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ASSESSMENT OF SURFACE ROUGHNESS IN MQL ASSISTED TURNING PROCESS OF TITANIUM ALLOY WITH APPLICATION OF TOPSIS-AHP METHOD

The optimization of surface roughness values considered as one of the most significant issues regarding turning process of titanium alloys with the use of minimum quantity lubrication (MQL) method. With such an aim in mind, the application of TOPSIS-AHP method is implemented in order to establish the most favourable cutting parameters for the following values of surface roughness: R_a, R_q and R_z in machining of titanium alloys regarding MQL conditions. The proposed methodology consists of the two stages. At the beginning, tests on turning process were performed on CNC lathe, taking feed rate, approach angle, and cutting speed as input parameters. Then, the TOPSIS-AHP method was applied on the given experimental data and the optimum machining parameters were determined. The findings from current investigations showed that, lower values of cutting speed, feed rate and middle value of approach angle shows the optimal results.

1. INTRODUCTION

Currently, surface quality is valued by many manufacturing industries, and due to the fact that it influences a series of mechanical features, for instance corrosion resistance or creep life, it is regarded as a critical performance parameter. What is more, it affects also other significant properties, such as lubrication, conduction of heat and electricity, friction, and wear [1,2]. It can be therefore stated that obtaining of good quality surface if of great importance, as for parts of machine [3]. Factors contributing to determination of machine parts' quality include for example: feed rate, cutting speed, cut depth, material of tool as well as tool geometry [4,5]. However, cutting fluids are regarded as the most influential factor [6]. The application of cutting fluids is dually beneficial: firstly, it positively affects on surface finishing due to reduction of temperature; and secondly, this strategy guarantees appropriate lubrication between tool-chip interfaces. Nowadays, there are plenty

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of environment-friendly methods to be applied, e.g. minimum quantity lubrication (MQL), dry machining, as well as cryogenic cooling, or flood cooling. Out of these, MQL demonstrated noteworthy results in terms of decreasing expenses connected with machining process, cutting fluid amount, and quality of surface produced. Many scholars undertook to examine the application of the aforementioned technique in machining. The method has provided some satisfying outcomes [7-10]. For example, the use of MQL reduces the tendency to build up edge, which positively affects the quality of the machined surface. Furthermore, it is also found that if the cutting process conditions are not managed efficiently, and then it obstructs the productivity by generating additional expenses related to the equipment and material wasted in the process. As an example, the parameters values of unexpected machining output, like for instance higher temperature (up to 500 °C) or cutting force result in a higher surface roughness value of workpieces, as well as an excessive wearing of cutting inserts, which negatively influences its lifespan [11]. The increasing the tool life period is difficult to determine. The solution can be achieved due to optimization of the performance indices, so as to obtain setting of the input parameter, which would be relevant to the most favourable quality outputs, and to reduce the machining expense [12].

With the aim of selecting the best possible composition of process parameters, the method of Multi Criteria Decision Making i.e., Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) has become very favoured around the globe. The fundamental concept of TOPSIS is that the best choice shall to be as close to the ideal solution as possible and at the same time remote from the solution which is non-ideal [13]. In earlier studies, TOPSIS has been effectively adapted to resolve issues in various fields like management of water and human resources, as well as administration of supply chain and non-traditional machining processes [14]. Lan performed the CNC turning experiments and the parameters were optimized by means of applying both the TOPSIS and Taguchi approaches. The outcome exhibits that the composition of the proposed methods gives very satisfactory results [15].

Yuvaraj and Kumar conducted the Multi Response optimization of abrasive water jet (AWJ) machining process criteria, applying TOPSIS with Taguchi method. They found that Multi Response characteristics of AWJ process of cutting can be improved by this method [16]. Singh et al. optimized the turning parameters using TOPSIS and Taguchi method while machining GFRP composites. The results exposed that the combination of TOPSIS with Taguchi method can be efficiently integrated towards a flexible compatible multi-response optimization methodology [17].

