MULTI-OBJECTIVE OPTIMIZATION OF TURNING PARAMETERS USING THE COMBINED MOORA AND ENTROPY METHOD

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ABSTRACT

Selection of optimum machining parameters in machining operations leads to good functional attributes for the machined components and increased productivity. In this work, machining parameters and nose radius are optimized in turning of EN25 steel with coated carbide tool by the application of combined Multi-Objective Optimization by Ratio Analysis (MOORA) and entropy measurement method. The selected machining parameters are cutting speed, feed rate, depth of cut and nose radius for minimization of surface roughness, micro-hardness and maximization of Material Removal Rate (MRR). Entropy concept has been used to assign the weight criteria of each objective being considered. The optimum combination of machining parameters and nose radius are obtained using normalized assessment values. The results obtained in the analysis are validated and the results based on turning process responses can be effectively improved.

Keywords: turning; EN25 steel; machining parameters; combined MOORA and entropy method.

OPTIMISATION DES PARAMÈTRES DE COUPE LORS D'OPÉRATIONS DE TOURNAGE PAR UNE APPROCHE COMBINANT LES MÉTHODES DE MOORA ET D'ENTROPIE

RÉSUMÉ

La sélection des paramètres de coupe optimaux lors d'opérations de tournage assure le fonctionnement adéquat d'une machine et permet d'augmenter sa productivité. Dans cette étude, les paramètres de la machine et le rayon du bout de l'outil recouvert de carbure sont optimisés pour des opérations de tournage sur de l'acier EN 25 par une approche combinant les méthodes de MOORA et d'entropie. Les paramètres de la machine choisis sont la vitesse de coupe, la vitesse de déplacement, la profondeur de coupe et le rayon du bout de l'outil, avec pour objectif de minimiser la rugosité de surface et la micro dureté, et de maximiser le taux d'enlèvement de matériel (MRR). Un concept d'entropie a été utilisé pour trouver les poids de chacun des objectifs à considérer. La combinaison optimale des paramètres de la machine et le rayon est obtenue en utilisant le concept de valeur normalisée. Les résultats obtenus dans cette analyse ont été validés et démontrent que les procédés de tournage peuvent être améliorés de façon efficace.

Mots-clés : tournage; acier EN25; paramètres d'usinage; méthode de Moora et méthode d'entropie.

1. INTRODUCTION

The selection of proper machining parameters and tool geometry leads to quality, accuracy and functional attributes of the machined component [1]. Tool nose radius is an important objective parameter in turning operation to obtain high machining performance [2]. It is also significant tool geometry in the estimation of surface roughness [3]. Proper selection of tool nose radius improves machinability and tool life by tool tip temperature reduction and minimum surface roughness [4].

Surface roughness measurement is an important performance characteristic in machinability studies [5]. The quality of the machined component is assured by surface roughness measurement which is an important part of manufacturing. In machining operation, products with high quality are produced by setting proper machining parameters [6]. Nowadays, manufacturing industries pay special attention to obtaining good surface finish in machining operations [7]. In machining operations, surface roughness and rate of material removal are important production parameters [8]. Micro-hardness is an important factor in the machining operation for assesment of the surface integrity. Micro-hardness measurement is used to analyze the functional behaviour of the machined surface and to estimate the work hardening effect due to machining operations. Micro-hardness measurement is used to determine the difference between machining affected zones and the bulk material [9, 10]. The highest production rate with reduced cost is achieved by high rate of material removal. The rate of material removal influences the cost of machining, therefore optimum machining parameters selection is important for high material removal rate (MRR) [11].

The optimal machining parameters setting plays a significant role to improve the performance of any machining operation. Generally, the optimum machining parameters are considered based on the experience and datas from standard handbooks. However, this is not an optimal one in most of the situations [12]. Hence, prediction of optimum machining parameters is a very important task in turning operation to obtain good machining performance.

In real time manufacturing, the decision-making process is more difficult due to various interests and values of different decision makers. There is a need for simple, systematic and logical procedure to solve decision-making problems effectively. The MOORA method is one of the Multi-Criteria Decision-Making (MCDM) methods which use statistical procedure for the selection of the best alternative from the given alternatives. This method generates most suitable alternatives by considering both beneficial (maximization) and non-beneficial (minimization) alternatives and eliminates unsuitable alternatives for strengthening the existing selection procedure. The MOORA method involves lesser computations, comprehensiveness and robustness which can solve multiple numbers of criteria simultaneously [13]. In the solution of multi-objective optimization, the relative importance of each criterion can be calculated using the entropy measurement concept. In information theory, entropy is a measure of how disorganized a system is. While applying the entropy concept for weight measurement, it is evident that an attribute having high entropy has a high diversity of output parameters. This attribute has a significant effect on the output parameter [14].

