Applied Engineering Letters Vol.7, No.4, 143-153 (2022) e-ISSN: 2466-4847

MULTI-OBJECTIVE OPTIMIZATION IN TURNING PROCESS USING RIM METHOD

UDC:519.863:621.941
Original scientific paper https://doi.org/10.18485/aeletters.2022.7.4.2

Nguyen Hong Son[1*], Vo Thi Nhu Uyen[1]

[1]Hanoi University of Industry, Hanoi City, 100000, Vietnam

Abstract:
In all machining methods, surface roughness greatly influences the working ability and the life of parts. Besides, material removal rate (MRR) is the parameter that reflects machining productivity. Low surface roughness and high MRR values are ideal for most of the methods. This article presents a research on multi-objective optimization of turning process. The material used in the experiments is SCM440steel. And Taguchi method is applied to design an orthogonal array (L27), in which five parameters are selected as the input of testing process including cutting tool material, tool nose radius, spindle speed, feed rate and depth of cut. In addition, Reference Ideal Method (*RIM*) is applied to identify the value of the input parameters to achieve the minimum surface roughness and the maximum *MRR*. Accordingly, in order to obtain the maximum *MRR* and the minimum surface roughness at the same time, it is necessary to use TiN coated cutting tool, with the tool nose radius of 0.6 mm, the cutting speed of 94.25 m/min, the feed rate of 0.16 mm/rev, and the depth of cut of 0.5 mm. Impact of input parameters on output parameters is also analyzed in this study.

ARTICLE HISTORY
Received: 10.09.2022.
Accepted: 30.11.2022.
Available: 31.12.2022.

KEYWORDS
Turning, surface roughness, MRR, multi-objective optimization, RIM, Taguchi

1. INTRODUCTION

Turning is the most common of the cutting machining methods [1]. It can be said that technological processes of making mechanical products are largely related to the method. This workload represents 40% of the total machining and number of lathes makes up 25-35% of total machines in a cutting workshop [2].

As other machining methods, the surface roughness and *MRR* are often chosen to evaluate the machining operation in turning. *MRR* is a representative factor for machining productivity, while surface roughness directly reflects the surface quality. Surface roughness greatly affects the corrosion resistance, wear resistance, fatigue strength and joint alignment (for redundancy in joints). For this reason, research on optimizing the turning process for the minimum surface roughness, or the maximum *MRR*, or both, are carried out in many published studies, some of which used Taguchi method for experimental design. Its advantage is the adequate number of tests to conduct despite many input parameters.

In the case of turning ductile cast iron FCD700 using a TiN-coated cutting tool with 2 mm of depth of cut, surface roughness reaches minimum value when the cutting speed and feed rate are 360 m/min and 0.2 mm/rev, respectively. Meanwhile *MRR* has the maximum when these two parameters are 360 m/min and 0.5 mm/rev, respectively. The signal-to-noise (S/N) ratio is applied to solve these optimization problems [3].

Upon dry turning 6061 aluminum workpiece with a diameter of 50mm, the optimal value of the cutting parameters was also found through the analysis of the S/N ratio. When the spindle speed is 710 rev/min, the feed rate is 0.2 mm/rev, and the depth of cut is 0.2 mm, the surface roughness reaches the minimum value [4].

*CONTACT: Nguyen Hong Son, e-mail: nguyenhongson@haui.edu.vn

The *S/N* ratio is used to optimize the turning operation of aluminum – 2014 aloy with a high speed steel (*HSS*) cutting tool [5]. To earn the minimum of surface roughness, spindle speed, feed rate and depth of cut are 1700 rev/min, 35 mm/min and 0.4 mm, respectively.

The result of turning the 2014 aluminum alloy using the carbide tool and the TiN coated carbide tool demonstrates that the carbide tool should be used with values of cutting speed, feed rate and depth of cut are 314 m/min, 0.05 mm/rev and 0.5 mm to have the minimum of surface roughness. The optimization of the cutting parameters was also determined by the S/N ratio [6].

One study carried out experiments of turning 6082 aluminium alloy specimens 28 mm in diameter. Three types of cutting tools used included *HSS* tool, Carbide tool and cobalt tool with 5% carbon contents. When applying the *S/N* ratio, the study suggests that: (1) in case of *HSS* tool, the *MRR* has maximum value when the spindle speed is 900 rev/min, flank angle is 8^0 and the depth of cut is 1.1 mm; (2) *MRR* is largest when using carbide tool if the spindle speed is 615 rev/min, flank angle is 4^o and depth of cut is 0.9 mm; (3) with cobalt tool, *MRR* reach the maximum when the values of spindle speed, flank angle and depth of cut are 615 rev/min, 40 and 0.7 mm, respectively [7].

The *S/N* ratio was also applied to optimize the turning process of some workpieces from different materials with coated carbide CNMg120408 tool [8]. The spindle speed, feed rate, depth of cut and workpiece material (including three aluminum grades of 6061, 6063 and 6082) were the four parameters to be adjusted in each experiment. The test specimens are 32 mm in diameter. This study claims that surface roughness is of minimum value when turning 6063 aluminums with spindle speed of 500 rev/min, feed rate of 0.1 mm/min and depth of cut of 0.5 mm.

