Applied Engineering Letters Vol.7, No.1, 1-9 (2022) e-ISSN: 2466-4847

EFFECT OF CUTTING PARAMETERS ON THE SURFACE ROUGHNESS AND ROUNDNESS ERROR WHEN TURNING THE INTERRUPTED SURFACE OF 40X STEEL USING HSS-TiN INSERT

UDC: 621.91
Original scientific paper https://doi.org/10.18485/aeletters.2022.7.1.1

Do Duc Trung

Faculty of Mechanical Engineering, Hanoi University of Industry, Hanoi City, 100000, Vietnam

Abstract:
This paper presents a research on investigating the effect of cutting parameters on the surface roughness (R_a) and roundness error (RE) when turning the interrupted surface of 40X steel. The TiN coated high speed steel (HSS-TiN) inserts were used in this research. The cutting parameters include cutting velocity, feed rate, and depth of cut. The Box-Behnken method was applied to develop an experimental matrix with fifteen experiments. The influences of cutting parameters on R_a and RE were found using Pareto chart. Two equations that presented the relationship between Ra, RE and cutting parameters were established. These two equations were used to predict R_a and RE. Genetic algorithm (GA) was also used to determine the optimal values of cutting parameters to simultaneously ensure the minimum values of R_a and RE. The further works of this study was also mentioned in this paper.

ARTICLE HISTORY
Received: 23.08.2021.
Accepted: 13.02.2022.
Available: 31.03.2022.

KEYWORDS
Interrupted surface, turning, 40X steel, HSS-TiN, surface roughness, roundness error, GA

1. INTRODUCTION

40X steel (according to GOST-4543 standard of the Russian Federation) is an alloy steel commonly used to make parts such as gears, worms, splined shafts, etc. If the study on turning the continuity surface of 40X steel or equivalent steels has been done in many studies [1-6], up to the present time, it can be affirmed that there are no published studies on turning the interrupted surface of this steel.

Parts as mentioned above are the ones with interrupted surfaces and often require small Ra and RE. Grinding methods are commonly used to achieve these requirements. However, if the turning method is used in this case, it will be more flexible than the grinding method, i.e. multiple surfaces can be turned in a single attachment, and especially the use of coolant is not required [7]. Another special thing is that the turning method gives a higher yield than the grinding one, sometimes the R_a when turning is also smaller than when grinding [8]. In addition, in some cases when turning a interrupted surface, the tool life is even longer than when turning a continuity surface [9]. Another advantage is that when turning, the residual stress of the surface layer is the compressive residual stress, while if using the grinding method, the residual stress of the surface layer is the tensile residual stress [10].

When performing a study on turning interrupted surfaces, most of the authors have used CBN inserts to machine different types of materials. Several main findings of those studies are presented as follows. When turning Inconel 718 steel, the depth of cut affects on the plastic deformation of the workpiece surface layer more than the influence of the cutting velocity and the feed rate, and increasing the cutting force does not increase tool wear [11]. When turning AISI D6 tool steel, when the cutting velocity is low, it is easier to chip the tool than when the cutting velocity is high [12]. When turning Ti6Al4V alloy, the temperature transferred

*CONTACT: D.D. Trung, e-mail: doductrung@haui.edu.vn

to the cutting tool depends on the number of grooves on the part but does not depend on the cutting parameters [13]. When turning ductile iron, the number of grooves on the workpiece, the feed rate, and the depth of cut all have a great influence on the tool life. When the values of these parameters increase, the tool life decreases (increase in tool wear rate) [14]. When turning ASSAB 760 steel, if increasing the cutting velocity, feed rate, and depth of cut, they all make the increasing of the temperature transferred to the workpiece and the cutting tool [15]. When turning AISIE-52100 steel, if machining at low cutting velocity, it is better to use a low-content CBN tool than a high content CBN tool. The cutting force increases as the cutting velocity increases, and the axial force increases rapidly with the amount of tool wear [10].