While going through the available literature survey, it has been intensified that the approach of TOPSIS-AHP technique was engaged quite well by scholars and researchers for the purpose of experimentation and Multi Response optimization in the field of engineering applications. In the present paper, we discuss the optimization of the machining parameters in MQL assisted machining process of titanium alloy, with application of TOPSIS-AHP method. The following values of roughness were taken into account in this study: maximum peak to valley (R_z), average roughness (R_a), as well as root mean square (R_q).

2. EXPERIMENTAL SETUP

2.1. CUTTING TOOL AND MACHINED MATERIAL

It is known that titanium and its alloys, thanks to high strength, low weight ratio and outstanding corrosion resistance, are widely used in surgery and medicine as well as in aerospace, automotive, chemical plant, power generation, oil and gas extraction, sports, and other major industries. However, the machining of titanium alloys is not easy and still causes many technological problems. Therefore, for the purpose of testing, a titanium Grade 2 alloy was used, which diameter is equal to 50 mm and length is amounting to 150 mm. Table 1 presents the chosen machined material chemical composition. In order to conduct tests, the inserts of cubic boron nitride (CCGW 09T304-2, rhombic, Clearance 80°, Positive 7°, nose radius 0.4 mm) have been applied. For the tests a case of external turning was chosen.

Table 1. Chemical composition of Titanium Grade 2

C	Fe	H	O	N	Ti
0.1 % max	0.3 %	0.015 %	0.25 %	0.03 %	99.2 %

2.2. TURNING TESTS AND MQL CONDITIONS

The CNC lathe of high accuracy (Sprint 16 TC managed by a Siemens control system), which is able to manage three axes at the same time (X, Y and Z axis), was applied to machining of the relevant super alloy, respectively (Fig. 1).

Fig. 1. Experimental setup

The MQL system was composed by NOGA MQL model with water soluble cutting oil (Protosle MQ make) having a ratio of 20:1. The values of flow rate of 300 ml/hr, rate and pressure of air flow amounting to 60 l/min and 5 bar remained unchanged during the turning experiments, as shown in Fig. 2. The MQL nozzles were placed – one before and the other behind the cutting tool and they were directed at the tool-chip contact zone.

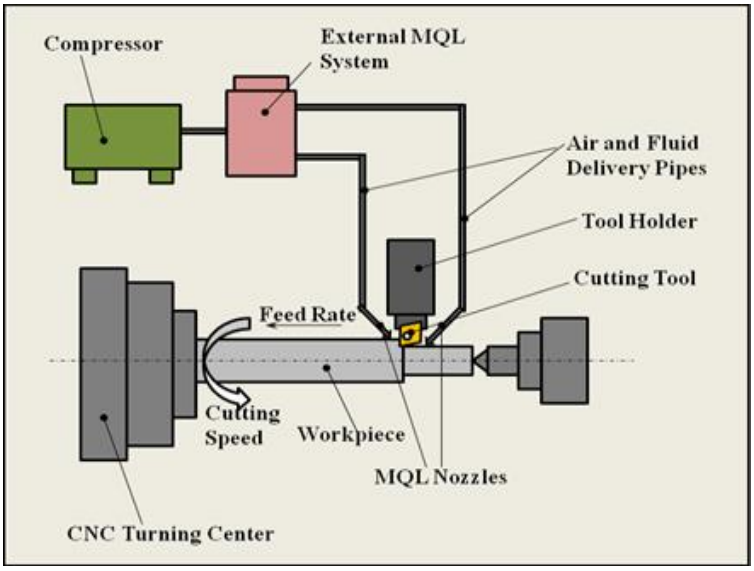

Fig. 2. Scheme of MQL cooling system

2.3. SURFACE ROUGHNESS MEASUREMENTS

In order to measure the aforementioned values of roughness, i.e. root mean square (R_q), maximum peak to valley (R_z), and average roughness (R_a), a portable tester of roughness (SJ301-MITUTOYO make) was applied. The measurements have been performed at 3 distinct spots of the completed machined material in the direction of motion of the tool, and its mean has been applied for the experimentation. The full process of measurement of surface roughness values is shown in Fig. 3.