The above studies demonstrate that experiments based on the Taguchi method are successful in solving the optimal problem of the turning method in some cases. When the Taguchi is the only method to be used for optimizing the turning operation, the *S/N* is also the only measure to be applied, however, it is unable to solve the problems but single-objective optimization. In studying the turning process, a number of studies combined several multi-objective optimization methods with the Taguchi method to avoid this disadvantage.

Upon turning UD-GFRP materials with a PCD coating cutter, multi-objective optimization was performed by combining the Taguchi method with the Principal Component Analysis (*PCA*) method [9]. In each experiment, the authors chose six inputs including cutting environment (dry, wet and cooled), tool nose radius, tool rake angle, feed rate, cutting speed and depth of cut. The results reveals that to obtain the smallest surface roughness and the greatest *MRR*, it is necessary to perform the tests in the cooled environment with the value of tool nose radius, tool rake angle, feed rate, cutting speed, and depth of cut are 0.8 mm, 0^0, 0.2 mm/rev, 159.66 m/min and 1.4 mm, respectively. Previously, the *S/N* ratio was applied to show that the surface roughness only has the minimum in the dry condition with the value of the tool nose radius, tool rake angle, feed rate, cutting speed, and depth of cut are 0.8 mm, 0^0, 0.1 mm/rev, 110.84 m/min and 0.8 mm, respectively. The analysis of the *S/N* was also used to determine that in a cooled environment, tool nose radius, tool rake angle, feed rate, cutting speed, and depth of cut are 0.8 mm, 0^0, 0.2 mm/rev, 159.66 m/min and 1.4 mm, *MRR* reaches the maximum.

Several researchers optimized the AISI 1040 steel turning process [10]. In their study, three cutting tools including Brazed tip, TiN coated insert and TiAlN coated insert were used in three cutting environment including dry, MQL and wet. The Taguchi is combined with ANOVA (analysis of variance) to perform multi-objective optimization. The results show that in the case of dry turning with TiAlN-coated cutting tool, when the cutting speed is 50.55 m/min, the feed rate is 0.2107 mm/rev and the depth of cut is 1 mm, the reaches the maximum *MRR* and the minimum surface roughness.

Upon dry turning AISI 316L steel with a *PVD* coated cermet insert, surface roughness is minimum and *MRR* is maximum if the cutting speed is between 125 and 260 m/min, the feed rate ranges from 0.08 to 0.16 mm/rev and the depth of cut varies between 0.1 and 0.3 mm [11]. In order to define that range of cutting parameters, the Taguchi is combined with regression model.

The Taguchi method was combined with Grey Relational Analysis (*GRA*) to optimize the LM 25 alloy turning process using the tungsten carbide insert [12]. The study indicates that surface roughness and total machining cost are smallest and *MRR* is largest when a cutting fluid Ahonol-7 is applied with irrigation flow rate of 75 Ml/h, while the cutting speed is 150.79 m/min, the feed rate is 0.15 mm/min and the depth of cut is 0.9 mm.

The Taguchi and GRA method were combined in the use of DNMG 150608-PM4025 cutting tool for turning C45 steel [13]. This study revealed the highest *MRR* and lowest surface roughness are achieved if the cutting speed is 400 m/min, the feed rate is 0.1 mm/rev and the depth of cut is 1.2 mm.

The regression model and artificial neural network method were combined to optimize multiple objectives of the AZ61 magnesium alloy turning process [14]. The cutting tool was VCGT160404 FN-AL. This study determined that the multi-objective optimization of maximum *MRR* and minimum surface roughness if the cutting speed is 200 m/min, the feed rate is 0.0902 mm/rev and the depth of cut is 1.12 mm.

The above research suggests that cutting parameters and cutting tools are often selected as input parameters for optimizing turning operation. This can be explained by the reason: it is likely more convenient and quicker for the operator to adjust value of the cutting parameters than to change/control the others (technology system, vibration...). Furthermore, the combination of the Taguchi method with an optimization tool is successful in solving the multi-objective problem. Besides, some other tools combined with the Taguchi are also effective for the multi-objective optimization. Such tools are also known as multi-criteria decision making (*MCDM*) [15-17]. Fuzzy *MOORA* (Multiobjective Optimization On the basis of Ratio Analysis) method was used for multi-objective optimization of the turning process of commercial pure titanium [18]. Five methods consisting of *MOORA*, *TOPSIS* (Technique for Order Preference by Similarity to Ideal Solution), *BWM* (Best-Worst Method), *WSA* (Weighted Sum Approach) and *VIKOR* (ViseKriterijumska Optimizacija I Kompromisno Resenje) were used simultaneously for multi-objective optimization of turning four different materials including AISI 4140, AISI 1040, Al-7075, Al-2024 [19]. The methods of *TOPSIS*, *WSA*, *GRA* were mixed for the multi-objective optimization of the turning operation with three different materials including AISI-1010, AISI-1050, Al-7075 [20], etc.

