Original Research Article: full paper

(2022), «EUREKA: Physics and Engineering» Number 2

A RESEARCH ON APPLICATION OF THE MEASUREMENT OF ALTERNATIVES AND RANKING ACCORDING TO COMPROMISE SOLUTION METHOD FOR MULTI-CRITERIA DECISION MAKING IN THE GRINDING PROCESS

Hoang Xuan Thinh
Center for Mechanical Engineering[1]

Do Duc Trung✉
Faculty of Mechanical Engineering[1]
doductrung@haui.edu.vn

[1]Hanoi University of Industry
298 Cau Dien str., Bac Tu Liem District, Hanoi, Vietnam, 100000

✉**Corresponding author**

Abstract

The efficiency of cutting methods in general and the grinding method in particular is evaluated through many parameters such as surface roughness, machining productivity, system vibrations, etc. The machining process is considered highly efficient when it meets the set requirements for these parameters such as ensuring the small surface roughness, small vibrations, and high productivity, etc. However, for each specific machining condition, sometimes the set criteria for the output criteria are opposite. In these cases, it is required to solve the Multi-Criteria Decision Making (MCDM) which means making the decision to ensure the harmonization of all criteria. In this study, a study on multi-criteria decision making in the grinding process of 9CrSi steel using CBN grinding wheels is presented. The experimental process was carried out with sixteen experiments according to an orthogonal matrix that designed by the Taguchi method. The workpiece velocity, feed rate, and depth of cut were changed in each experiment. At each experiment, the responses were determined including surface roughness (*Ra*), the vibration of the grinding wheel shaft in the three directions, corresponding to *Ax*, *Ay*, and *Az*, and material removal yield (*Q*). Four determination methods of weights for criteria were used. The Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) method was applied for multi-criteria decision making. The objective of this study is to identify an experiment that simultaneously ensures the small values of *Ra*, *Ax*, *Ay*, and *Az* and large value *Q*.

Keywords: MCDM, MARCOS, Entropy, Grinding, Surface roughness, Vibration, Material removal yield.

DOI: 10.21303/2461-4262.2022.002120

1. Introduction

Under the rapid development of the machine manufacturers and cutting tool manufacturers, the cutting methods are increasingly providing high productivity and accuracy. Even so, grinding is still often considered as a machining method with the highest precision. Most surfaces with high requirements for precision are still performed by the grinding method.

The 9CrSi steel (DIN standard – German) is a low alloy steel with high hardness. This steel is equivalent to steel grades 150Cr14, 90CrSi5 (DIN standard – Germany), 9CrSi (GB standard – China), 9XC or 9KHS (GOST standard – Russian Federation). This steel is used to manufacture the dies, drill bits, and cutters. In addition, this steel is also used to manufacture the mechanical parts that require high strength such as gears, piston shafts, rolling shafts, and so on. The above parts all have surfaces with high requirements for precision and small surface roughness. For final machining of these surfaces, the grinding method is often used. So, several studies have been conducted to determine the values of the machining parameters to ensure one/several criteria when grinding this steel or equivalent steels. Study on determination of the coolant concentration, coolant flow, workpiece velocity, feed rate, and depth of cut when surface grinding the 9SiCr steel with aluminum oxide grinding wheels to ensure the minimum surface roughness [1]. Determining the values of dressing parameters (dressing feed rate, coarse dressing depth, coarse dressing times, fine dressing depth, fine dressing times, non-feeding dressing) in surface grinding process of 9CrSi steel using aluminum oxide grinding wheels to simultaneously ensure the minimum values of surface roughness and flatness tolerance [2]. Determining the value of dressing parameters to ensure the minimum surface roughness when using aluminum oxide grinding wheels for external and internal cylindrical grinding of 9CrSi steel [3, 4]. In another study, the values of dressing parameters were also determined to simultaneously ensure the small surface roughness, small cutting force, and large life of grinding wheels when surface grinding of 90CrSi steel with aluminum oxide grinding wheels [5].