2. LITERATURE REVIEW

The literature review has been done in three areas, namely, the effect of the nose radius in turning operation, the application of MOORA method in manufacturing environment, and the weight criteria calculation using the entropy concept in multi-objective optimization.

2.1. Effect of Nose Radius in Turning Operation

Neseli et al. [15] investigated the effect of tool geometry (nose radius, rake angle and approach angle) on surface quality in turning of AISI 1040 steel. The Response Surface Methodology (RSM) concept was used to develop the model for surface roughness. The result revealed that the tool nose radius was a significant output parameter. Kini and Chincholkar [8] studied the effect of machining parameters and nose radius on composite material turning operation using coated carbide tool. A second-order mathematical model was developed to create relationship between machining parameters, nose radius and output parameters. Senthilkumar and Tamizharasan [4] analyzed the effect of insert shape, relief angle and nose radius on flank wear, surface roughness and MRR using Taguchi method. The results indicated that nose radius and insert shape are the important factors.

Aggarwal et al. [16] experimentally investigated the effect of machining parameters, nose radius and cutting environment on surface roughness in turning operation using the Taguchi and RSM methods. The feed rate and nose radius are important and influential parameters. Abhang and Hameedullah [2] determined optimum machining parameters in turning operation using Grey Relational Analysis (GRA). The input parameters include cutting speed, feed rate, nose radius, types of lubricant and output parameters were surface roughness and chip thickness. The results showed that a large nose radius produces chatter and burr on the tool. Saini et al. [17] identified optimum machining parameters and nose radius for minimization of surface roughness and tool wear in turning of AISI H-11 steel using RSM concept. A mathematical model was developed by RSM concept and adequacy of model was checked by analysis of variance. Javidi et al. [3] analyzed the effect of machining parameters and nose radius on the estimation of fatigue life in turning operation. The result revealed that feed rate and nose radius were the main parameters to control residual stress. Navas et al. [18] studied the effect of cutting parameters on residual stress in turning medium carbon steel. The result indicated that feed and larger tool nose radius produced more tensile residual stresses and improved surface finish. Sharman et al. [19] investigated the surface integrity and residual stresses with different types of nose radius in turning Inconel 718. The result revealed that larger tool nose radius leads to surface integrity issue due to inadequate chip thickness at the trailing edge. Motorcu [20] optimized machining parameters and nose radius on surface roughness in turning of AISI 8660 using Taguchi method. The results revealed that feed rate followed by depth of cut were the important parameters on surface roughness. Bhushan [21] predicted the optimum cutting parameters and nose radius in turning of composite materials to minimize power consumption and maximize tool life using RSM concept and desirability analysis. The result revealed a 13.55% power reduction and a 22.12% increased tool life.

2.2. Applications of MOORA Method in Manufacturing Environment

Ray [22] optimized suitable cutting fluid in a traditional manufacturing system using MOORA method. The result mentioned that selected cutting fluid was used to achieve green manufacturing for minimization of environmental impact and maximization of quality. Gadakh et al. [23] optimized welding process parameters simultaneously using MOORA method. Six case studies were considered to explain the applicability of this technique. This technique proved its applicability and potentiality to solve difficult industrial decision-making problems in manufacturing background. Chaturvedi et al. [24] investigated electro-chemical machining process for the selection of optimum machining parameters by MOORA method. This method was reliable for solving multiple objectives with consideration of quality development for any process. Chakraborty [13] devised a MOORA method to solve decision-making problems in manufacturing environment. Six illustrations were considered to demonstrate the MOORA method. Gadakh [25] used the MOORA method to optimize different milling process parameters simultaneously. This method was simple and contains lesser mathematical steps. Karande and Chakraborty [26] used the MOORA method for the selection of materials of a given product. This method is very simple to realize, easy to execute and provided the best alternatives. The result revealed that obtained optimum material conditions are similar to the earlier research output. Ic et al. [27] devised MOORA based Taguchi method to solve multiple criteria in decision-making problems simultaneously. An illustration was considered to reveal the proposed method. This method was used to transfer multi-criteria optimization problems into an equivalent single criteria optimization problem and involves appropriate procedure to solve multiple objectives simultaneously. Rajesh et al. [28] used the Taguchi method combined with MOORA in wear study of composite material for optimization of process

Table 1. Chemical composition of EN 25 steel.