Reference Ideal Method (*RIM*) is a method for multi-objective optimization, introduced in the first time in 2014 [21]. It was applied in a number of cases such as: selecting aircraft for the Spanish army [22], optimizing milling process [23-25]. One important advantage of this method over other *MCDM* methods is that there is no need to normalize data. As a consequence, the obstacles in choosing a data normalization method are removed in the use of this method [26]. However, it appears that no research is published on the application of this method for multi-objective optimization of turning process to date. This is the reason for application of *RIM* in this study.

The next sections of this research are implemented as follows: multi-objective optimization steps under *RIM* method, experimental process of turning steel SCM440, analysis of experimental results, application of *RIM* method for multi-objective optimization of turning operation, and conclusions as well as the work to be done in the next research.

2. RIM METHOD

RIM is a method for multi-objective optimization. It is based on the concept of "*ideal solution*" and performed by the following steps [21]:

Step 1: Normalized process.

In this step, the reference ideal interval is defined as (1).

$$d_{min}(x,[C,D]) = \min(|x-C|,|x-D|) \tag{1}$$

Where:

x is the value of a criterion at a certain alternative.

[*C*, *D*] is the ideal reference interval.

The next step of the normalized process is to determine the normalization value using the following equation:

$$f(x,[A,B],[C,D]) = \begin{cases} 1 & if\ x \in [C,D] \\ 1-\dfrac{d_{min}(x,[C,D])}{|A-C|} & if\ x \in [A,C] and\ A \neq C \\ 1-\dfrac{d_{min}(x,[C,D])}{|D-B|} & if\ x \in [D,B]\ and\ D \neq B \end{cases} \tag{2}$$

Where [*A*, *B*] is the range of values from the smallest to the largest of a certain criterion.

Step 2: Normalize the valuation matrix *X* with the reference ideal.

$$Y = \begin{bmatrix} f(x_{11}, t_1, s_1) & \dots & f(x_{1n}, t_n, s_n) \\ f(x_{21}, t_1, s_1) & \dots & f(x_{2n}, t_n, s_n) \\ \dots & \dots & \dots \\ f(x_{m1}, t_1, s_1) & \dots & f(x_{mn}, t_n, s_{1n}) \end{bmatrix} \quad (3)$$

Where function *f* is defined as (2), *n* the number of criteria, *m* the number of alternatives

Step 3: Determine the weight for each criterion, where *i* is the criterion.

$$\sum_{i=1}^{n} w_i = 1 \ and \ 0 < w_i < 1 \quad (4)$$

Step 4: Calculate the weighted normalized matrix Y'

$$Y' = Y.W = \begin{bmatrix} y_{11} \cdot w_1 & \dots & y_{1n} \cdot w_n \\ y_{21} \cdot w_1 & \dots & y_{2n} \cdot w_n \\ \dots & \dots & \dots \\ y_{m1} \cdot w_1 & \dots & y_{mn} \cdot w_n \end{bmatrix} \quad (5)$$

Step 5: Calculate the variation to the normalized reference ideal for each alternative.

$$I_i^+ = \sqrt{\sum_{j=1}^{m} \left(y'_{ij} - w_j\right)^2} \quad (6)$$

$$I_i^- = \sqrt{\sum_{j=1}^{n} \left(y'_{ij}\right)^2} \quad (7)$$

Where:

i = 1, 2, … m (alternative)

j = 1, 2, … n (criterion)

Step 6: Calculate the relative index

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

Where: 0 < R_i < 1, i = 1, 2, ….*m*

Step 7: Order the alternatives based on R_i. The alternative with highest R_i is the most optimal.

3. EXPERIMENT OF TURNING OPERATION

3.1. Material

SCM440 steel was used to carry out experiments. It is capable of withstanding heavy loads, good wear resistance, and high impact resistance. The steel is commonly used to produce components for variable loads such as drive shafts, gears, plastic injection molds, roller shafts, etc.

Table 1 shows the designation of the steel according to several standards. Some mechanical properties of this steel are presented in the Table 2. The composition of steel determined by analysis on a spectrophotometer is presented in Table 3. Steel specimens with diameter of 30mm and length of 300mm are heat-treated to reach the hardness of 52HRC.

Table 1. Designation of SCM440 steel in several standards

Country	Japan	USA	Germany	China	UK	France
Standard	JIS	AISI	DIN	GB	BS	NF
Symbols	SCM440	4140	10083-3	42CrMo	42CrMo4	42CrMo4

Table 2. Mechanical properties of SCM440 steel

Properties	Unit	Value
Yield strength min	MPa	940
Tensile strength	MPa	> 1040
Youngs module	GPa	210
Poisson´s ratio	-	0.3
Shear module	GPa	80
Density	kg/m^3	7800

Table 3. Chemical composition of SCM440 steel

Element	C	Si	Mn	Cr	Mo	S	P
%	0.42	0.26	0.68	1.02	0.22	0.022	0.018

3.2. Machine and cutting tools

DOOSAN CNC lathes are used to implement the experiments (Fig. 1).

Three types of cutting tools include: TiN-coated, TiCN-coated and TiAlN-coated. They are products of Lungaloy (Japan). Each type of them is also used with three different radius of 0.2 mm, 0.4 mm and 0.6 mm.