Study on the determination of the value of machining parameters when grinding 9CrSi steel (or equivalent steel of 90CrSi) was carried out with all three popular grinding methods such as surface grinding, external cylindrical grinding, and internal cylindrical grinding as some of the studies mentioned above. However, all studies used aluminum oxide grinding wheels during the experimental process. This is also understandable because the cost of these grinding wheels is lower than other grinding wheels (CBN grinding wheel, etc.). These studies have not taken full the advantages provided by CBN grinding wheels. The CBN grinding wheel is able to maintain the sharpness of abrasive particles better than aluminum oxide grinding wheel, so the life of CBN grinding wheels is longer than that of aluminum oxide grinding wheels, which reduces the cost of dressing and the cost of grinding wheel wear as well as the cost for stopping the grinding process to perform dressing. The ability to well maintain the shape stability of abrasive particles also makes the surface roughness better when grinding with CBN grinding wheels than that with aluminum oxide grinding wheels. The thermal stability of CBN grinding wheels is better than aluminum oxide ones, which makes it possible to use CBN grinding wheels for dry grinding (no need to use coolants), this is the unique advantage of CBN grinding wheels that aluminum oxide grinding wheels cannot do [6–8]. These advantages when using CBN grinding wheels, sometimes bring better economic and technical efficiency than the use of aluminum oxide grinding wheels, especially when using aluminum oxide stone, a significant cost of coolant and environmental remediation costs must be taken into account.

Through some of the above studies, it was also shown that the studies have not considered the vibration of grinding wheels during the grinding process. A small amount of grinding wheel vibration even has a significant effect on the depth of cut of abrasive particles on the machined surface, thereby affecting on the grinding productivity, the quality of machined surfaces, and wear of grinding wheels [9–12]. The vibrations in general and the vibrations of grinding wheel shafts in particular include two types: forced vibration and self-vibration. Finding solutions to reduce forced vibration is much more complicated than self-vibration. It can be said that because the forced vibration depends on the precision of the machine, the balance level of grinding wheels, while the self vibration depends heavily on the technological parameters in the grinding process. Thus, it is clear that it is much easier to change the value of technological parameters than to change the precision of grinding machines or grinding wheels [11, 13, 14]. Therefore, to reduce the vibrations of grinding wheel shafts, it should first find solutions to reduce the forced vibration by determining the reasonable value of parameters in the machining process. However, when a vibration component in one direction decreases, it is not guaranteed that the vibration components in remaining directions also decrease [13]. In such case, it is required to determine the value of parameters in the machining process by multi-criteria decision making method [13, 15].

Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) is a multi-criteria decision-making method first recommended in 2020 [16]. Although it has only been published for a short time, this method has been applied for multi-criteria decision making in some studies such as in the selection of intermediate transport modes among countries in the Danube region [17], in multi-criteria decision making to reduce risks in road traffic [18], in the selection of stackers/unloaders for service in small warehouses [19], in the selection of human resources (employees) of a carrier [20], in the selection of costs in the construction sector [21], etc. However, up to the present time, there have not been studies that apply the MARCOS method for multi-criteria decision making for cutting methods in general and for grinding methods in particular.

In this study, the grinding experimental process of 9CrSi steel using CBN grinding wheel was performed. At each experiment, five parameters including Ra, *Ax*, *Ay, Az,* and *Q* were determined. The MARCOS method were applied to determine an experiment which ensures that the four parameters *Ra*, *Ax*, *Ay* and *Az* have the same minimum value, and *Q* has the maximum value.

2. Materials and methods

2. 1. The Measurement of Alternatives and Ranking according to Compromise Solution method

The steps to implement multi-criteria decision making according to the Measurement of Alternatives and Ranking according to Compromise Solution method (MARCOS) method are as follows [16]:

Step 1. Build a multi-criteria decision-making matrix, called the initial matrix as by (1).

$$X=\begin{bmatrix} x_{11} & x_{12} & ... & x_{1n} \\ x_{21} & x_{22} & ... & x_{21} \\ ... & ... & ... & ... \\ x_{m1} & x_{m2} & ... & x_{mn} \end{bmatrix}, \quad (1)$$

where m is the number of options, n is the number of criteria, x_{mn} is the value of the criterion n in the option m.

