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Optimization Of The Process Of Turning 35KMH Steel By Using Genetic Algorithm

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***Abstract*- Experimental process of turning 35KMH steel on CNC lathe machine was carried out in this study. The experiments were carried out according to a central composite design matrix with a total of 31 experiments. The cutting tool used in the experimental process was a TiAlN coated cutting tool with a tool nose radius of 0.8 mm. At each experiment, the values of four parameters will be changed, including the cutting speed, the feed rate, the cutting depth and the coolant flow rate (coolant is Tetyl cool 1240, with concentration 6%). Surface roughness was selected as the criterion to evaluate the turning process. The analysis of experimental results by Pareto chart has determined the influence of input parameters on the surface roughness. A regression model showing the relationship between the surface roughness and four input parameters has been developed. Genetic algorithm was used to determine the optimal values of input parameters. The purpose of the optimization problem is to determine the values of the input parameters to ensure the minimum surface roughness. The results of the optimization problem have also been verified experimentally. Finally, the further development direction for the further studies has also been proposed in this study.**

Key words: Turning process, 35KMH steel, surface roughness, genetic algorithm, optimization

I. INTRODUCTION

A lot of published documents has confirmed that turning is one of the most popular machining methods among the cutting machining methods. This method is used to machine many different types of surfaces such as cylindrical, tapered, threaded, flat, profiled surfaces. A mechanical product may have to be made by many various machining methods, but of which the work volume done by the turning method can account for up to 40% [1].

Surface roughness is the most common parameter for evaluating the cutting methods in general and the turning method in particular. This parameter has a direct influence on the durability and working ability of machine parts. That ability is shown through the wear resistance, corrosion resistance, fatigue strength, etc. of the parts. These properties of the parts are all governed by the surface roughness [2-3]. This is the most obvious answer to the statement stated above. In order to be able to turn the surface of the part with small roughness, many studies have been carried out. Among them, the studies investigating the influence of technological parameters on surface roughness accounted for the largest proportion.

When turning AISI 1018 steel, if the rake angle of the cutting tool is positive in value and the tool nose radius is small in value, the surface roughness will be small in value. Conversely, when the cutting speed is low and the feed rate is large, the surface roughness will increase [4].

When turning AISI 1026 steel, if the length of the cutting tool is small, the surface roughness will be of small value. The parameters of the cutting speed, the feed rate, and the tool nose radius have negligible influence on the surface roughness [5].

Turning 15-5PH stainless steel with TiAlN coated cutting tools showed that all five parameters including the cutting speed, the feed rate, the cutting depth, the coolant concentration and the coolant temperature all had a significant influence on the surface roughness [6].

When applying to PVD coated cutting tools to turn AISI1040 steel has shown that the feed rate has a greater influence on the surface roughness than the influence of the cutting speed [7].

When turning medium carbon steel, it was found that the cutting depth has a greater influence on the surface roughness than the influence of the cutting speed. The feed rate has an influence on the surface roughness at the last position of the three cutting parameters [8].

Only through a few studies mentioned above, it has been shown that the surface roughness is influenced by many factors that in one study can be said to be very difficult or impossible to investigate all these parameters. For that reason, the scientists often choose the parameters that the workers can easily control to investigate. Therefore, the cutting mode parameters are considered to be the simplest and most effective selection in controlling and monitoring the surface roughness.

35KMH steel (GOST - Russia standard) is a commonly used steel to manufacture high-load-bearing components such as rotating shafts, drive shafts and bearings. The advantages of this steel are high hardness, high compressive strength, good impact resistance, high temperature resistance.

However, because of this steel's high hardness, when turning this steel, the cutting heat will be very high. High cutting heat not only affects the cutting tool shelflife, but also directly affects the surface roughness (due to plastic deformation). Therefore, some solutions to reduce the cutting heat when turning this steel need to be studied carefully. Among the solutions to reduce heat, the solution using a reasonable cooling lubrication method is considered the most useful one. However, up to this point of time, there have been no studies that fully investigate the influence of the cutting parameters and the cooling lubrication parameters on the surface roughness when turning this type of steel announced.