3.3. Experiment plan

In this study, five input parameters are selected for the experimental matrix including: insert material (*IM*), tool nose radius (*r*), spindle speed (*n*), feed rate (*f*) and depth of cut (a_p). Three levels of each parameter were considered as shown in Table 4. This selection is based on recommendation from manufacturer of the cutting tools. Experimental matrix designed under the Taguchi approach is an orthogonal matrix L27, as shown in Table 5.

Fig. 1. Machine

3.4. Experimental condition

The experiments were carried out under the condition: using 420 industrial oil (produced by Vietnam) which has concentration of 8%, irrigation flow rate of 12 liters/min; each cutting tool is used only once so as to eliminate the effect of tool wear on the output parameters.

3.5. Measuring instrument

Surface roughness of each test sample is measured by machine Rugosurf 10G from TESA Techonology (Switzerland). The standard length of measurement is set at 0.8 mm. Each specimen is measured at least 3 times; the measuring direction is parallel to the center line of the sample (perpendicular to the cutting velocity vector). Fig. 2 contains pictures of some test samples and surface roughness tester. The surface roughness of each test is the average of the successive measurements.

Fig. 2. Test samples and surface roughness tester

MRR is defined as:

$$MRR = \frac{1}{60} n \,.\pi.d.f.a_p \quad (\text{mmm}^3/\text{s}) \qquad (9)$$

Where: *n* is spindle speed, *d* is diameter of workpiece, *f* is feed rate and a_p is depth of cut.

Table 4. Levels of parameters

Parameter	Symbol	Unit	Value at level		
			1	2	3
Insert material	*IM*	-	TiN	TiCN	TiAlN
Tool nose radius	*r*	mm	0.2	0.4	0.6
Spindle speed	*n*	rev/min	600	800	1000
Feed rate	*f*	mm/rev	0.08	0.12	0.16
Depth of cut	a_p	mm	0.2	0.35	0.5

Table 5. Othogonal array (L27)

No.	*IM*	*r*	*n*	*f*	a_p	*IM*	*r* (mm)	*n* (rev/min)	*f* (mm/rev)	a_p (mm)
1	1	1	1	1	1	TiN	0.2	600	0.08	0.2
2	1	1	1	1	2	TiN	0.2	600	0.08	0.35
3	1	1	1	1	3	TiN	0.2	600	0.08	0.5
4	1	2	2	2	1	TiN	0.4	800	0.12	0.2
5	1	2	2	2	2	TiN	0.4	800	0.12	0.35
6	1	2	2	2	3	TiN	0.4	800	0.12	0.5
7	1	3	3	3	1	TiN	0.6	1000	0.16	0.2
8	1	3	3	3	2	TiN	0.6	1000	0.16	0.35
9	1	3	3	3	3	TiN	0.6	1000	0.16	0.5
10	2	1	2	3	1	TiCN	0.2	800	0.16	0.2
11	2	1	2	3	2	TiCN	0.2	800	0.16	0.35

Table 5. Othogonal array (L27) - *continuation of the Table 5 from the previous page*

12	2	1	2	3	3	TiCN	0.2	800	0.16	0.5
13	2	2	3	1	1	TiCN	0.4	1000	0.08	0.2
14	2	2	3	1	2	TiCN	0.4	1000	0.08	0.35
15	2	2	3	1	3	TiCN	0.4	1000	0.08	0.5
16	2	3	1	2	1	TiCN	0.6	600	0.12	0.2
17	2	3	1	2	2	TiCN	0.6	600	0.12	0.35
18	2	3	1	2	3	TiCN	0.6	600	0.12	0.5
19	3	1	3	2	1	TiAlN	0.2	1000	0.12	0.2
20	3	1	3	2	2	TiAlN	0.2	1000	0.12	0.35
21	3	1	3	2	3	TiAlN	0.2	1000	0.12	0.5
22	3	2	1	3	1	TiAlN	0.4	600	0.16	0.2
23	3	2	1	3	2	TiAlN	0.4	600	0.16	0.35
24	3	2	1	3	3	TiAlN	0.4	600	0.16	0.5
25	3	3	2	1	1	TiAlN	0.6	800	0.08	0.2
26	3	3	2	1	2	TiAlN	0.6	800	0.08	0.35
27	3	3	2	1	3	TiAlN	0.6	800	0.08	0.5

4. RESULT AND DISCUSSION

The order of experiments is shown in Table 5. Results of surface roughness and *MRR* are presented in Table 6.

Based on the results in Table 6, the influence of the cutting parameters on surface roughness is shown in Fig. 3. According to (9), parameters including spindle speed, depth of cut, feed rate clearly affect the *MRR*. Increasing the value of these parameters increases the *MRR*. The tool nose radius and the insert material are not in formula (9), thus not affecting the MRR. Fig. 3 shows that: The tool nose radius has the greatest impact on surface roughness, followed by the cutting tool material and the feed rate. Meanwhile the spindle speed and depth of cut are inconsiderable to surface roughness. This is also similar to the results of turning AISI 1045 steel [27] and turning 9XC steel [28]. Data in Table 6 also reveal that surface roughness has the minimum value (0.210 µm) in trial No.20, while *MRR* has the maximum (equal to 134.041 mm^3/s) in the trial No. 9. In the remaining experiments, although the surface roughness is probably small, the *MRR* is not large. Hence, it is substantial to identify which is considered “best” of the 27 experiments that were conducted. In other words, in that experiment, the surface roughness is “minimum” and *MRR* is “maximum” at the same time. Consequently, it is necessary to solve the multi-objective problem.