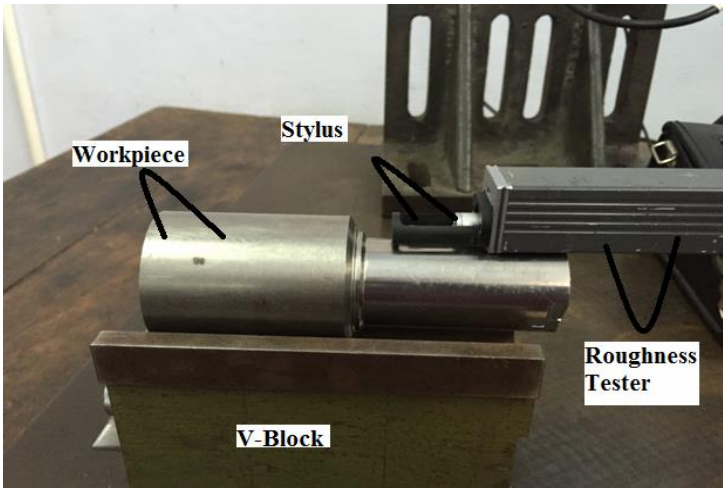

Fig. 3. Measurement of values of roughness

2.4. CUTTING CONDITIONS

The tests of turning were conducted by shifting of the feed rate parameter (f), as well as cutting speed (v_c), and approach angle (φ). As a result of premature tool operation, a poor surface finish was noticed in case of higher parameters of cutting speed (above 300 m/min). Nevertheless, in case of lower cutting speed (>200 m/min), such occurrence was not observed. Therefore, it was decided to select the 200 m/min-300 m/min of cutting speed parameter for machining of titanium Grade 2 alloy with regard to conditions of MQL, when values of approach angle and feed rate were determined in virtue of literature review and suggestions of the tool's manufacturer. For the purpose of tests, a fixed depth of cutting depth of 1 mm has been applied. The results of examinations were shown in Table 2.

Table 2. Exploratory design and their outcomes

Machining Parameters					Responses		
No.	V_c m/min	f mm/rev	φ Deg. (°)		R_a (µm)	R_q (µm)	R_z (µm)
1	200	0.2	75		0.74	0.66	2.86
2	250	0.1	60		0.53	0.8	2.19
3	250	0.1	90		0.57	0.72	2.4
4	250	0.15	75		0.7	0.81	2.75
5	250	0.2	90		0.92	1.32	3.83
6	250	0.15	75		0.67	0.81	2.74
7	250	0.2	60		0.88	1.1	3.63
8	300	0.15	90		0.84	0.95	3.07
9	250	0.15	75		0.65	0.81	2.73
10	200	0.1	75		0.44	0.56	2.07
11	250	0.15	75		0.65	0.81	2.76
12	200	0.15	90		0.76	0.9	3.02
13	300	0.15	60		0.97	1.18	3.64
14	200	0.15	60		0.76	0.92	3.15
15	250	0.15	75		0.65	0.81	2.77
16	300	0.2	75		0.97	1.24	3.52
17	300	0.1	75		0.49	0.63	2.24

3. RESULTS AND DISCUSSIONS

The objective of the study is to perform the multi-response optimization with an application of TOPSIS-AHP method for evaluating a minimum surface roughness values while turning titanium (grade-2) alloy under MQL conditions. The process is described below:

TOPSIS Method

The decision model of titanium (grade-2) alloy turning parameters under MQL conditions are shown in Fig. 4.