In addition to CBN inserts, the processes of turning interrupted surface with other types of cutting tools have also been performed by several authors and some conclusions have been reached. When turning AISI 52100 steel, cutting tools made of ceramic composites tend to break due to impact during the cutting process [16]. When using a cutting tool as PVD coated cemented carbide to turn the interrupted surface of Ti-6Al-4V and Ti-5553 alloys, if assessing the machining process by the tool life, the ability to machine Ti-6Al-4V material is inferior compared to Ti-5553 material [17]. In documents [18,19] when turning interrupted surfaces of AISI 8620 steel, the following conclusions were made: (1) Carbide cutting tools have a higher life than CBN ones, but the surface roughness when using CBN inserts is better than using carbide inserts; (2) CBN inserts when cutting interrupted surface will have a greater life than when cutting continuously surface; (3) If the insert is carbide, the interrupted surface degree of the workpiece greatly affects the tool wear, but if the insert is CBN, the effect of the interrupted surface is negligible on the tool wear; and (4) At a low or medium cutting velocity ($\leq$ 140 m/min), the life of carbide insert is comparable to that of CBN insert. But at a higher cutting velocity, the life of carbide insert is less than that of CBN insert; Surface roughness when using both types is less than 1.6 μm.

High speed steel (HSS) has been used for a long time to make a variety of cutting tools (milling tools, turning tools, drill tools). The insert made of HSS with high plasticity is suitable for discontinuous (impact) cutting conditions. If the HSS insert is coated with a layer of alloy with high hardness and high wear resistance, it will ensure all three factors: high hardness, high wear resistance, and high durability.

One of the inserts of this type that has been being used commonly is the titanium-nitric coated HSS insert (HSS-TiN). In fact, this type of inserts is being used a lot to turn the interrupted surfaces such as splined shafts, used in the process of repairing lead screws, gears, etc. This work is also conducted by the authors of this paper on a daily basis in production. However, after trying to search on the internet, the author of this paper could not find any study on using this type of inserts to turn interrupted surfaces in general and turn interrupted surfaces of 40X steel in particular.

A small number of published studies (as mentioned above) on turning interrupted surfaces often choose tool wear (tool life) as the evaluation criterion. This is a very meaningful action both economically and technically. However, the survey studies on R_a and RE of the machined surface when turning interrupted surfaces are still very modest. Meanwhile, these two parameters have a great influence on the working ability of machine parts [20,21]. Therefore, the survey of these two parameters when turning interrupted surfaces is not only novel in interrupted surface turning technology but also has high practical significance.

In order to fill the gaps in 40X steel interrupted surface turning technology, in this study, HSS-TiN inserts will be used to machine this type of surface. The main purpose of this study is to determine the influence of cutting parameters on R_a and RE when using HSS-TiN inserts to turn the interrupted surface of 40X steel. Then, this study also determines the optimal value of cutting parameters to simultaneously ensure the small R_a and RE.

2. TURNING EXPERIMENTS

2.1 Experimental system

The structure of a steel sample is shown in Figure 1. Total length of the steel sample is 300 (mm), two cylindrical shafts have a diameter of 40 (mm) and a length of 50 (mm), the shaft part with the interrupted surface has a diameter of 50.35 (mm). Samples were prepared by a method of rough turning, center drilling and six-groove milling. These sample sizes correspond to the splined shafts in a gearbox of some machine tools [22]. After milling the groove, the steel sample has been heat treated to a hardness of 54 HRC.

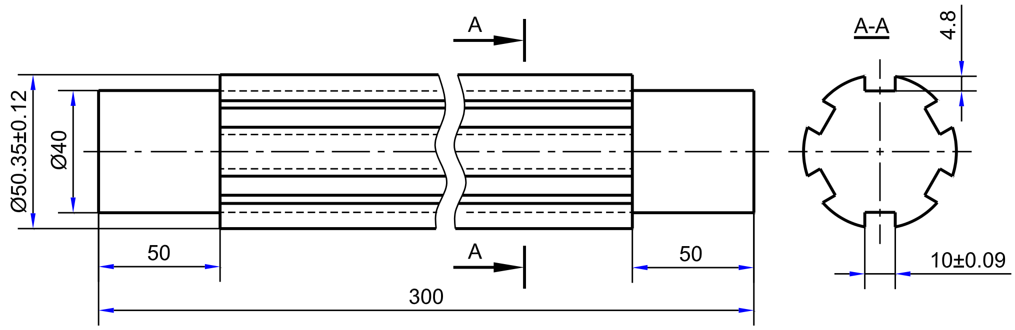

Fig. 1. Workpiece geometry

Fig. 2. Experimental machine

The experiments were carried out on a CNC lathe of Doosan (Figure 2). The HSS-TiN inserts were used during the experiments (Figure 3). This insert is a product of Hoffmann (USA). According to the information from the supplier, the insert has a hardness of 90HRC.