Table 6. Result of the experiments

No.	*IM*	*r* (mm)	*n* (rev/min)	*f* (mm/rev)	a_p (mm)	*Ra* (µm)	*MRR* (mmm^3/s)
1	TiN	0.2	600	0.08	0.2	0.784	16.085
2	TiN	0.2	600	0.08	0.35	1.482	28.149
3	TiN	0.2	600	0.08	0.5	1.725	40.212
4	TiN	0.4	800	0.12	0.2	1.563	32.170
5	TiN	0.4	800	0.12	0.35	0.92	56.297
6	TiN	0.4	800	0.12	0.5	1.003	80.425
7	TiN	0.6	1000	0.16	0.2	2.243	53.617
8	TiN	0.6	1000	0.16	0.35	1.609	93.829
9	TiN	0.6	1000	0.16	0.5	0.877	134.041
10	TiCN	0.2	800	0.16	0.2	0.296	42.893

Table 6. Result of the experiments - *continuation of the Table 6 from the previous page*

11	TiCN	0.2	800	0.16	0.35	0.364	75.063
12	TiCN	0.2	800	0.16	0.5	0.815	107.233
13	TiCN	0.4	1000	0.08	0.2	1.094	26.808
14	TiCN	0.4	1000	0.08	0.35	2.957	46.914
15	TiCN	0.4	1000	0.08	0.5	1.031	67.021
16	TiCN	0.6	600	0.12	0.2	1.002	24.127
17	TiCN	0.6	600	0.12	0.35	3.143	42.223
18	TiCN	0.6	600	0.12	0.5	1.576	60.319
19	TiAlN	0.2	1000	0.12	0.2	0.372	40.212
20	TiAlN	0.2	1000	0.12	0.35	0.210	70.372
21	TiAlN	0.2	1000	0.12	0.5	0.351	100.531
22	TiAlN	0.4	600	0.16	0.2	0.884	32.170
23	TiAlN	0.4	600	0.16	0.35	1.962	56.297
24	TiAlN	0.4	600	0.16	0.5	0.533	80.425
25	TiAlN	0.6	800	0.08	0.2	0.554	21.447
26	TiAlN	0.6	800	0.08	0.35	1.576	37.532
27	TiAlN	0.6	800	0.08	0.5	1.628	53.617

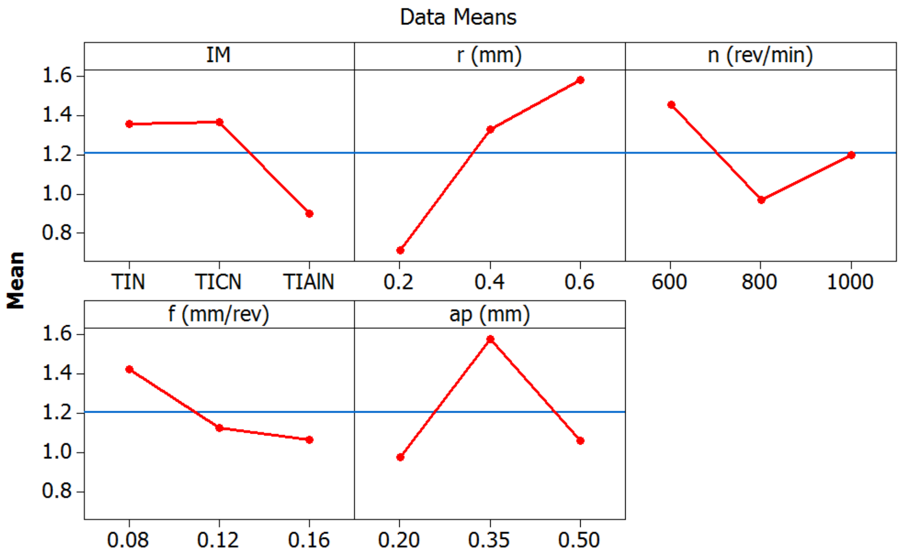

Fig. 3. Main effects plot for Ra

5. MULTI-OBJECTIVE OPTIMIZATION WITH RIM METHOD

According to Table 6, the surface roughness reached the minimum of 0.21 µm and the maximum of 3.143 µm. Besides, the *MRR* reached the maximum of 134,041 mm^3/s and the minimum of 16,065 mm^3/s.

Then:

[A, B] = [0.21 3.143 16.065 134.041]

[C, D] = [0.21 0.21 134.041 134.041].

Equation (1) is applied to determine the ideal reference interval of *Ra* and *MRR*. Equation (2) is used to define the normalized valuation of *Ra* and *MRR*. Equations (3) to (7) allow to calculate I_i^+ and I_i^-, where the weight of surface roughness and MRR are chosen to be equal, $w_1 = w_2 = 0.5$ [29-31]. All the indices are shown in Table 7.

Equation (8) is used to calculate R_i of 27 alternatives. Then, the alternatives is ordered based on R_i. The results are presented in Table 8.

