

Where, l_j^+ and l_j^- are the best and worst values of the j criterion ($j=1,2, \dots, n$).

Step 5: Determining the values of better options D_i^+ and worse options D_i^- by:

$$D_i^+ = \sqrt{\sum_{j=1}^n (l_{ij} - l_j^+)^2} \quad (6)$$

$$D_i^- = \sqrt{\sum_{j=1}^n (l_{ij} - l_j^-)^2} \quad (7)$$

In (6) and (7) $i = 1, 2, \dots, m$.

Step 6: Finding closeness coefficient values R_i of each alternative by:

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (8)$$

Where, $i = 1, 2, \dots, m; 0 \leq R_i \leq 1$.

Step 7: The order of alternatives is determined by maximizing the value of R .

2.2. Method for determining the weight of criteria

The Entropy method was used to calculate the weights of the criteria in this work.

This method can be implemented using the steps outlined below [7].

Step 1: Calculate the indicator's normalized values by:

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

Step 2: Determine the Entropy for each indicator by:

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

Step 3: Find the weight of each indicator:

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

3. EXPERIMENTAL SETUP

An experiment was performed to find the best experimental setup to get the lowest SR and highest MRS in CBN grinding on a CNC milling machine. The experimental setup is depicted in figure 1, which includes a CNC milling machine (Model M-V50C - Japan), a CBN grinding wheel, CBN wheel dresser equipment (V-TDM-2 type), SKD11 workpiece samples, and a roughness meter (SURFTEST SV-3100).

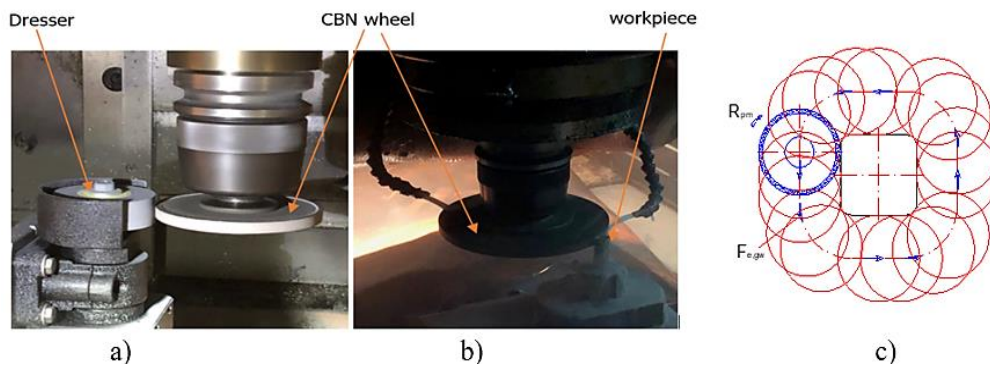


Figure 1. Experimental setup [8]:

a) Dressing setup; b) Grinding setup; c) Grinding schema.

Table 1 displays the input parameters and their levels. These input factors are the most basic parameters of the grinding process on a CNC milling machine. Other parameters, such as the surface hardness of the workpiece, coolant, and wheel toolpath, are preserved. The Taguchi method was also used with design L18 (6^1+3^3). As a result, 18 test runs were required for the investigation. The experimental matrix, as well as the SR and MRS values, are shown in table 2.

Table 1. Input factors and their levels.

No.	Input factors	Level					
		1	2	3	4	5	6
1	Depth of dressing cut (mm)	0.005	0.01	0.015	0.02	0.025	0.03
2	Revolution of spindle speed (rpm)	4000	4500	5000	-	-	-
3	Feed rate (mm/min)	2000	2500	3000	-	-	-
4	Wheel diameter (mm)	100	125	150	-	-	-

Table 2. Experimental plan and output results.