In this study, an experiment will be conducted to investigate the influence of the cutting speed, the feed rate, the cutting depth and the coolant flow rate on the surface roughness when turning 35KMH steel. The optimal values of these parameters will also be found to ensure a minimum surface roughness. Finally, the further development direction for the further studies has also been proposed in this article.

II. EXPERIMENTAL PROCESS

2.1. Experimental system

35KMH steel was used in this study. The steel sample has length and diameter dimensions of 330 mm and 32 mm, respectively.

DOOSAN-branded Lynx CNC lathe machine was used to carry out the experiment in this study (Figure 1).

The cutting tool used in this study is TiAl coated, with a tip nose radius of 0.8 mm, which is a cutting tool with good cutting ability, high temperature resistance and wear resistance.

The coolant used in this study is Tectyl cool 1240 oil, with concentration 6% (Korea). This type of oil has the advantage of excellent cooling ability, good lubricity is also a prominent advantage of this oil. Another outstanding feature of this type of oil is that it almost does not cause rust on the part surface as well as the parts of the machining system. That is the reason why this type of oil is being used a lot when machining and cutting with CNC machines in general and CNC lathe machine in particular.

For each experimental sample, the surface roughness measurement was conducted at least three times, the roughness measurement direction is perpendicular to the direction of the cutting velocity vector. The roughness value at each experimental sample is the average value of consecutive measurements.

Fig 1. Experimental machine

2.2. Experimental design

The experimental design used in this study is the central composite design (CCD). According to this experiment, the number of experiments will include 2^k original experiments (at encoding degrees -1 and +1), 2k axial experiments (at encoding degree ± α) and the number of center point experiments selected by 7. In which, k is the number of input parameters, $\alpha = (2^k)^{0.25}$ [9]. Thus, with the number of input parameters equal to 4, the experimental matrix will include 31 experiments. The values of input parameters at the degrees are shown in Table 1, the experimental matrix is shown in Table 2.

Table 1. The values at the degrees of parameters

Parameters	Symbol	Unit	Level				
			-2	-1	0	1	2
Cutting speed	Vc	m/min	50	70	90	110	130
Feed rate	f	mm/rev	0.09	0.12	0.15	0.18	0.21
Depth of cut	a_p	mm	0.20	0.35	0.5	0.65	0.80
Flow	F	Litre/min	6	9	12	15	18

Table 2. The eperimental matrix and its results

No.	Code value				Actual value				Ra (μm)	Ra* (μm)
	v_c	f	a_p	Q	v_c (m/min)	f (mm/rev)	a_p (mm)	F (litre/min)		
1	0	0	0	-2	90	0.15	0.5	6	1.202	1.194
2	1	-1	-1	-1	110	0.12	0.35	9	0.753	0.749
3	0	0	0	0	90	0.15	0.5	12	0.884	0.886
4	1	1	-1	1	110	0.18	0.35	15	0.831	0.823
5	0	0	0	2	90	0.15	0.5	18	0.561	0.594
6	-1	-1	-1	1	70	0.12	0.35	15	0.544	0.568
7	-1	1	1	-1	70	0.18	0.65	9	1.336	1.318
8	-2	0	0	0	50	0.15	0.5	12	0.992	1.021