Table 7. Indices calculation based on RIM

No.	d_{min} (Ra, [C, D])	d_{min} (MRR, [C, D])	f (Ra)	f (MRR)	I_i^+	I_i^-
1	0.574	-117.956	0.804	2.000	0.5094	1.0778
2	1.272	-105.892	0.566	1.898	0.4984	0.9901
3	1.515	-93.829	0.483	1.795	0.4742	0.9296
4	1.353	-101.871	0.539	1.863	0.4895	0.9699
5	0.71	-77.744	0.758	1.659	0.3510	0.9120
6	0.793	-53.616	0.730	1.454	0.2644	0.8136
7	2.033	-80.424	0.307	1.682	0.4861	0.8547
8	1.399	-40.212	0.523	1.341	0.2931	0.7196
9	0.667	0	0,773	1.000	0.1137	0.6318
10	0.086	-91.148	0.971	1.773	0.3866	1.0105
11	0.154	-58.978	0.947	1.500	0.2513	0.8871
12	0.605	-26.808	0.794	1.227	0.1534	0.7308
13	0.884	-107.233	0.699	1.909	0.4788	1.0164
14	2.747	-87.127	0.063	1.739	0.5964	0.8698
15	0.821	-67.02	0.720	1.568	0.3167	0.8628
16	0.792	-109.914	0.730	1.932	0.4850	1.0325
17	2.933	-91.818	0.000	1.778	0.6336	0.8891
18	1,366	-73.722	0.534	1.625	0.3897	0.8552
19	0.162	-93.829	0.945	1.795	0.3986	1.0144
20	0	-63.669	1.000	1.540	0.2698	0.9180
21	0.141	-33.51	0.952	1.284	0.1440	0.7992
22	0.674	-101.871	0.770	1.863	0.4468	1.0082
23	1.752	-77.744	0.403	1.659	0.4447	0.8536
24	0.323	-53.616	0.890	1.454	0.2338	0.8525
25	0.344	-112.594	0.883	1.954	0.4808	1.0722
26	1.366	-96.509	0.534	1.818	0.4707	0.9475
27	1.418	-80.424	0.517	1.682	0.4179	0.8796

Table 8. Order the alternatives

No.	IM	r (mm)	n (rev/min)	f (mm/rev)	a_p (mm)	Ra (µm)	MRR (mmm^3/s)	R_i	Ranking
1	TiN	0.2	600	0.08	0.2	0.784	16.085	0.6790	18
2	TiN	0.2	600	0.08	0.35	1.482	28.149	0.6652	21
3	TiN	0.2	600	0.08	0.5	1.725	40.212	0.6622	23
4	TiN	0.4	800	0.12	0.2	1.563	32.170	0.6646	22
5	TiN	0.4	800	0.12	0.35	0.92	56.297	0.7221	10
6	TiN	0.4	800	0.12	0.5	1.003	80.425	0.7547	7
7	TiN	0.6	1000	0.16	0.2	2.243	53.617	0.6375	24
8	TiN	0.6	1000	0.16	0.35	1.609	93.829	0.7106	12
9	TiN	0.6	1000	0.16	0.5	0.877	134.041	0.8475	1
10	TiCN	0.2	800	0.16	0.2	0,296	42.893	0.7233	9
11	TiCN	0.2	800	0.16	0.35	0.364	75.063	0.7792	5

Table 8. Order the alternatives - *continuation of the Table 8 from the previous page*

12	TiCN	0.2	800	0.16	0.5	0.815	107.233	0.8265	3
13	TiCN	0.4	1000	0.08	0.2	1.094	26.808	0.6798	17
14	TiCN	0.4	1000	0.08	0.35	2.957	46.914	0.5933	26
15	TiCN	0.4	1000	0.08	0.5	1.031	67.021	0.7315	8
16	TiCN	0.6	600	0.12	0.2	1.002	24.127	0.6804	16
17	TiCN	0.6	600	0.12	0.35	3.143	42.223	0.5839	27
18	TiCN	0.6	600	0.12	0.5	1.576	60.319	0.6870	15
19	TiAlN	0.2	1000	0.12	0.2	0.372	40.212	0.7179	11
20	TiAlN	0.2	1000	0.12	0.35	0.210	70.372	0.7728	6
21	TiAlN	0.2	1000	0.12	0.5	0.351	100.531	0.8473	2
22	TiAlN	0.4	600	0.16	0.2	0.884	32.170	0.6929	13
23	TiAlN	0.4	600	0.16	0.35	1.962	56.297	0.6575	25
24	TiAlN	0.4	600	0.16	0.5	0.533	80.425	0.7848	4
25	TiAlN	0.6	800	0.08	0.2	0.554	21.447	0.6904	14
26	TiAlN	0.6	800	0.08	0.35	1.576	37.532	0.6681	20
27	TiAlN	0.6	800	0.08	0.5	1.628	53.617	0.6779	19

The data in Table 8 indicate that trial No.9 is “the best”, while trial No.17 is “the worst”. In the trial No.9, *MRR* has the largest value among 27 experiments conducted, while surface roughness is 0.877 µm. Although this is not the smallest value of surface roughness, it is still relatively small, ranked tenth out of twenty-seven trials (higher than trial No.1, No.10, No.11, No.12, No.19, No.20, No.21, No.24 and No.25). It can be said that considering purpose of determining the value of the input parameters for achieving the “minimum” surface roughness and the “maximum” *MRR*, test No.9 is “the best”. As a result, the TiN-coated cutting tool, the tool nose radius of 0.6 mm, the spindle speed of 1000 rev/min, the feed rate of 0.16/rev and depth of cut of 0.5 mm are the substantial inputs for having the minimum surface roughness and the maximum *MRR* when turning SCM440 steel.