Material	C	Si	Mn	Ni	Cr	Mo	S	P	Fe
EN 25 steel	0.293	0.185	0.629	2.49	0.577	0.51	0.02	0.02	Balance

parameters simultaneously. The result concluded that wear resistant property of composite material was enhanced.

2.3. Weight Criteria Calculation Using Entropy Concept in Multi-Objective Optimization

Rajesh et al. [29] optimized machining parameters and nose radius in turning of composite material using GRA with entropy measurement concept. The results revealed the efficiency of this approach. Entropy method was used to determine the weight criteria of each output parameters. Jangra et al. [14] devised combined methods of Taguchi technique, GRA and entropy measurement for simultaneous optimization of electric discharge machining parameters. Grey relational grade values were calculated by determining the weight of each machining parameter using the entropy method. Better machining characteristics were obtained using this integrated approach. Sharma and Yadava [30] used simultaneous multi-objective optimization using GRA coupled with entropy method. This technique was applied to convert multi-objective optimization into an equivalent single objective optimization. The weight factor corresponding to each objective function was calculated using entropy measurement method.

From the literature review, it is observed that only limited studies are involved in the estimation of optimum machining parameters and nose radius in turning operation using MOORA method. Also, limited studies were reported for the estimation of weight criteria using entropy concept in turning process parameters optimization. According to the authors' knowledge, no literature was reported for machining parameter optimization using combined MOORA and entropy method. Therefore, more studies are needed to analyze the proposed method for the selection of optimum machining parameters and nose radius in turning of EN25 steel with CVD coated carbide tools. Hence, this research study focuses on the estimation of the optimum machining parameters and nose radius that minimize surface roughness and micro-hardness, and maximize MRR simultaneously using combined MOORA and entropy method.

3. EXPERIMENTAL SETUP

EN25 steel, according to DIN specifications, 1.674332 NiCrMn10-4 is used as work piece material and the chemical composition is given in Table 1. This work piece material has better mechanical strength than carbon steel; hence, it is suitable for die holder, drive shaft, axle, and gear [31]. The selected work pieces are round rod with a 38 mm diameter and turning operations are carried out on 120 mm length in CNC turning centre with coolant conditions. Chemical Vapor Deposition (CVD) multi-layer coated turning insert is used as the cutting tool material. This coated tool is made of three layers (TiN/TiCN/AL_2O_3), in which TiN generates heat resistance and minimizes coefficient of friction, TiCN provides wear resistance and thermal stability and Al_2O_3 provides wear resistance at high hardness. Taguchi's mixed level L_{18} orthogonal array is used to minimize experiments to be carried out. In this study, cutting speed, feed rate, depth of cut and nose radius are selected as input parameters in turning operation. Table 2 shows the level of input parameters and their values.

Mitutoyo Surftest SJ 301 roughness testing machine is utilized to measure the surface roughness of the machined component. Surface roughness is determined at three places in the machined samples and average value is considered for analysis.

For the measurement of micro-hardness at the machined surface, Vickers micro-hardness tester is used. Machined samples are cut and then mounted using abrasive cutter and hot mounting machine. The mounted

Table 2. Levels of machining parameters and their values.

Factors	Symbol	Level 1	Level 2	Level 3
Nose radius (mm)	r	0.4	0.8	–
Cutting speed (m/min)	v	107	173	239
Feed rate (mm/rev)	f	0.09	0.17	0.25
Depth of cut (mm)	d	0.4	0.8	1.2

Table 3. Experimental results.

Sl. no	Nose radius (mm)	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (μm)	Micro-hardness (Hv)	MRR (cm^3/min)
1	0.4	107	0.09	0.4	0.96	367	3.85
2	0.4	107	0.17	0.8	1.18	372	14.55
3	0.4	107	0.25	1.2	1.67	374	32.10
4	0.4	173	0.09	0.4	1.02	381	6.22
5	0.4	173	0.17	0.8	1.14	385	23.52
6	0.4	173	0.25	1.2	1.59	391	51.90
7	0.4	239	0.09	0.8	1.12	397	17.20
8	0.4	239	0.17	1.2	1.34	401	48.75
9	0.4	239	0.25	0.4	1.61	394	23.90
10	0.8	107	0.09	1.2	1.21	396	11.55
11	0.8	107	0.17	0.4	2.27	382	7.276
12	0.8	107	0.25	0.8	2.98	388	21.40
13	0.8	173	0.09	0.8	1.32	407	12.45
14	0.8	173	0.17	1.2	2.12	411	35.29
15	0.8	173	0.25	0.4	3.11	402	17.30
16	0.8	239	0.09	1.2	1.54	426	25.81
17	0.8	239	0.17	0.4	2.19	418	16.25
18	0.8	239	0.25	0.8	3.24	421	47.80