No.	Input parameters				Output results	
	aed	Rpm	Fe	d	Ra (µm)	MRS (g/h)
1	0.005	4000	2000	100	0.5640	2.1933
2	0.005	4500	2500	125	0.5140	21.4465
3	0.005	5000	3000	150	0.2660	0.9161
4	0.01	4000	2000	125	0.3950	3.6771
5	0.01	4500	2500	150	0.3613	1.2421
6	0.01	5000	3000	100	0.3993	5.7262
7	0.015	4000	2500	100	0.3997	5.9976
8	0.015	4500	3000	125	0.2820	3.2727
9	0.015	5000	2000	150	0.2037	3.3251
10	0.02	4000	3000	150	0.7403	3.7553
11	0.02	4500	2000	100	0.5997	4.7941
12	0.02	5000	2500	125	0.3277	20.9084
13	0.025	4000	2500	150	0.6490	3.4458
14	0.025	4500	3000	100	0.7457	7.8089
15	0.025	5000	2000	125	0.2737	5.0633
16	0.03	4000	3000	125	0.8177	4.0054
17	0.03	4500	2000	150	0.4487	3.6447
18	0.03	5000	2500	100	0.6483	6.5775

4. DETERMINING THE BEST ALTERNATIVE WHEN CBN GRINDING SKD11 TOOL STEEL

This section outlines how to determine the best experimental setup for CBN grinding SKD11 tool steel using the TOPSIS method for the MCDM problem and the Entropy method to calculate the criteria weights.

4.1. Calculating the weights for the criteria

The weights of criteria are calculated using the Entropy method as follows (see section 2.2): Equation (9) is used to find the normalized values p_{ij} . Equation (10) is used to compute the Entropy value for each indicator m_{e_j} . At last, using equation (11), calculate the w_j weight of the criteria. The Ra and MRS weights were found as 0.5485 and 0.4515, respectively.

4.2. Finding the best experimental setup using TOPSIS method

Section 2.1 explains how to solve the MCDM problem using the TOPSIS method. As a result, Equation (2) is used to determine normalized k_{ij} values, and Equation (3) is used

to predict normalized weighted l_{ij} values (3). The A^+ and A^- values of Ra and MRS are determined by Equations (4) and (5). Ra and MRS are equal to 0.0551 and 0.2843 for A^+ , and 0.2211 and 0.0121 for A^- , respectively. Moreover, the D_i^+ and D_i^- values were computed using formulas (6) and (7). Finally, the ratio R_i was calculated using Equation (8). Table 3 displays the results of using the TOSIS method to calculate several parameters and rank the alternatives. Also, figure 2 shows the relation between the solutions and the R_i values.

Table 3. Several calculated results and ranking of alternatives.

Solutions	k_{ii}		l_{ij}		D_i^+	D_i^-	R_i	Rank
	Ra	MRR	Ra	MRR				
1	0.278	0.064	0.152	0.0291	0.2732	0.0706	0.205	15
2	0.253	0.630	0.139	0.2843	0.0839	0.2843	0.772	2
3	0.131	0.027	0.072	0.0121	0.2727	0.1492	0.354	8
4	0.195	0.108	0.107	0.0487	0.2412	0.1200	0.332	9
5	0.178	0.036	0.098	0.0165	0.2712	0.1235	0.313	10
6	0.197	0.168	0.108	0.0759	0.215	0.1298	0.377	7
7	0.197	0.176	0.108	0.0795	0.2115	0.1316	0.383	5
8	0.139	0.096	0.076	0.0434	0.2418	0.1482	0.380	6
9	0.100	0.098	0.055	0.0441	0.2402	0.1691	0.413	4
10	0.365	0.110	0.200	0.0498	0.2758	0.0431	0.135	17
11	0.296	0.141	0.162	0.0636	0.2453	0.0782	0.242	14
12	0.162	0.614	0.089	0.2772	0.0343	0.2963	0.896	1
13	0.320	0.101	0.175	0.0457	0.2673	0.0566	0.175	16
14	0.368	0.229	0.202	0.1035	0.2327	0.0934	0.286	12
15	0.135	0.149	0.074	0.0671	0.218	0.157	0.419	3
16	0.403	0.118	0.221	0.0531	0.2846	0.041	0.126	18
17	0.221	0.107	0.121	0.0483	0.2451	0.1061	0.302	11
18	0.320	0.193	0.175	0.0872	0.2309	0.0879	0.276	13