Step 2. Build an expanded initial matrix that adding ideal solutions (AI) and opposite solutions to ideal solutions (AAI).

$$X=\begin{matrix} AAI \\ A_1 \\ A_2 \\ ... \\ A_m \\ AI \end{matrix}\begin{bmatrix} x_{aa1} & x_{aa2} & ... & x_{aan} \\ x_{11} & x_{12} & ... & x_{1n} \\ x_{21} & x_{22} & ... & x_{2n} \\ ... & ... & ... & ... \\ x_{m1} & x_{m2} & ... & x_{mn} \\ x_{ai1} & x_{ai2} & ... & x_{ain} \end{bmatrix}. \quad (2)$$

Where:

$$AAI=\min\left(x_{ij}\right), \text{ if } j \text{ is the bigger the better criterion,}$$

$$AAI=\max\left(x_{ij}\right), \text{ if } j \text{ is the smaller the better criterion,}$$

$$AI=\max\left(x_{ij}\right), \text{ if } j \text{ is the bigger the better criterion,}$$

$$AI=\min\left(x_{ij}\right), \text{ if } j \text{ is the smaller the better criterion.}$$

Step 3. Normalize the expanded initial matrix according to the (3) and (4):

$$n_{ij}=\frac{x_{AI}}{x_{ij}}, \text{ if } j \text{ is the smaller the better criterion,} \quad (3)$$

$$n_{ij}=\frac{x_{ij}}{x_{AI}}, \text{ if } j \text{ is the bigger the better criterion.} \quad (4)$$

Step 4. Build a normalized matrix based on the weight of criteria, with the normalized value calculated according to the (5):

$$v_{ij}=n_{ij}\cdot w_j, \quad (5)$$

where w_j is the weight of the criterion j.

Step 5. Calculate the coefficients K_i^+ and K_i^- according to the (6):

$$K_i^-=\frac{S_i}{S_{AAI}}, \quad (6)$$

$$K_i^+ = \frac{S_i}{S_{AI}}, \tag{7}$$

where S_i, S_{AAI} and S_{AI} are the total value of v_{ij}, x_{aai} and x_{ai}, respectively, with $i = 1, 2, …., m$.

Step 6. Calculate the functions $f(K_i^+)$ and $f(K_i^-)$ according to the (8) and (9):

$$f\left(K_i^-\right) = \frac{K_i^+}{K_i^+ + K_i^-}, \tag{8}$$

$$f\left(K_i^+\right) = \frac{K_i^-}{K_i^+ + K_i^-}, \tag{9}$$

Step 7. Calculate the function $f(K_i)$ according to the following formula and rank the solution:

$$f\left(K_i\right) = \frac{K_i^+ + K_i^-}{1 + \frac{1 - f\left(K_i^+\right)}{f\left(K_i^+\right)} + \frac{1 - f\left(K_i^-\right)}{f\left(K_i^-\right)}}. \tag{10}$$

Rank the solution according to the principle that the one with the maximum value of the function $f(K_i)$ is considered the best solution.

2. 2. Experimental process

Steel workpieces were used during the experimental process with dimensions including the long of 60 mm, the wide of 40 mm and the high 10 mm. The preparation for experimental workpiece is carried out by the steps of rough milling, heat treatment to reach a hardness of 61±0.5 HRC, and rough grinding. The APSG-820/2A surface grinder (Taiwan) was used during the experiment. The hydraulic pump system was used to control the workpiece velocity and feed rate of the machine. Therefore, these two parameters can be controlled steplessly. The depth of cut is adjusted by the vernier on the machine, each bar of the vernier corresponds to the amount of up/down movement of the grinding wheel which is 0.005 mm.

The CBN grinding wheel of type HY-180x13x31.75-100#-2 (Korea) was used in the experiment. In symbols of the grinding wheel, HY is the manufacturer's own symbol, 180 is the outer diameter of the grinding wheel, 13 is the width of the grinding wheel, 31.75 is the inner diameter of the grinding wheel, 100# is the granularity, 2 is the thickness of the grinding wheel layer (inside is aluminum disc).

The three-component vibration sensor of type 4525-B-001 is mounted on the protection cap of grinding wheels. The vibration signal measured by such vibration sensor is transmitted to the data converter and then transmitted to the computer by the transmission cable. PULSE software was installed in the computer to process data. The value of vibration components (in the three directions *X*, *Y*, *Z*) is calculated according to the average value of such component during the time the grinding wheel cuts into the surface of the workpiece.