Fig. 3. HSS-TiN inserts

The geometry parameters of the insert used include: nose radius of 0.3 mm, rake angle of 7^0, clearance angle of 6^0, plane point angle of 55^0, and chip breaker angle of 6^0. In each experiment, a brand new insert was used. This is done to eliminate the influence of tool wear on the responses.

N64 industrial oil mixed with water at a concentration of 6% was used as a coolant during the experiment. This solution is injected into the cutting zone at flow rate of 12 l/min and a pressure of 4 MPa [23]. The value of these parameters as well as the cutting parameters are adjusted through a touch screen of the lathe.

After each experiment, the workpiece was washed with alcohol and waited to be dry before measuring R_a and RE. The SJ-201 surface tester was used to measure R_a. 3D coordinate measuring machine of Crysta-Plus M544 type was used to measure RE. When measuring the R_a, the standard length has been set to 0.8 mm, the diameter of a measuring head is 0.005 mm, the displacement of the measuring head is parallel to the shaft centerline, each sample is measured at least three times, the R_a value at each experiment is the average value of the measurements. The RE is also measured at least three times per sample in three different cross-sections, the RE is also calculated as the average of the measurements.

2.2 Experimental matrix

To survey the effect of cutting parameters on the R_a and RE when turning, it is necessary to first develop an experimental matrix according to a certain sequence. In addition, the survey on the effect of cutting parameters on the responses is the basis for selecting the value of cutting parameters in order to achieve specific goals of the machining process. Therefore, the method of developing an experimental matrix must be suitable in building the relationship between the input parameters and the responses. Box-Behnken is one of several experimental design methods that meet these requirements. This method is also suitable in designing experiments for optimization purposes [24,25]. According to this matrix design, each input parameter needs three value levels, corresponding to the three encoding levels, -1, 0 and 1. Of which the value of parameters at encoding level 0 is the average value of such parameter at the remaining two levels. Figure 4 shows the diagram of experiments when designing the experimental matrix with three input parameters according to the Box-Behnken method. Each black dot represents an experiment. The black dot corresponding to point C represents the experiment at level 0, [24,25].

The value of cutting parameters at the value levels are shown in Table 1. Since there are no published studies on turning interrupted surfaces of 40X steel, the selection of values as shown in Table 1 is done based on experience in actual production.

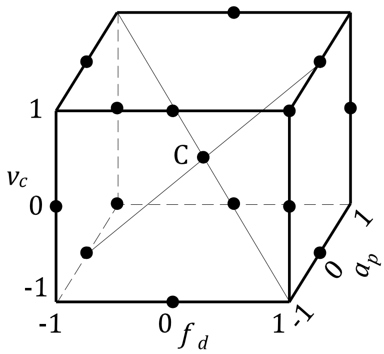

Fig. 4. Experimental diagram with three input parameters according to the Box-Behnken method

Minitab 16 software was used to design an experimental matrix with a total of fifteen experiments as shown in Table 2. In this table, experiments #13, #14, and #15 are the ones where all input parameters are at encoding level 0 (point C in Figure 4) [24,25].

Table 1. Cutting parameters

Parameter	symbol	unit	Value at levels		
			-1	0	1
Cutting velocity	v_c	m/min	50	75	100
Feed rate	f_d	mm/rev	0.11	0.25	0.39
Depth of cut	a_p	mm	0.1	0.35	0.6

2.3 Results and Discussion

The results of measuring R_a and RE have been included in Table 2. Except in experiment #6, fourteen of the fifteen R_a values in this table are of the roughness level 7 to 8 (out of fourteen levels of roughness). This shows that using HSS-TiN inserts to turn 40X steel interrupted surfaces also gives similar results with conventional finishing turning methods [26]. In addition, fifteen out of sixteen R_a values are all less than 1.6 μm. This also shows that using HSS-TiN inserts to turn 40X steel interrupted surfaces also achieves the same R_a as when turning AISI 8620 steel interrupted surfaces with CBN and carbide inserts [19].

All values of RE in Table 2 belong to the roundness level from 5 to 7 (there are total 16 levels of roundness, look up the roundness level based on the diameter of the workpiece and the value of RE [27]). These levels of RE (from 5 to 7) are similar to the levels of RE when turning continuity surfaces [26], and are also within the range of RE levels when grinding [28,29]. The obtained results on R_a and RE as analyzed show that the empirical determination of input parameters is appropriate.