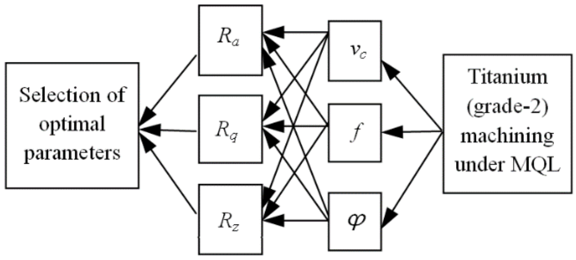

Fig. 4. Decision model of titanium (grade-2) turning parameters under MQL conditions

The complete method is presented as per the following:

Step 1: The TOPSIS approach is ranked as one of the best techniques choosing alternative options for removing the units of all parameters. Besides, the method takes a normalized value. Table 3 presents the normalized performance of the matrix (r_{ij}) produced with the use of the equation below (1):

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \quad i = 1, 2\ldots 17;\ j = 1, 2, 3 \tag{1}$$

In which i = number of experimental runs, j = number of output responses, m = number of alternatives, X_{ij} = normalized value of ith experimental run related to the jth output response.

Step 2: The relative normalized weight (W_j) of each attribute is assigned using analytic hierarchy process (AHP) as per the procedure followed by Rao [18]: (i) counting the geometric mean (GM_i) of ith row, and (*ii*) normalizing thfe geometric means of rows in the analyzed matrix. The aforesaid procedure can be expressed in the form of the following equation (2):

$$GM_i = \left\{\prod_{j}^{N} a_{ij}\right\}^{\frac{1}{N}} \text{ and } W_j = GM_i / \sum_{i=1}^{N} GM_i \tag{2}$$

(*iii*) Then determine the maximum eigen value (λ_{max}) (i_v) Compute the index of consistency ($CI = (\lambda_{max} - N)/(N - 1)$), where N = number of attributes or responses, a_{ij} stands for the comparative value of attribute i in regard to response j. The smaller the value of CI, the smaller (v). Acquire the random index (RI) for the amount of attributes applied during decision-making the deviation from the consistency (v_i). Calculate the consistency ratio ($CR = CI/RI$). Generally, a CR amounting to 0.1 or less is regarded as satisfactory. What is more, it also demonstrates an informed judgment which could be referential to the researcher's knowledge of the problem.

Finally, every attribute's weight is measured by the aforementioned AHP method, as shown in B_i square matrix:

$$B_i = \begin{matrix} Attribute \\ Ra \\ Rq \\ Rz \end{matrix} \begin{bmatrix} Ra & Rq & Rz \\ 1 & 5 & 7 \\ 1/5 & 1 & 3 \\ 1/7 & 1/3 & 1 \end{bmatrix}$$

Every attribute's normalized weight are the following: for tool wear R_a = 0.730645; R_q = 0.188394 and R_z = 0.0809612. The $\lambda_{\max}$ value is equal to 3.06489 and CR = 0.0559376; this result is much lower than the acceptable CR value of 0.1. Therefore, the consistency of the adopted judgments is to satisfied.

Step 3: The weighted normalized matrix (V_{ij}) is achieved by means of the outcome of the normalized value (r_{ij}) and weighted values (W_j) as shown in Table 3:

$$V_{ij} = W_j * r_{ij} = i = 1, 2\ldots 17;\ j = 1, 2, 3 \tag{3}$$

Step 4: The subsequent step depends on acquiring the positive ideal (V+) and negative ideal (V-) solutions with the use of Eq. (4). These are given as:

$$V^+ = \{[\max (V_{ij}) \,/\, j \in J\,] \text{ or } [\min (V_{ij}) \,/\, j \in J'\,]\ i = 1, 2\ldots 17\} \tag{4}$$

$V_1^+ = 0.106239$ $\quad V_1^- = 0.234209$

$V_2^+ = 0.02817$ $\quad V_2^- = 0.0664$

$V_3^+ = 0.013768$ $\quad V_3^- = 0.025474$

Step 5: This step relies on calculating of the criteria performance as the best (S_i^+) and the worst (S_i^-) alternative distance from the V+ and V – values respectively. The S_1^+ and S_1^- values were indicated with the use of the equation (5) and (6). Performances of each alternative, considering the best and the worst conditions, are presented on Table 3.

$$S_i^+ = \sqrt{\sum_{i=1}^{17} (V_{ij} - V_j^+)^2} \tag{5}$$

$$S_i^- = \sqrt{\sum_{i=1}^{17} (V_{ij} - V_j^-)^2} \tag{6}$$

where i = 1, 2… 17.