Surface roughness was measured by a SJ-210 surface roughness tester (Japan). The standard length of the measurement has been set to 0.8 mm. After grinding, the steel samples were washed with alcohol before measuring. Each steel sample was measured for roughness at least three times, and then the average value of such measurements was taken. The material removal capacity when surface grinding is calculated according to the following (11) [22].

$$Q = f \cdot a_p \cdot v_w, \tag{11}$$

where f is the feed rate, a_p is the depth of cut, and v_w is the workpiece velocity.

The cutting parameters that would be changed during the experiments include workpiece velocity, feed rate and depth of cut. Each cutting parameter has been selected with four values corresponding to the four encoding levels 1, 2, 3, and 4 as presented in **Table 1**. The selection of the value of cutting parameters is based on the thickness of the grinding wheel, technological capability of the machine, and on the basis of referring to their value in literature [13, 22]. The grinding process is carried out in the condition that no cooling solution is used (dry grinding).

Table 1
Cutting parameters

Cutting velocity	Unit	Symbol	Value at level			
			1	2	3	4
Workpiece velocity	m/min	v_w	5	10	15	20
Feed rate	mm/stroke	f	2	5	8	10
Depth of cut	mm	a_p	0.005	0.01	0.015	0.02

With cutting parameters as mentioned above, a matrix with sixteen experiments was designed according to the Taguchi method as shown in **Table 2**. The experiments were performed in the order of experiments in **Table 2**. The response values of such experiments have also been included in **Table 2**.

Table 2
Orthogonal matrix L16 and results

Trial	v_w (m/min)	f (mm/stroke)	a_p (mm)	Ra (μm)	A_x (μm)	A_y (μm)	A_z (μm)	Q (mm^3/min)
1	5	2	0.005	0.446	1.785	6.643	6.843	50
2	5	5	0.01	1.113	2.425	10.525	2.902	250
3	5	8	0.015	1.246	3.321	14.224	3.885	600
4	5	10	0.02	1.935	3.678	17.852	4.406	1000
5	10	2	0.01	0.446	3.062	5.238	3.112	200
6	10	5	0.005	1.064	3.814	14.558	4.121	250
7	10	8	0.02	1.654	4.581	17.888	4.886	1600
8	10	10	0.015	1.924	5.226	22.224	5.702	1500
9	15	2	0.015	0.337	4.444	24.708	4.123	450
10	15	5	0.02	0.998	5.12	18.012	5.206	1500
11	15	8	0.005	1.622	5.886	22.226	6.226	600
12	15	10	0.01	1.844	6.234	26.128	6.786	1500
13	20	2	0.02	0.531	5.6	18.883	5.405	800
14	20	5	0.015	1.023	6.123	21.987	6.501	1500
15	20	8	0.01	1.664	7.244	27.012	7.421	1600
16	20	10	0.005	2.012	7.345	28.021	7.923	1000

According to the data in **Table 2**, the parameters Ra, Ax, Ay and Az have the minimum values in experiments No. 9, No. 1, No. 5, No. 2, respectively, while Q has the maximum value at experiment No. 15. Thus, it is also affirmed that there is no experiment out of the total of sixteen performed experiments that simultaneously ensure that all four parameters Ra, Ax, Ay and Az have the minimum value, and Q has the maximum value. Therefore, it is only possible to find one experiment where the four parameters Ra, Ax, Ay and Az are considered to be the minimum and Q is considered to be the maximum based on knowing the weight of each response, and then the multi-criteria decision making method is also needed to be applied to do this task.

3. Results and discussion

Determining the weight for the criteria is a compulsory mission when implementing multi-criteria decision making. The order of ranking solutions depends directly on the method of determining the weights of the criteria. Four weight methods were used in this study are Equal method, Rank Order Centroid (ROC) weight method, Rank-Sum (RS) weight method, and Entropy method. Detailed descriptions of these methods can be found in the literature [23, 24].

These methods were applied to identify the weight of each criterion in each case. The identified results of weight were listed in **Table 3**.

Table 3
Weights of the criteria according to different methods

Weight method	Ra	A_x	A_y	A_z	Q
Equal	0.2	0.2	0.2	0.2	0.2
ROC	0.4567	0.2567	0.1567	0.0900	0.0400
RS	0.3333	0.2667	0.2000	0.1333	0.0667
Entropy	0.4791	0.1745	0.2144	0.0901	0.0419

Applying the MARCOS method, the initial matrix was determined. This matrix is one matrix that contains the last five columns in **Table 2**. Building the expanded initial matrix and the results by (2), were presented in **Table 4**.