Minitab 16 statistical software was also used to survey the effect of cutting parameters on the responses. In Figures 5 and 6, respectively, are Pareto charts regarding the effect of cutting parameters on R_a and RE. When performing this analysis, the significance level was selected to be 0.05, which means that the results obtained are accurate to at least 95% [24,25].

In both charts, the red line is the limit one in the Pareto chart, which has coordinates equal to 2.201. The gray rectangles represent the effect of the input parameters on the output parameters. Any rectangle that exceeds the red limit line indicates that the input parameter corresponding to such rectangle significantly affects the responses.

Table 2. Experimental matrix and results

No.	Cutting parameters						*Responses*			
	Code value			Actual value						
	v_c	f_d	a_p	v_c (m/min)	f_d (mm/rev)	a_p (mm)	R_a (µm)	RE (µm)	R_a^* (µm)	RE^* (µm)
1	-1	-1	0	*50*	*0.11*	*0.35*	0.828	8.789	0.767	8.507
2	-1	1	0	*50*	*0.39*	*0.35*	1.139	8.907	1.221	8.388
3	1	-1	0	*100*	*0.11*	*0.35*	1.003	11.249	1.079	11.257
4	1	1	0	*100*	*0.39*	*0.35*	1.613	7.556	1.832	7.328
5	0	-1	-1	*75*	*0.11*	*0.1*	1.453	8.001	1.486	7.473
6	0	1	-1	*75*	*0.39*	*0.1*	2.417	7.162	2.308	6.871
7	0	-1	1	*75*	*0.11*	*0.6*	0.904	12.040	1.155	11.871
8	0	1	1	*75*	*0.39*	*0.6*	1.430	8.355	1.539	8.424
9	-1	0	-1	*50*	*0.25*	*0.1*	1.139	7.349	1.300	6.726
10	1	0	-1	*100*	*0.25*	*0.1*	1.560	7.381	1.773	6.855
11	-1	0	1	*50*	*0.25*	*0.6*	0.817	8.969	0.761	8.985
12	1	0	1	*100*	*0.25*	*0.6*	1.215	11.434	1.212	10.546
13	0	0	0	*75*	*0.25*	*0.35*	0.916	8.207	0.989	7.988
14	0	0	0	*75*	*0.25*	*0.35*	0.919	8.301	0.989	7.988
15	0	0	0	*75*	*0.25*	*0.35*	0.920	8.146	0.989	7.988

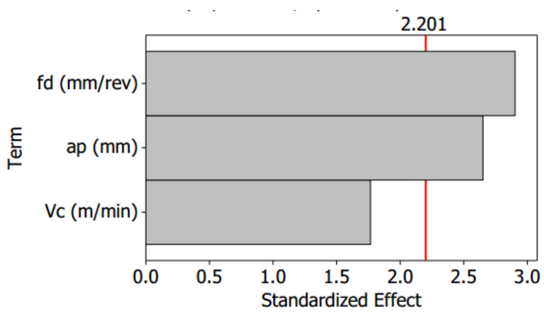

Fig. 5. Pareto chart of the standardized effects for R_a

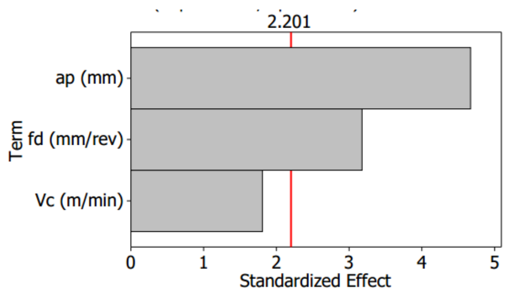

Fig. 6. Pareto chart of the standardized effects for RE

Accordingly, Figure 5 shows that feed rate is the parameter with the greatest influence on R_a, followed by the influence of the depth of cut, while the cutting velocity has negligible influence on R_a. The reason for this phenomenon can be explained as follows: when the feed rate changes, the change in R_a is a very obvious thing, which has been known in many studies, in addition, this issue is also consistent with the results of theoretical studies when we can predict the R_a according to the formula $R_a = 321\, f_d^2 / r_\varepsilon$, where r_ε is the nose radius [30, 31].