6. CONCLUSIONS

In this research, the SCM440 steel turning operation is carried out using three different types of cutting tools (TiC, TiCN and TiAlN). For each type of cutting tools, the tool nose radius, spindle speed, depth of cut, feed rate are selected as the input cutting parameters. Analysis of experimental results determines the influence of cutting parameters on surface roughness. The *RIM* method is also used for multi-objective optimization of the turning process. Some conclusions are drawn as follows.

- The tool nose radius greatly affects the surface roughness, followed by the material of cutting tool and the feed rate, while the spindle speed and depth of cut have a negligible impact on the surface roughness.
- The *RIM* method is applied successfully to solve multi-objective problem. The result demonstrates that in order to achieve the “minimum” surface roughness and the “maximum” *MRR*, the cutting tool is ideally TiN-coated and tool nose radius is 0.6 mm, spindle speed is 1000 rev/min (corresponding to cutting spedd of 94.25 m/min), feed rate is 0.16 mm/rev and depth of cut is 0.5 mm.

The *RIM* method is used effectively for the first time in optimizing the turning operation. It is also promising to be successful for solving multi-objective problem in different machining methods.

REFERENCE

[1] D.D. Trung, Effect of cutting parameters on the surface roughness and roundness error when turning the interrupted surface of 40X steel using HSS-TiN insert. *Applied Engineering Letters*, 7(1), 2022: 1-9. https://doi.org/10.18485/aeletters.2022.7.1.1

[2] T.V. Dich, N.T. Binh, N.T. Dat, N.V. Tiep, T.X. Viet, Manufacturing technology. *Science and Technics Publishing House*, Ha Noi, 2003.

[3] H. Yanda, J.A. Ghani, M.N.A.M. Rodzi, K. Othman, C.H.C. Haron, Optimization of material removal rate, surface roughness and tool life on conventional dry turning of FCD700. *International Journal of Mechanical and Materials Engineering*, 5(2), 2010: 182-190.

[4] M.S. Ranganath, Vipin, R.S. Mishra, Optimization of surface roughness and material removal rate on conventional dry turning of aluminium (6061). *International Journal of Advance Research and Innovation*, 1, 2014: 62-71.

[5] A. Aswal, A. Jha, A. Tiwari, Y. Kumar Modi, CNC turning parameter optimization for surface roughness of aluminium-2014 alloy using Taguchi methodology. *Journal Européen des Systèmes Automatisés*, 52(4), 2019: 387-390. https://doi.org/10.18280/jesa.520408

[6] A. Pridhvijit, B.C. Yeldose, Experimental Study and Parameter Optimization of Turning Operation of Aluminium Alloy-2014. *International Journal of Engineering Research and General Science*, 3(5), 2015: 525-530.

[7] R. Aryan, F. John, S. Kumar, A. Kumar, Optimization of turning parameters of AL-Alloy 6082 using Taguchi method. *International Journal of Advance Research and Innovation*, 5(2), 2017: 268-275.

[8] V.V.D. Sahithi, T. Malayadrib, N. Srilatha, Optimization of turning parameters on surface roughness based on Taguchi technique. *Materials Today: Proceedings*, 18, 2019: 3657-3666. https://doi.org/10.1016/j.matpr.2019.07.299

[9] M. Gupta, S. Kumar, Investigation of surface roughness and MRR for turning of UD-GFRP using PCA and Taguchi method. *Engineering Science and Technology, an International Journal*, 18(1), 2015: 70-81. https://doi.org/10.1016/j.jestch.2014.09.006

[10] S.G. Dambhare, S.J. Deshmukh, A.B. Borade, Machining parameter optimization in turning process for sustainable manufacturing. *International Journal of Industrial Engineering Computations*, 6, 2015: 327-338. https://doi.org/10.5267/j.ijiec.2015.3.002

[11] Y. Touggui, S. Belhad, S. Mechraou, A. Uysa, M.A. Yallese, M. Temmar, Multiobjective optimization of turning parameters for targeting surface roughness and maximizing material removal rate in dry turning of AISI 316L with PVDcoated cermet insert. *SN Applied Sciences*, 2(1360), 2020: 1-14. https://doi.org/10.1007/s42452-020-3167-4

[12] S. Dhanalakshmi, T. Rameshbabu, Multi-Aspects optimization of process parameters in CNC Turning of LM 25 alloy using the Taguchi-Grey approach. *Metals*, 10(4), 2020: 453. https://doi.org/10.3390/met10040453