Table 4
Expanded initial matrix

No.	Ra	A_x	A_y	A_z	Q
AAI	2.012	7.345	28.021	7.923	50
A_1	0.446	1.785	6.643	6.843	50
A_2	1.113	2.425	10.525	2.902	250
A_3	1.246	3.321	14.224	3.885	600
A_4	1.935	3.678	17.852	4.406	1000
A_5	0.446	3.062	5.238	3.112	200
A_6	1.064	3.814	14.558	4.121	250
A_7	1.654	4.581	17.888	4.886	1600
A_8	1.924	5.226	22.224	5.702	1500
A_9	0.337	4.444	24.708	4.123	450
A_{10}	0.998	5.12	18.012	5.206	1500
A_{11}	1.622	5.886	22.226	6.226	600
A_{12}	1.844	6.234	26.128	6.786	1500
A_{13}	0.531	5.6	18.883	5.405	800
A_{14}	1.023	6.123	21.987	6.501	1500
A_{15}	1.664	7.244	27.012	7.421	1600
A_{16}	2.012	7.345	28.021	7.923	1000
AI	0.337	1.785	5.238	2.902	1600

Let's apply (3) and (4) to determine the normalized matrix as shown in **Table 5**.

Let's apply (5) to build a normalized matrix depending on the weight of criteria. Where first calculate the case that the weight of criteria is determined by the Equal method ($w_j = 0.2$, with $j = 1 \div 5$). The results are presented in **Table 6**.

Table 5
Normalized matrix

No.	R_a	A_x	A_y	A_z	Q
AAI	0.1675	0.2430	0.1869	0.3663	0.0313
A_1	0.7556	1.0000	0.7885	0.4241	0.0313
A_2	0.3028	0.7361	0.4977	1.0000	0.1563
A_3	0.2705	0.5375	0.3683	0.7470	0.3750
A_4	0.1742	0.4853	0.2934	0.6586	0.6250
A_5	0.7556	0.5830	1.0000	0.9325	0.1250
A_6	0.3167	0.4680	0.3598	0.7042	0.1563
A_7	0.2037	0.3897	0.2928	0.5939	1.0000
A_8	0.1752	0.3416	0.2357	0.5089	0.9375
A_9	1.0000	0.4017	0.2120	0.7039	0.2813
A_{10}	0.3377	0.3486	0.2908	0.5574	0.9375
A_{11}	0.2078	0.3033	0.2357	0.4661	0.3750
A_{12}	0.1828	0.2863	0.2005	0.4276	0.9375
A_{13}	0.6347	0.3188	0.2774	0.5369	0.5000
A_{14}	0.3294	0.2915	0.2382	0.4464	0.9375
A_{15}	0.2025	0.2464	0.1939	0.3911	1.0000
A_{16}	0.1675	0.2430	0.1869	0.3663	0.6250
AI	1.0000	1.0000	1.0000	1.0000	1.0000

Table 6
Normalized matrix taking into account the weight of criteria

No.	*Ra*	A_x	A_y	A_z	Q
AAI	0.0335	0.0486	0.0374	0.0733	0.0063
A_1	0.1511	0.2000	0.1577	0.0848	0.0063
A_2	0.0606	0.1472	0.0995	0.2000	0.0313
A_3	0.0541	0.1075	0.0737	0.1494	0.0750
A_4	0.0348	0.0971	0.0587	0.1317	0.1250
A_5	0.1511	0.1166	0.2000	0.1865	0.0250
A_6	0.0633	0.0936	0.0720	0.1408	0.0313
A_7	0.0407	0.0779	0.0586	0.1188	0.2000
A_8	0.0350	0.0683	0.0471	0.1018	0.1875
A_9	0.2000	0.0803	0.0424	0.1408	0.0563
A_{10}	0.0675	0.0697	0.0582	0.1115	0.1875
A_{11}	0.0416	0.0607	0.0471	0.0932	0.0750
A_{12}	0.0366	0.0573	0.0401	0.0855	0.1875
A_{13}	0.1269	0.0638	0.0555	0.1074	0.1000
A_{14}	0.0659	0.0583	0.0476	0.0893	0.1875
A_{15}	0.0405	0.0493	0.0388	0.0782	0.2000
A_{16}	0.0335	0.0486	0.0374	0.0733	0.1250
AI	0.2000	0.2000	0.2000	0.2000	0.2000

Let's apply (6) to (10) to calculate the respective values K_i^-, K_i^+, $f(K_i^-)$, $f(K_i^+)$ and $f(K_i)$. The results are presented in **Table 7**. The results of ranking solutions according to the value of $f(K_i)$ were included in **Table 7**.