In Figure 6, it is shown that the depth of cut has a greater influence on the RE than the feed rate, while the cutting velocity is still a parameter that has negligible influence on the RE. This issue can be explained as follows: When changing the depth of cut, it will change the radial force component acting on the surface of the part, thus affecting the RE [32]; When the feed rate changes, it will change the time of impact of the radial force on the part, thus also affecting the RE [33].

$$R_a = 1.2900 + 0.0192 \cdot v_c - 5.9519 \cdot f_d - 4.0005 \cdot a_p - 0.0001 \cdot v_c^2 + 15.1956 \cdot f_d^2 + 5.3573 \cdot a_p^2 + 0.0214 \cdot v_c \cdot f_d - 0.0009 \cdot v_c \cdot a_p - 3.1286 \cdot f_d \cdot a_p \quad (1)$$

With: R^2 = 0.9457, R^2-Adj = 0.8479

$$RE = 5.4090 + 0.0049 \cdot v_c + 4.1838 \cdot f_d + 6.2904 \cdot a_p + 0.0004 \cdot v_c^2 + 32.2321 \cdot f_d^2 + 0.6360 \cdot a_p^2 - 0.2722 \cdot v_c \cdot f_d + 0.0573 \cdot v_c \cdot a_p - 20.3286 \cdot f_d \cdot a_p \quad (2)$$

With: R^2 = 0.9707, R^2-Adj = 0.9181

Also from the use of Minitab 16 software to analyze the results, two equations representing the relationship between input parameters and output parameters were found as in formulas (1) and (2). The factor of determination (R^2) and the adjusted factor of determination (R^2-Adj) of each equation were also found. The significance of these factors has been discussed in detail in many studies [34,35]. All of these factors are very close to 1, which shows that these equations have a great match with the experimental data. From there, it is shown that these two equations can be used to predict R_a and RE with specific values of input parameters located in the surveyed domain. These two equations are used to predict surface roughness (R_a*) and roundness error (RE*), the results are also included in Table 2. The chart comparing the measured and predicted values of these two parameters is presented in Figures 7 and 8, respectively. Observing these two figures, it can be found that the calculated values are very close to the experimental values, the average deviation between the calculated results and the experimental ones is 7.37% for R_a and 3.21% for RE.

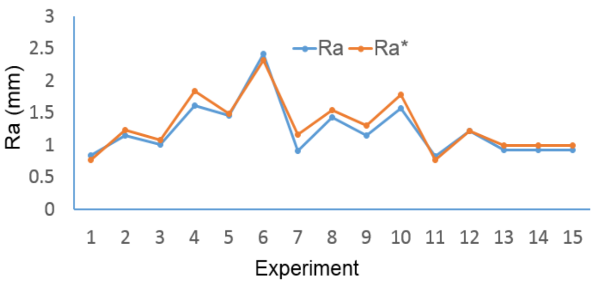

Fig. 7. Surface roughness in experiment (R_a) and prediction (R_a*)

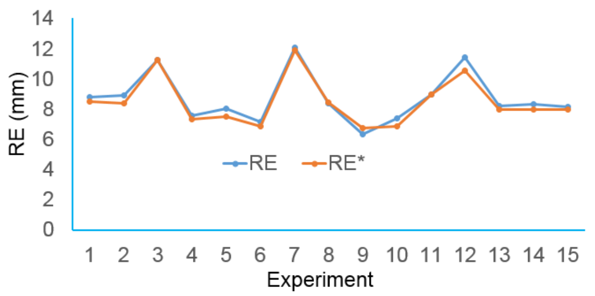

Fig. 8. Roundness error in experiment (RE) and prediction (RE*)

The two equations (1) and (2) are also the basis for determining the value of cutting parameters to ensure the minimum R_a and RE. This content is presented in the next part of this paper.

3. OPTIMIZATION OF THE TURNING PROCESS

As R_a and RE have the same unit, the problem on simultaneous optimization of the objectives $R_a \rightarrow$ min, RE $\rightarrow$ min can be written as.

$$f(x) = w_1 \cdot R_a + w_2 \cdot RE \rightarrow min \qquad (3)$$

Of which w_1 and w_2 are weights of R_a and RE, respectively, meeting $w_1 + w_2 = 1$.