Step 6: The closeness coefficient parameter (C_i) was established for every alternative, with the use of the equation (7):

$$C_i = \frac{S_i^-}{S_i^- + S_i^+}\quad i = 1, 2\ldots 17;\ 0 \le C_i \le 1 \tag{7}$$

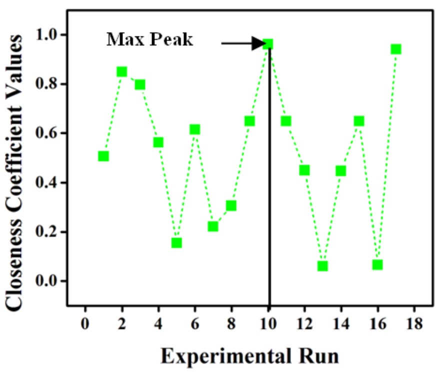

Fig. 5. Closeness coefficient values in every examination

The ideal solution was chosen as per the preference ranking method ordered by the value of C_i value, being really near to the positive solution. Table 3 also describes the value of closeness coefficient. From these 17 values, the exp. no. 10 (max C_i value) describes the ideal multi-response characteristics parameters during MQL turning of titanium (grade-2) alloy as exhibits in Fig. 5.

Table 3. Normalized Values, weighted normalized values, values of closeness coefficient and alternatives' ranking

Normalized Values			Weighted Normalized Values			Separation Measures		Closeness Coefficients	
R_a	R_q	R_z	R_a	R_q	R_z	S_1^+	S_1^-	C_i	Ranking
0.244	0.176	0.235	0.178	0.033	0.019	0.067	0.068	0.505227	10
0.175	0.213	0.180	0.127	0.040	0.014	0.021	0.116	0.848941	3
0.188	0.192	0.197	0.137	0.036	0.015	0.027	0.107	0.796468	4
0.231	0.216	0.226	0.169	0.040	0.018	0.058	0.075	0.562173	9
0.304	0.352	0.315	0.222	0.066	0.025	0.117	0.021	0.154348	15
0.221	0.216	0.225	0.161	0.040	0.018	0.051	0.082	0.614218	8
0.290	0.293	0.298	0.212	0.055	0.024	0.105	0.029	0.222076	14
0.277	0.253	0.252	0.202	0.047	0.020	0.093	0.041	0.305804	13
0.214	0.216	0.224	0.156	0.040	0.018	0.047	0.087	0.648775	5
0.145	**0.149**	**0.170**	**0.106**	**0.028**	**0.013**	**0.005**	**0.139**	**0.960811**	**1**
0.214	0.216	0.227	0.156	0.040	0.018	0.047	0.087	0.648623	6
0.251	0.240	0.248	0.183	0.045	0.020	0.074	0.060	0.449033	11
0.320	0.315	0.299	0.234	0.059	0.024	0.127	0.008	0.059932	17
0.251	0.245	0.259	0.183	0.046	0.020	0.074	0.060	0.446752	12
0.214	0.216	0.227	0.156	0.040	0.018	0.047	0.087	0.648572	7
0.320	0.331	0.289	0.234	0.062	0.023	0.127	0.008	0.065244	16
0.161	0.168	0.184	0.118	0.031	0.014	0.008	0.127	0.940514	2

4. CONCLUSION

The present work performs a multi-response optimization during the turning process of grade-2 titanium alloys with regard to MQL conditions. It has been found that, an application of TOPSIS-AHP method is effective in solving multi-response problems. Experiment no. 10 consisting of the following values: cutting speed amounting to 200 m/min, feed rate of 0.10 mm/rev, and approach angle of 75°, showed the best multi-response characteristics for minimum surface roughness values.

A practical value of this investigations concerns the indication, that proper selection of machining parameters and the MQL cooling strategy determine the optimal value of surface roughness.

This paper is a prestudy to investigate the reliability of the TOPSIS method in machining. Therefore, in the future, it is planned to check the correctness of the operation of the TOPSIS analysis for input data extended by the tool nose radius, tool life, cooling process parameters, etc.

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