With the same implementation as above, the options for different weight methods have also been ranked. The results of ranking options of the methods are presented in **Table 8**.

Table 7

Several parameters in MARCOS and ranking of options

No.	K_i^-	K_i^+	$f(K_i^-)$	$f(K_i^+)$	$f(K_i)$	Rank
A_1	0.006295	0.000373	0.055877	0.944123	0.000371	2
A_2	0.005651	0.000334	0.055877	0.944123	0.000333	3
A_3	0.004823	0.000285	0.055877	0.944123	0.000285	7
A_4	0.004694	0.000278	0.055877	0.944123	0.000277	10
A_5	0.007127	0.000422	0.055877	0.944123	0.000420	1
A_6	0.004208	0.000249	0.055877	0.944123	0.000248	14
A_7	0.005205	0.000308	0.055877	0.944123	0.000307	5
A_8	0.004615	0.000273	0.055877	0.944123	0.000272	11
A_9	0.005454	0.000323	0.055877	0.944123	0.000322	4
A_{10}	0.005188	0.000307	0.055877	0.944123	0.000306	6
A_{11}	0.003332	0.000197	0.055877	0.944123	0.000197	16
A_{12}	0.00427	0.000253	0.055877	0.944123	0.000252	12
A_{13}	0.004759	0.000282	0.055877	0.944123	0.000281	8
A_{14}	0.004707	0.000279	0.055877	0.944123	0.000278	9
A_{15}	0.004268	0.000253	0.055877	0.944123	0.000252	13
A_{16}	0.003334	0.000197	0.055877	0.944123	0.000197	15

Table 8

Ranking of options for different weight methods

No.	Weight method			
	Equal	ROC	RS	Entropy
A_1	2	1	2	2
A_2	3	4	4	3
A_3	7	6	6	4
A_4	10	10	10	6
A_5	1	2	1	1
A_6	14	7	7	5
A_7	5	11	9	7
A_8	11	12	12	11
A_9	4	3	3	13
A_{10}	6	8	8	8
A_{11}	16	13	15	12
A_{12}	12	14	13	14
A_{13}	8	5	5	9
A_{14}	9	9	11	10
A_{15}	13	15	14	15
A_{16}	15	16	16	16

The results of ranking solutions in **Table 8** showed that with different weight methods, the results of ranking options are also different. These results were in full agreement with the comments in the literature [23]. However, it was surprising to find that the best solution and the second-best solution were interchanged among the weight methods. In particular, the solution #1 is considered to be the best one if the weights of criteria are determined by the *ROC* method, while for the other three weight methods, solution #1 is the second-best. For solution #5, when determining weights by the *ROC* method, solution #5 is the second-best one, and when applying other weight methods, solution #5 is the best one. This said that solution #1 and #5 were really the two «best» ones, and the selection between these two solutions is based on the decision maker. This viewpoint can be clarified as follows: selecting the solution #1 if preferring to select *Ax* with a small value; and selecting the solution #5 if preferring to choose the *Ay*, *Az* with a small value and *Q* with a large value. Either selection still ensures the same value of surface roughness (equal to 0.446 μm). However, when the number of criteria is large, choosing which criteria should be prioritized can be confusing for decision makers. Then a stability assessment for the rating results should be performed. This is also the content that needs to be done in future research.