For parts with interrupted surfaces such as splined shafts, worms, the R_a and RE have a great influence on the product's working performance. Therefore, in this study, the weights of these two parameters were selected equally, ie $w_1 = w_2 = 0.5$. Since equations (1) and (2) are established on the basis of experimental results in Table 2, corresponding to the survey domain of input parameters as shown in Table 1. Therefore, the optimization problem is also applied only within the surveyed range of input parameters. That is, the optimization problem is written in the form.

$$\begin{cases} f(x) = w_1 \cdot R_a + w_2 \cdot RE \rightarrow min \\ R_a, RE > 0 \\ 50\ m/min \leq v_c \leq 100\ m/min \\ 0.11\ mm/rev \leq f_d \leq 0.39\ mm/rev \\ 0.1\ mm \leq a_p \leq 0.6\ mm \end{cases} \qquad (4)$$

GA has been used to solve the optimization problem. Such algorithm has been used with great success in many studies. In order to apply this algorithm in solving optimization problems, the values of parameters, including population number, crossover probability, mutation probability, should be specified. These values have been chosen as shown in Table 3 [36].

Table 3. Several parameters in GA and responses

Population number	100
Crossover probability	0.25
Mutation probability	0.05
Workpiece velocity	50 (m/min)
Feed rate	0.177 (mm/rev)
Depth of cut	0.1 (mm)
f(x)	3.880 (μm)

GA program was programed using Visual basic in Microsoft excel. Solving the problem in formula (4) with the parameters of the algorithm as shown in Table 3, the results produce a graph of the fitness function as indicated in Figure 9.

In the first stage, the graph of the fitness function moves very slowly from the top down, then goes parallel to the horizontal axis in the rest of the distance. That proves that the value of parameters of the genetic algorithm selected in Table 3 are appropriate. The optimal value of cut parameters as well as the found value of function *f(x)* have also been included in Table 3.

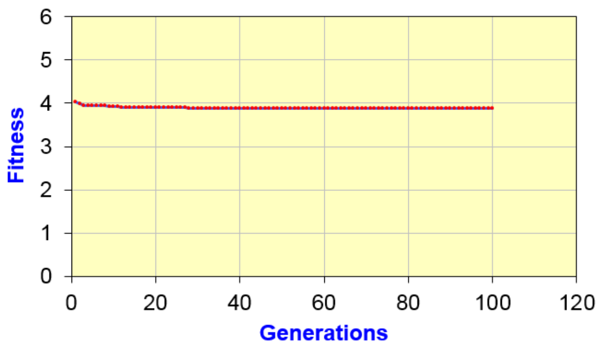

Fig. 9. Graph of the fitness function

Thus, the optimal values of cutting velocity, feed rate and depth of cut are 50 m/min, 0.177 mm/rev and 0.1 mm, respectively. These values are again used to calculate R_a and RE according to formulas (1) and (2), the results are presented in Table 4. The turning process was also performed on five steel samples with these values of cutting parameters, the results of measuring R_a and RE also included in this table. The mean value of R_a and RE when machining is equal to the optimal value of cutting parameters, 1.385 μm and 7.063 μm, respectively. The difference from comparing the experimental value and the calculated value is 12.90% for R_a and 7.1% for RE

Table 4. Values of R_a and RE corresponding to optimal values of cutting parameters

Runs	Optimum value			Response			
	v_c (m/min)	f_d (mm/rev)	a_p (mm)	R_a (μm)		*RE* (μm)	
				Predicted	Measured	Predicted	Measured
1	50	0.175	0.1	1.206	1.361	6.557	6.819
2					1.394		6.995
3					1.346		7.208
4					1.401		7.348
5					1.424		6.948

4. CONCLUSION

In this study, the experimental turning the interrupted surfaces of 40X steel was carried out using HSS-TiN inserts. Some conclusions are drawn as follows:

1. Of the three cutting parameters, feed rate is the one that has the greatest influence on R_a, followed by the influence of the depth of cut. The cutting velocity has negligible effect on the R_a. Depth of cut is the parameter with the greatest influence on RE, followed by the influence of feed rate. The cutting velocity also has a negligible effect on the RE;
2. Two equations showing the relationship between R_a, RE and cutting parameters have been established. Using these equations to predict R_a and RE, the difference between the predicted and experimental results is 7.37% for R_a and 3.21% for RE;
3. Genetic algorithms have been used to solve the multi-objective optimization problem. The optimal value of cutting velocity is 50 m/min, feed rate is 0.177 mm/rev, and the depth of cut is 0.1 mm. For this set of optimal values of the cutting parameters, the R_a is 1.385 μm and the RE is 7.063 μm;
4. If only evaluating the turning process through R_a and RE, the use of HSS-TiN inserts is suitable for turning interrupted surfaces of 40X steel. This information provides a significant cost saving compared to the use of other more expensive inserts, such as CBN inserts;
5. Surveying the effect of cutting parameters on the tool wear as well as determining the value of cutting parameters to ensure that all three parameters, R_a, RE, and tool wear have the minimum value at the same time are the future works of the author of this article.