From table 3 and figure 2, it is clear that option 12 is the best choice. This is due to the fact that it has the highest value of R_i ($R_i = 0.896$). As a result, the optimal solution includes the following parameters: dressing cut depth $a_{ed} = 0.02$ (mm), wheel revolution $R_{pm} = 5000$ (rpm), feed rate $F_c = 2500$ (mm/min), and wheel diameter $d = 125$ (mm).

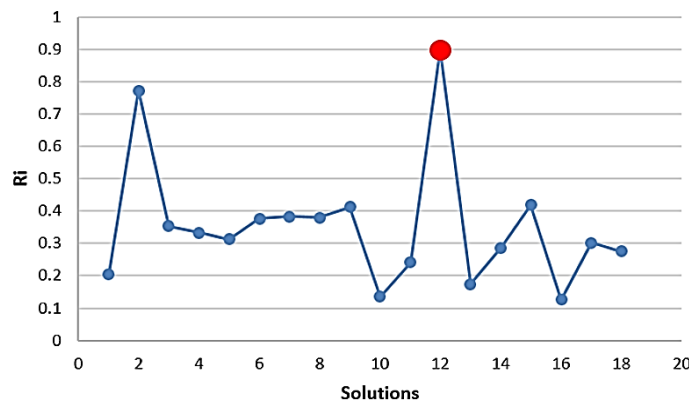


Figure 2. Relation between solution and the value of R_i .

5. CONCLUSIONS

In this paper, the TOPSIS method was used to determine the best experimental setup for CBN grinding SKD11 tool steel on CNC machines in order to achieve the lowest SR and highest MRS at the same time. Furthermore, the weights of the criteria were calculated using the Entropy method. According to the study's findings, alternative 12 is the best solution because it has the highest R_i value. Among the 18 trials, experimental run No. 12 demonstrated the best performance feature, with a maximum value of R_i ($R_i=0.896$). The following experimental parameters were proposed: $a_{ed}=0.02$ (mm), $R_{pm}=5000$ (rpm), $F_e=2500$ (mm/min), and $d=125$ (mm). This result is very suitable for selecting the input process factors when CBN grinding batch parts in a CNC milling machine.

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TÓM TẮT

Ứng dụng phương pháp TOPSIS để ra quyết định đa tiêu chí khi mài CBN thép dụng cụ SKD11

Bài báo này giới thiệu kết quả của nghiên cứu ra quyết định đa tiêu chí (MCDM) khi mài CBN thép dụng cụ SKD11 trên máy phay CNC. Trong nghiên cứu này, phương pháp TOPSIS đã được áp dụng để giải bài toán MCDM, và phương pháp Entropy được sử dụng để tìm trọng số của các tiêu chí. Bên cạnh đó, hai tiêu chí đã được chọn: độ nhám bề mặt (RS) và tốc độ loại bỏ vật liệu (MRS). Hơn nữa, một thí nghiệm với thiết kế $L18 (6^1 + 3^3)$ đã được thực hiện bằng phương pháp Taguchi. Trong thí nghiệm này, bốn thông số đầu vào bao gồm chiều sâu cắt a_{ed} (mm), tốc độ đá mài R_{pm} (vòng/phút), tốc độ tiến dao F_e (mm/phút) và đường kính đá mài d (mm) đã được khảo sát. Từ kết quả của nghiên cứu này, setup thí nghiệm tốt nhất đã được đề xuất.

Từ khóa: Đá mài CBN; MCDM; Phương pháp TOPSIS; Độ nhám bề mặt; Tốc độ bóc tách vật liệu; Vật liệu SKD11.