4. Conclusions

The grinding experimental process of 9CrSi steel using CBN grinding wheels was performed in the order of an orthogonal matrix including sixteen experiments in this study. At each experiment, the value of five criteria, including *Ra*, *Ax*, *Ay*, *Az,* and *Q*, were determined. Four weight methods for the criteria were performed, including Equal, ROC, RS, and Entropy. The MARCOS method was applied for multi-criteria decision making. The conclusions are drawn as follows:

– with different weight methods, the order of ranking solutions is also different, but the two solutions considered the «best» have been determined in all four cases using different weight methods;

– when using the Equal, RS, and Entropy weight methods, the best solution is one solution that the workpiece velocity, the feed rate, and the depth of cut of are 0.005 mm, and 10 m/min, 2 mm/stroke, 0.01 mm, respectively. Select this solution when the small *Ax* priority is the number one priority;

– when using the ROC weight method, the best option is the one that the workpiece velocity, feed rate and depth of cut of these two options are 5 m/min, 2 mm/stroke, 0.005 mm, respectively. Select this solution if the priority belongs to *Ay*, *Az,* and *Q*;

– this is the first time that the MARCOS method was applied for multi-criteria decision-making in the grinding process. The implementation method applied in this study can also be applied to perform multi-criteria decision making for other machining processes.

Acknowledgments

This work was supported by Hanoi University of Industry (Vietnam).

References

[1] Tung, L. A., Pi, V. N., Ha, D. T. T., Hung, L. X., Banh, T. L. (2018). A Study on Optimization of Surface Roughness in Surface Grinding 9CrSi Tool Steel by Using Taguchi Method. Lecture Notes in Networks and Systems, 100–108. doi: https://doi.org/10.1007/978-3-030-04792-4_15

[2] Anh Tung, L., Pi, V. N., Lien, V. T., Thi Hong, T., Hung, L. X., Tien Long, B. (2019). Optimization of dressing parameters of grinding wheel for 9CrSi tool steel using the taguchi method with grey relational analysis. IOP Conference Series: Materials Science and Engineering, 635 (1), 012030. doi: https://doi.org/10.1088/1757-899x/635/1/012030

[3] Xuan Tu, H., Thao, L. P., Thi Hong, T., Thi Thanh Nga, N., Trung, D. D., Gong, J., Pi, V. N. (2019). Influence of dressing parameters on surface roughness of workpiece for grinding hardened 9XC tool steel. IOP Conference Series: Materials Science and Engineering, 542 (1), 012008. doi: https://doi.org/10.1088/1757-899x/542/1/012008

[4] Xuan Hung, L., Ngoc Pi, V., Thi Hong, T., Hong Ky, L., Thi Lien, V., Anh Tung, L., Tien Long, B. (2019). Multi-objective Optimization of Dressing Parameters of Internal Cylindrical Grinding for 9CrSi Aloy Steel Using Taguchi Method and Grey Relational Analysis. Materials Today: Proceedings, 18, 2257–2264. doi: https://doi.org/10.1016/j.matpr.2019.07.007

[5] Hong, T. T., Cuong, N. V., Ky, L. H., Nguyen, Q. T., Long, B. T., Tung, L. A. et. al. (2020). Multi-Criteria Optimization of Dressing Parameters for Surface Grinding 90CrSi Tool Steel Using Taguchi Method and Grey Relational Analysis. Materials Science Forum, 998, 61–68. doi: https://doi.org/10.4028/www.scientific.net/msf.998.61