specimen is subjected to a sequence of polishing using 180 to 1000 grit SiC metallurgical papers. The sequence of polishing consists of using 180, 240, 320, 400, 600, 800 and 1000 grit SiC papers. Further the hand polished specimens are polished on cloth polishing machine with the help of fine alumina powder to achieve mirror like surface. The micro-hardness is calculated at three locations and the average value is considered for further analysis.

The productivity of any machining operation mainly depends on its rate of material removal. MRR is calculated as shown below [11]

$$\text{MRR} = v \times f \times d \ \text{cm}^3/\text{min}, \tag{1}$$

where v represents cutting speed in m/min; f represents feed rate in mm/rev; d denotes depth of cut in mm. The experimental runs and values of response obtained are shown in Table 3.

4. METHODOLOGY

In manufacturing environment, decision-making of range of alternatives and selection of the best one is an important work. MCDM can be applied to select and rank optimum machining conditions. MOORA is one of the MCDM methods used to select best alternatives among a given number of alternatives. This problem involves various objectives or criteria and also conflict with each other. They are beneficial (maximization) and non-beneficial (minimization) objectives. MOORA method considers both beneficial and non beneficial objectives for solving and ranking optimum alternatives simultaneously. MOORA method uses an efficient procedure to find the weight criteria of each objective. Entropy method is used to assign weight criteria of each objective in multi-objective optimization. Entropy measurement concept is employed to calculate the relative importance of each output parameters. The weight measurement using entropy concept is based on the rationale that characteristics having maximum diversity of output parameters have a major influence on the output parameters. Hence, an effort has been made to combine MOORA and entropy methods to estimate the optimum machining parameters and nose radius in turning of EN25 steel.

The following steps are involved to estimate the optimal machining parameters using combined MOORA and entropy method:

Step 1: Problem description and establishment of objectives.
In the present work, surface roughness and micro-hardness are selected as non beneficial attributes and MRR is selected as a beneficial attribute.

Step 2: Construction of decision matrix.
The decision matrix is used to represent the experimental results with respect to various output parameters. The decision matrix D_{mxn} is represented as

$$D_{mxn} = \begin{bmatrix} X_{11} & X_{12} & \cdots & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & \cdots & X_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{m1} & X_{m2} & \cdots & \cdots & X_{mn} \end{bmatrix}, \tag{2}$$

where X_{ij} indicates the experimental result of ith alternative on jth attribute, m indicates the number of experiments, and n refers to the number of output parameters. The decision matrix $D_{18\times 3}$ is given in Table 4.

Step 3: Normalization of input data.
Generally, normalization is needed, as the variety and unit of output value may be different from others. The meaning of normalization is converting the original score into a comparable score. The output values presented in the decision matrix are normalized with the help of equation (3). The value of normalized decision matrix $N_{18\times 3}$ is presented in Table 4.

The expression used to determine the normalized decision matrix (N_{ij}) is given by

$$N_{ij} = \frac{x_{ij}}{\sqrt{\sum x_{ij^2}}} \quad \text{for} \quad i = 1, m : j = 1, \ldots, n, \tag{3}$$

where x_{ij} and N_{ij} are original and normalized score of decision matrix, respectively.

Step 4: Determination of solution to the multi-objective optimization problem.
The normalized scores are added in the case of beneficial or maximization objective and subtracted in the case of non-beneficial or minimization objective. Then the multi-objective optimization becomes

$$Y_i = \sum_{j=1}^{g} N_{ij} - \sum_{j=g+1}^{n} N_{ij}, \tag{4}$$

where g represents the number of attributes for maximization,(n-g) represents the number of attributes for minimization, and Y_i is the normalized assessment value of ith alternative with respect to all attributes. Table 4 shows the normalized assessment value of selected output parameters.

Table 4. Decision matrix and normalized values of output parameters and corresponding assessment value.