[13] F. Puh, Z. Jurkovic, M. Perinic, M. Brezocnik, S. Buljan, Optimization of machining parameters for turning operation with multiple quality characteristics using Grey relational analysis. *Tehnički vjesnik*, 23(2), 2016: 377-382. https://doi.org/10.17559/TV-20150526131717

[14] N.H. Alharthi, S. Bingol, A.T. Abbas, A.E. Ragab, M.F. Aly, H.F. Alharbi, Prediction of cutting conditions in turning AZ61 and parameters optimization using regression analysis and artificial neural network. *Advances in Materials Science and Engineering*, 2018, 2018: 1-11. https://doi.org/10.1155/2018/1825291

[15] D.D. Trung, N.V. Thien, N.T. Nguyen, Application of TOPSIS method in multi-objective optimization of the grinding process using segmented grinding wheel. *Tribology in Industry*, 43(1), 2021: 12-22. https://doi.org/10.24874/ti.998.11.20.12

[16] N.T. Nguyen, D.D. Trung, Combination of Taguchi method, Moora and Copras techniques in multi-objective optimization of surface grinding process. *Journal of Applied Engineering Science*, 19(2), 2021: 390-398. https://doi.org/10.5937/jaes0-28702

[17] N.T. Nguyen, D.D. Trung, A study on the surface grinding process of the SUJ2 steel using CBN slotted grinding wheel. *AIMS Materials Science*, 7(6), 2020: 871-886. https://doi.org/10.3934/matersci.2020.6.87

[18] Khan, K. Maity, D. Jhodkar, An Integrated Fuzzy-MOORA Method for the Selection of Optimal Parametric Combination in Turing of Commercially Pure Titanium. *Optimization of Manufacturing Processes,* 2020(719), 2020: 163-184. https://doi.org/10.1007/978-3-030-19638-7_7

[19] M.A. Sofuoglu, R.A. Arpoglu, S. Orak, Multi objective optimization of turning operation using hybrid decision making analysis. *Anadolu University Journal of Science and Technology A - Applied Sciences and Engineering*, 18(3), 2017: 595-610.

[20] M.A. Sofuoglu, S. Orak, A Novel Hybrid Multi Criteria Decision Making Model: Application to Turning Operations. *International Journal of Intelligent Systems and Applications in Engineering*, 5(3), 2017: 124-131.

[21] E.C. Perez, M.T. Lamata, J.L. Verdegay, RIM-Reference ideal method in multicriteria decision making. *Information Sciences*, 337-338, 2016: 1-10. https://doi.org/10.1016/j.ins.2015.12.011

[22] J.M. Sánchez-Lozano, O.N. Rodríguez, Application of fuzzy reference ideal method (FRIM) to the military advanced training aircraft selection. *Applied Soft Computing Journal*, 88, 2020: 106061. https://doi.org/10.1016/j.asoc.2020.106061

[23] M.A. Sofuoğlu, A new hybrid decision making model to optimize machining operations. *The Online Journal of Science and Technology*, 8(2), 2018: 5-8.

[24] S. Gurgen, F.H. Cakır, M.A. Sofuoglu, S. Orak, M.C. Kushan, H. Li, Multi-criteria decision-making analysis of different non-traditional machining operations of Ti6Al4V. *Soft Computing*, 23, 2019: 5259-5272. https://doi.org/10.1007/s00500-019-03959-8

[25] D.D. Trung, Multi-objective optimization of SKD11 steel milling process by Reference Ideal Method. *International journal of geology*, 15, 2021: 1016. https://doi.org/10.46300/9105.2021.15.1

[26] V.R. Ravipudi, L. Jaya, R-method: A simple ranking method for multi-attribute decision-making in the industrial environment. *Journal of Project Management*, 6, 2021: 223-230. https://doi.org/10.5267/j.jpm.2021.5.001

[27] S. Nguyen Hong, U. Vo Thi Nhu, Multi-objective Optimization in Turning Operation of AISI 1055 Steel Using DEAR Method. *Tribology in Industry*, 41(1), 2021: 57-65. https://doi.org/10.24874/ti.1006.11.20.01

[28] U. Vo Thi Nhu, S. Nguyen Hong, Improving accuracy of surface roughness model while turning 9XC steel using a Titanium Nitride-coated cutting tool with Johnson and Box-Cox transformation. *AIMS Materials Science*, 8(1), 2021: 1-17. https://doi.org/10.3934/matersci.2021001

[29] G.K. Kumar, Ch.M. Rao, V.V.S. Kesava Rao, Investigation of effects of speed and depth of cut on multiple responses using Vikor analysis. *International Journal of Modern Trends in Engineering and Research*, 5, 2018: 164-168.

[30] D.D. Trung, Application of TOPSIS an PIV Methods for Multi - Criteria Decision Making in Hard Turning Process. *Journal of Machine Engineering,* 21(4), *2021: 57-71.* https://doi.org/10.36897/jme/142599

[31] R. Kumar, R. Dubey, S. Singh, S. Singh, C. Prakash, Y. Nirsanametla, G. Krolczy, R. Chudy, Multiple - Criteria Decision-Making and Sensitivity Analysis for Selection of Materials for Knee Implant Femoral Component. *Materials*, 14(8), 2021: 2084. https://doi.org/10.3390/ma14082084