[6] Sinha, M. K., Setti, D., Ghosh, S., Venkateswara Rao, P. (2016). An investigation on surface burn during grinding of Inconel 718. Journal of Manufacturing Processes, 21, 124–133. doi: https://doi.org/10.1016/j.jmapro.2015.12.004
[7] Shi, Z., Malkin, S. (2005). Wear of Electroplated CBN Grinding Wheels. Journal of Manufacturing Science and Engineering, 128 (1), 110–118. doi: https://doi.org/10.1115/1.2122987
[8] Yu, T. (2016). Material removal modeling and life expectancy of electroplated CBN grinding wheel and paired polishing. Iowa State University. doi: https://doi.org/10.31274/etd-180810-5672
[9] Lee, K. W., Wong, P. K., Zhang, J. H. (2000). Study on the grinding of advanced ceramics with slotted diamond wheels. Journal of Materials Processing Technology, 100 (1-3), 230–235. doi: https://doi.org/10.1016/s0924-0136(00)00403-9
[10] Marinescu, I. D., Hitchiner, M. P., Uhlmann, E., Rowe, W. B., Inasaki, I. (2006). Handbook of Machining with Grinding Wheels. CRC Press, 632. doi: https://doi.org/10.1201/9781420017649
[11] Malkin, S., Guo, C. (2008). Grinding technology: Theory and Applications of Machining with Abrasives. New York: Industrial Press, 372.
[12] Cao, Y., Guan, J., Li, B., Chen, X., Yang, J., Gan, C. (2012). Modeling and simulation of grinding surface topography considering wheel vibration. The International Journal of Advanced Manufacturing Technology, 66 (5-8), 937–945. doi: https://doi.org/10.1007/s00170-012-4378-7
[13] Nguyen, N.-T., Duc Trung, D. (2020). A study on the surface grinding process of the SUJ2 steel using CBN slotted grinding wheel. AIMS Materials Science, 7 (6), 871–886. doi: https://doi.org/10.3934/matersci.2020.6.871
[14] Liu, T., Deng, Z., Lv, L., She, S., Liu, W., Luo, C. (2020). Experimental Analysis of Process Parameter Effects on Vibrations in the High-Speed Grinding of a Camshaft. Strojniški Vestnik – Journal of Mechanical Engineering, 66 (3), 175–183. doi: https://doi.org/10.5545/sv-jme.2019.6294
[15] Nguyen, N.-T., Tien, D. H., Trung, D. D. (2020). Multi-Objective Optimization when Surface Grinding the 3X13 Steel by Combining the General Reduced Gradient Algorithm and Harmonic Mean Method. Advances in Science, Technology and Engineering Systems Journal, 5 (5), 395–400. doi: https://doi.org/10.25046/aj050550
[16] Stević, Ž., Pamučar, D., Puška, A., Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). Computers & Industrial Engineering, 140, 106231. doi: https://doi.org/10.1016/j.cie.2019.106231
[17] Tadić, S., Kilibarda, M., Kovač, M., Zečević, S. (2021). The assessment of intermodal transport in countries of the danube region. International Journal for Traffic and Transport Engineering, 11 (3), 375–391. doi: https://doi.org/10.7708/ijtte2021.11(3).03
[18] Stanković, M., Stević, Ž., Das, D. K., Subotić, M., Pamučar, D. (2020). A New Fuzzy MARCOS Method for Road Traffic Risk Analysis. Mathematics, 8 (3), 457. doi: https://doi.org/10.3390/math8030457
[19] Ulutaş, A., Karabasevic, D., Popovic, G., Stanujkic, D., Nguyen, P. T., Karaköy, Ç. (2020). Development of a Novel Integrated CCSD-ITARA-MARCOS Decision-Making Approach for Stackers Selection in a Logistics System. Mathematics, 8 (10), 1672. doi: https://doi.org/10.3390/math8101672
[20] Stević, Ž., Brković, N. (2020). A Novel Integrated FUCOM-MARCOS Model for Evaluation of Human Resources in a Transport Company. Logistics, 4 (1), 4. doi: https://doi.org/10.3390/logistics4010004
[21] Anysz, H., Nicał, A., Stević, Ž., Grzegorzewski, M., Sikora, K. (2020). Pareto Optimal Decisions in Multi-Criteria Decision Making Explained with Construction Cost Cases. Symmetry, 13 (1), 46. doi: https://doi.org/10.3390/sym13010046
[22] Brian Rowe, W. (2014). Principles of Modern Grinding Technology. William Andrew. doi: https://doi.org/10.1016/c2013-0-06952-6
[23] Gunantara, N. (2018). A review of multi-objective optimization: Methods and its applications. Cogent Engineering, 5 (1), 1502242. doi: https://doi.org/10.1080/23311916.2018.1502242
[24] Nguyen, N.-T., Trung, D. (2021). Combination of Taguchi method, MOORA and COPRAS techniques in multi-objective optimization of surface grinding process. Journal of Applied Engineering Science, 19 (2), 390–398. doi: https://doi.org/10.5937/jaes0-28702

Received date 21.10.2021
Accepted date 18.01.2022
Published date 31.03.2022

How to cite: *Thinh, H. X., Trung, D. D. (2022). A research on application of the measurement of alternatives and ranking according to compromise solution method for multi-criteria decision making in the grinding process. EUREKA: Physics and Engineering, 2, 101–110. doi: https://doi.org/10.21303/2461-4262.2022.002120*