Sl. no	Decision matrix $D_{18\times3}$			Normalized decision matrix $N_{18\times3}$			Normalized assessment
1	0.96	367	3.85	0.119363	0.218710	0.033342	–0.1012
2	1.18	372	14.55	0.146717	0.221689	0.125959	–0.0804
3	1.67	374	32.10	0.207642	0.222881	0.277851	–0.0502
4	1.02	381	6.22	0.126823	0.227053	0.053908	–0.0996
5	1.14	385	23.52	0.141744	0.229437	0.203653	–0.0553
6	1.59	391	51.90	0.197695	0.233012	0.449236	0.0070
7	1.12	397	17.20	0.139257	0.236588	0.148949	–0.0751
8	1.34	401	48.75	0.166611	0.238972	0.422022	0.0062
9	1.61	394	23.90	0.200182	0.234800	0.206873	–0.0755
10	1.21	396	11.55	0.150447	0.235992	0.100026	–0.0950
11	2.27	382	7.276	0.282244	0.227649	0.062980	–0.1486
12	2.98	388	21.40	0.370523	0.231224	0.185234	–0.1383
13	1.32	407	12.45	0.164124	0.242547	0.107817	–0.0992
14	2.12	411	35.29	0.263594	0.244931	0.305480	–0.0670
15	3.11	402	17.30	0.386687	0.239568	0.149745	–0.1583
16	1.54	426	25.81	0.191478	0.25387	0.223423	–0.0734
17	2.19	418	16.25	0.272297	0.249103	0.140674	–0.1264
18	3.24	421	47.80	0.402851	0.250890	0.413747	–0.0791

Step 5: The attributes being considered are more important than others in practical situations.
To identify the important attribute, it must be multiplied with its relative importance. If relative importance is considered, then the equation is modified as

$$Y_i = \sum_{j=1}^{g} W_j N_{ij} - \sum_{j=g+1}^{n} W_j N_{ij} \quad (j = 1, 2, \ldots, n), \tag{5}$$

where W_j represents weight of jth attribute and it is calculated by entropy measurement method.

Various steps are involved to calculate the relative importance of output parameters using entropy method.

From the weight measurement using entropy concept, it is evident that a characteristic having high entropy has a high diversity of output parameters. This characteristic has a major effect on the output parameter.

Mapping function $f_i : [0,1] \to [0,10]$ considered in entropy, must fulfill three criteria:

1. $f_i(0) = 0$;
2. $f_i(x) = f_i(1-x)$;
3. $f_i(x)$ is monotonic increasing in the range of $x \in (0, 0.5)$ [32].

Thus, the function $w_e(x)$ can be used as the mapping function in entropy measurement.

$$w_e(x) = xe^{1-x} + (1-x)e^x - 1. \tag{6}$$

The maximum value of this function occurs at $x = 0.5$, and the value $e^{0:5} - 1 = 0.6487$. In order to let the mapping result in the range [0, 1], the new entropy is defined as

$$W = \frac{1}{e^{0.5-1}} \sum_{i=1}^{m} W_e(x). \tag{7}$$

Summation of the normalized matrix in the entire sequence

$$D_k = \sum_{i=1}^{m} \gamma_i(k), \quad k = 1, 2, \ldots, n. \tag{8}$$

Normalized coefficient is determined as

$$S = \frac{1}{(e^{0.5-1}) \times m} = \frac{1}{0.06487 \times m}. \tag{9}$$

Estimation of entropy value of each objective is given as

$$e_k = s \sum_{i=1}^{m} w_e \left(\frac{\gamma_i(k)}{D_k} \right). \tag{10}$$

Summation of entropy is calculated as

$$E = \sum_{k=1}^{n} e_k. \tag{11}$$

Weight of each objective is obtained as

$$w_k = \frac{\frac{1}{(n-E)}(1-e_k)}{\sum_{k=1}^{n} \frac{1}{(n-E)}(1-e_k)}, \quad k = 1, 2, 3, \ldots, n. \tag{12}$$

In this work, m is considered as 18 and n is considered as 3. The computed entropy values of surface roughness, micro-hardness and MRR are 0.2515356, 0.217721 and 0.212248, respectively. The estimated weights of each output parameters are 0.333228, 0.332224 and 0.334548.

Step 6: Determination of optimum machining parameter level.
Optimum machining parameters level and nose radius are determined using higher value of normalized assessment value. The optimum values are $v = 173$ m/min, $f = 0.25$ mm/rev, $d = 1.2$ mm and nose radius $= 0.4$ mm.