REFERENCE

[1] O. Barıs, D. Halil, T. Mustafa, The effect of mechanical properties and the cutting parameters on machinability of AISI 5140 steel cooled at high cooling rates after hot forging. *Journal of polytechnic*, 22(4), 2019: 879-887 https://doi.org/10.2339/politeknik.479345

[2] R. Minodora, T. Lorena, H. Mioara, C. Ion, Tribological characterization of surface topography using abbott-firestone curve. *National tribology conference*, 24-26 September 2003, Galati, Romania, 208-213.

[3] V.V. Tinh, D.Q. Dung, N. .H. Thanh, Study on the tool wear mechanism when turning hard steel 40X. *Transport journal*, 6, 2018: 12-20.

[4] D.N. Tu, Program the machining of 40X alloy steel parts with complex surfaces on a CNC lathe, Master thesis. *Hanoi university of science and technology*, 2014.

[5] F. Kahraman, Optimization of cutting parameters for surface roughness in turning of studs manufactured from AISI 5140 steel using the Taguchi method. *Materials Testing*, 59(1), 2017: 77-80. https://doi.org/10.3139/120.110968

[6] K. Mustafa, A. Abdullah, Y.P. Danil, G. Khaled, M. Tadeusz, S. Shubham, Modeling of Cutting Parameters and Tool Geometry for Multi-Criteria Optimization of Surface Roughness and Vibration via Response Surface Methodology in Turning of AISI 5140 Steel. *Materials*, 13(19), 2020: 4242. https://doi.org/10.3390/ma13194242

[7] V.A.A. Godoy, A.E. Diniz, Turning of interrupted and continuous hardened steel surfaces using ceramic and CBN cutting tools. *Journal of Materials Processing Technology*, 211, 2011: 1014-1025. https://doi.org/10.1016/j.jmatprotec.2011.01.002

[8] F. Klocke, E. Brinksmeier, K. Weinert, Capability Profile of Hard Cutting and Grinding Processes. *CIRP Annals - Manufacturing Technology*, 54(2), 2005: 22-45. https://doi.org/10.1016/S0007-8506(07)60018-3

[9] A.J.D. Oliveira, A.E. Diniz, D.J. Ursolino, Hard turning in continuous and interrupted cut with PCBN and whisker-reinforced cutting tools. *Journal of Materials Processing Technology*, 209(12-13), 2009: 5262-5270 https://doi.org/10.1016/j.jmatprotec.2009.03.012

[10] T.J. Ko, H.S. Kim, Surface Integrity and Machineability in Intermittent Hard Turning. *The International Journal of Advanced Manufacturing Technology*, 18, 2001: 168-175 https://doi.org/10.1007/s001700170072

[11] T. Chwalczuk, M. Wiciak, A. Felusia, P. Kieruj, An Investigation of Tool Performance in Interrupted Turning of Inconel 718, *MATEC Web of Conferences*, 237, 2020: 02008. https://doi.org/10.1051/matecconf/201823702008

[12] R. Sehgal, M. Nayak, R.K. Sharma, Continuous and Interrupted Hard Turning Using CBN-L Tools at Moderate Cutting Speeds. *International Journal of Emerging Technology and Advanced Engineering* , 5(4), 2015: 41-46.

[13] P. Lequien, G. Poulachon, J.C. Outeiro, Thermomechanical analysis induced by interrupted cutting of Ti6Al4V under several cooling strategies. *CIRP Annals - Manufacturing Technology*, 67(1), 2018: 91-94. https://doi.org/10.1016/j.cirp.2018.03.018

[14] S. Ercan, A. Kubilay, C. Adem, Tool Wear Mechanism in Interrupted Cutting Conditions. *Materials and Manufacturing Processes*, 24, 2009: 476-483. https://doi.org/10.1080/10426910802714423

[15] M. Azuddin, Tool-workpiece temperature for continuous and interrupted cutting of ASSAB 760 steel with dry machining process, *Advanced Materials Research*, 476-478, 2012: 392-396 https://doi.org/10.4028/www.scientific.net/AMR.476-478.392

[16] X. Cu, J. Guo, Biomimetic fabrication, mechanical behavior and interrupted turning performance of the microscopic surface structures of Al2O3/TiC micronano-composite ceramic. *Journal of Alloys and Compounds*, 811, 2019: 152012. https://doi.org/10.1016/j.jallcom.2019.152012