5. RESULTS AND DISCUSSIONS

The experiments are carried out using L_{18} orthogonal matrix and the results are presented in Table 3. The most important measurement in MOORA method is used to analyze experimental results by normalized assessment. In this investigation, level of the maximum value of normalized assessment is used to obtain optimum machining parameters combinations. Table 4 shows data of normalized assessment value. In this study, two categories of output parameters are considered (i.e) maximization and minimization objectives. To achieve optimum conditions, minimization characteristics for surface roughness, micro-hardness and maximization characteristics for MRR are considered.

The weight factors are involved in solving multi-objective optimization. These weights can be assigned by engineers' experiences and importance of output parameters. Entropy measurement is also used to estimate the weight factors of each objective function. The calculated weights of surface roughness, micro-hardness and MRR are found to be 0.333228, 0.332224 and 0.334548, respectively. The calculated weights of surface roughness, micro-hardness and MRR are found to be 0.333228, 0.332224 and 0.334548, respectively.The estimated weight factor of each output parameters are roughly equivalent. The similar types of results are obtained by several researchers during weight determination in optimization of process parameters in turning, EDM and laser process [14, 29, 30]. Based on the high value of normalized assessment, a cutting

Table 5. Predicted and experimental values.

Responses	Predicted value	Experimental value
Surface roughness (μm)	1.59	1.54
Micro-hardness (Hv)	391	389
MRR (cm^3/min)	51.90	51.90
Normalized assessment Y_i	0.0070	0.0094

speed of 173 m/min, a feed rate of 0.25 mm/rev, a depth of cut of 1.2 mm and a nose radius of 0.4 mm are the optimum machining parameters.

The optimum result of nose radius is 0.4 mm. Generally, a large tool nose radius generates good surface finish when single objective is considered. But in this study, multiple objectives are optimized simultaneously for surface roughness, micro-hardness and MRR, the lower value of nose radius is achieved. At larger nose radius condition, there is a chance of chatter, insufficient chip thickness, unsatisfactory chip breaking at trailing edge and shorter tool life due to insufficient cutting edge engagement. The experimental results showed that optimum surface roughness value is obtained at medium level cutting speed. Micro-hardness of the machined surface is decreased when the cutting fluid is used. While machining, cutting fluid is used to reduce the friction and this reduced friction will influence the deformation of the machined layer, which is a major factor for determining the micro-hardness of the surface layer. Also, the reduction of temperature in the cutting zone is not enough to harden the work piece material. Hence, the application of cutting fluid influences the depth of hardening in the machined surfaces. Similar trend was observed by Krolcyzk et al. [9] during turning of duplex stainless steel with coated tool. Generally, feed rate and depth of cut influences MRR. In this study, optimum result shows high level of feed rate and high level depth of cut. Hence, reasonable rate of material removal is achieved at optimized conditions. The validation tests are carried out to confirm the optimal machining parameters achieved during the investigation. The optimum combination of machining parameters r1-v2-f3-d3 is obtained using the combined MOORA and entropy method in turning operation. Therefore, the above optimum machining parameters are considered for validation analysis [14]. The experimental result showed that responses in turning process can be improved effectively. Table 5 shows the predicted and experimental values.

It is noticed that, when compared with other MCDM methods (such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian (VIKOR), GRA etc.), the MOORA method is very simple to understand and easy to implement. This method is based only on simple ratio analysis and lesser mathematical computations, which may be quite useful and helpful to the decision makers who may not have a strong background in mathematics. Also, MOORA method involves less computational time due to its minimum computational steps. Another important advantage of this method is that its computational steps are not affected by the introduction of any extra parameter (for example v in VIKOR and *xi* in GRA methods) as it happens in other multi-objective optimization techniques. For this purpose, the MOORA method is highly desirable for various decision-making problems.

6. CONCLUSIONS

In this experimental study, the combined MOORA and entropy method is applied for the estimation of optimum machining parameters and nose radius to minimize surface roughness, micro-hardness and maximize MRR. The conclusions drawn from this study are as follows:

- Combined MOORA and entropy method is employed to select the optimum machining parameters in turning of EN25 steel with CVD coated tool.

- The high value of normalized assessment demonstrate the optimum cutting speed of 173 m/min, feed rate of 0.25 mm/rev, depth of cut 1.2 mm and nose radius 0.4 mm are essential parameters to minimize surface roughness, micro-hardness and maximize MRR simultaneously.

- Entropy measurement method is also employed to find the relative importance of surface roughness, micro-hardness, and MRR. The weight ratios are found to be 0.333228, 0.332224 and 0.334548, respectively.

- The optimum results are adopted in validation study and the results based on turning process responses can be effectively improved.

- The proposed method can be used for simultaneous optimization of other machining processes with different process parameters.

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