[17] A. Ugarte, R.M. Saoub, A. Garay, P.J. Arrazola, Machining behaviour of Ti-6Al-4V and Ti-5553 alloys in interrupted cutting with PVD coated cemented carbide. *Procedia CIRP*, 1, 2012: 202-207. https://doi.org/10.1016/j.procir.2012.04.035

[18] M. Dogra, V. Sharma, A. Sachdeva, N.M. Suri, Tool life and surface integrity issues in continuous and interrupted finish hard turning with coated carbide and CBN tools, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 226, 2012: 431-444 https://doi.org/10.1177/0954405411418589

[19] M. Dogra, V.S. Sharm, A. Sachdeva, N.M. Suri, Finish Hard Turning of Continuous and Interrupted Surfaces with Cubic Boron Nitride (CBN) and Coated Carbide Tools. *Materials and Manufacturing Processes*, 27(5), 2012: 523-530. https://doi.org/10.1080/10426914.2011.593238

[20] E.G. Plaza, A.R. Martín, P.J. Nunez, F. Mata, Diagnosis of roundness error in CNC turning operations through the optimum selection of on-line signals. *AIP Conference Proceedings*, 1431, 2012: 339-407. https://doi.org/10.1063/1.4707589

[21] P.J. Nunez López, J. Simao, E.M. Rubio, J.L.Rincon, Influence of the machining parameters on workpiece roundness error during turning operations, *Materials Science Forum*, 526, 2006: 127-132. https://doi.org/10.4028/www.scientific.net/MSF.526.127

[22] P. Dap, N.A. Tuan, *Machine tool design*, Science and technics publishing House, Hanoi, 1983.

[23] https://tanphuhieu.com/dau-cat-got/

[24] A. Dean, D. Voss, D. Draguljić, *Design and Analysis of Experiments - Second Edition*. Springer, 2007.

[25] D.D. Trung, Influence of Cutting Parameters on Surface Roughness in Grinding of 65G Steel. *Tribology in Industry*, 43(1), 2021: 167-176. https://doi.org/10.24874/ti.1009.11.20.01

[26] Y. Huang, L. Wang, S.Y. Liang, *Handbook of Manufacturing*. World Scientific Publishing, 2019. https://doi.org/10.1142/11006

[27] N. D. Loc, L. V. Tien, N. D. Ton, T. X Viet, *Handbook of Manufacturing Engineering – volume 1*, *Science and technics publishing House*, Hanoi, 2007.

[28] S. Malkin, C. Guo, *Grinding technology: Theory and Applications of Machining with Abrasives (2nd Edition). New York: Industrial Press*, 2008.

[29] I.D. Marinescu, M.P. Hitchiner, E. Uhlmann, W.B. Rowe, I. Inasaki, *Handbook of machining with grinding wheels*. *CRC Press*, 2006.

[30] M.P. Groover, *Fundamentals of Modern Manufacturing*, Prentice Hall. *Upper Saddle River*, NJ, 1996.

[31] P.J. Arrazola, A. Garay, L.M. Iriarte, M. Armendia, S. Marya, F.L. Maitre, Machinability of titanium alloys (Ti6Al4V and Ti555.3). *Journal of Materials Processing Technology*, 209(5), 2009: 2223-2230 https://doi.org/10.1016/j.jmatprotec.2008.06.020

[32] M.C. Shaw, Energy conversion in cutting and grinding. *CIRP Annals*, 45(1), 1996: 101-104. https://doi.org/10.1016/S0007-8506(07)63025-X

[33] W. Xu, Y. Wu, T. Sato, W. Lin, Effects of process parameters on workpiece roundness in tangential-feed centerless grinding using a surface grinder. *Journal of Materials Processing Technology*, 210(5), 2010: 759-766. https://doi.org/10.1016/j.jmatprotec.2010.01.003

[34] D. D. Trung, Influence of Cutting Parameters on Surface Roughness during Milling AISI 1045 Steel, *Tribology in Industry*, 42(4), 2020: 658-665. https://doi.org/10.24874/ti.969.09.20.11

[35] V.T.N. Uyen, N.H. Son, 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

[36] P.B. Khoi, D.D. Trung, N. Cuong, N.D. Man, Research on Optimization of Plunge Centerless Grinding Process using Genetic Algorithm and Response Surface Method. *International Journal of Scientific Engineering and Technology*, 4(3), 2015: 207-211.