9	2	0	0	0	130	0.15	0.5	12	0.786	0.782
10	1	-1	1	1	110	0.12	0.65	15	0.520	0.543
11	0	0	0	0	90	0.15	0.5	12	0.888	0.886
12	-1	-1	-1	-1	70	0.12	0.35	9	0.862	0.843
13	-1	1	1	1	70	0.18	0.65	15	1.025	1.048
14	0	0	0	0	90	0.15	0.5	12	0.886	0.886
15	-1	-1	1	-1	70	0.12	0.65	9	0.932	0.958
16	1	-1	1	-1	110	0.12	0.65	9	0.832	0.817
17	-1	1	-1	-1	70	0.18	0.35	9	1.253	1.249
18	0	0	0	0	90	0.15	0.5	12	0.883	0.886
19	1	1	-1	-1	110	0.18	0.35	9	1.154	1.205
20	-1	1	-1	1	70	0.18	0.35	15	0.940	0.922
21	1	-1	-1	1	110	0.12	0.35	15	0.432	0.418
22	0	0	0	0	90	0.15	0.5	12	0.880	0.886
23	0	0	0	0	90	0.15	0.5	12	0.882	0.886
24	0	0	0	0	90	0.15	0.5	12	0.883	0.886
25	1	1	1	1	110	0.18	0.65	15	0.916	0.903
26	0	0	-2	0	90	0.15	0.20	12	0.804	0.798
27	-1	-1	1	1	70	0.12	0.65	15	0.822	0.739
28	1	1	1	-1	110	0.18	0.65	9	1.234	1.228
29	0	0	2	0	90	0.15	0.80	12	0.962	0.993
30	0	2	0	0	90	0.21	0.5	12	1.279	1.274
31	0	-2	0	0	90	0.09	0.5	12	0.480	0.509

III. RESULTS AND DISCUSSION

The surface roughness value (*Ra*) at each experiment has also been included in Table 2. With the significance degree selected as 0.05, the Pareto chart representing the influence of the input parameters on the surface roughness is shown in Figure 2. From this chart, it can be seen that the line graph of all input parameters exceed the limit line in the Pareto chart (red line). Thus, it can be seen that all four input parameters significantly affect the surface roughness. In which the feed rate is the parameter that has the greatest influence on the surface roughness, followed by the influence of the coolant flow rate, the influence of the cutting speed on the surface roughness stands at the third position, the cutting depth is the parameter that affects the surface roughness at least among the four parameters investigated.

Also from the data in Table 2, a regression model of the surface roughness was developed as shown in Formula (1). This model has a coefficient of determination R^2 = 0.9892, and an adjusted coefficient of determination $R^2(adj)$ = 0.9797. Both of these coefficients are very close to 1, showing that the regression model (1) has a very high fit with the experimental data.

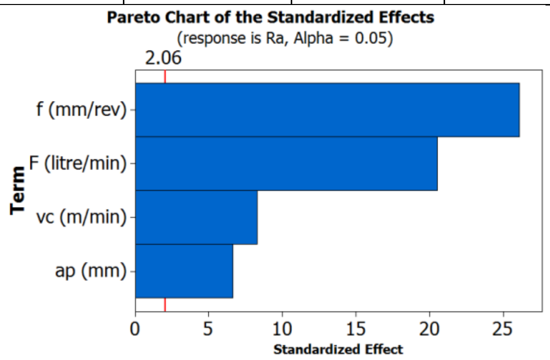

Fig 2. Pareto chart showing the influence of input parameters on Ra

$$Ra = 0.4275 - 0.00331 \cdot V_c + 6.89563 \cdot f + 0.56451 \cdot a_p - 0.02918 \cdot F + 0.00001 \cdot V_c^2 + 1.76918 \cdot f^2 + 0.10966 \cdot a_p^2 + 0.00023 \cdot F^2 + 0.02125 \cdot V_c \cdot f - 0.00383 \cdot V_c \cdot a_p - 0.00023 \cdot V_c \cdot F - 2.52778 \cdot f \cdot a_p - 0.14167 \cdot f \cdot F + 0.03111 \cdot a_p \cdot F \quad (1)$$

This model is the basis for predicting the surface roughness for specific values of the input parameters. Use the model (1) to predict the surface roughness corresponding to the values of the input parameters in Table 2. The predicted surface roughness value (*Ra**) has also been included in this table. Figure 3 shows a comparison chart of the surface roughness when doing experiment and predicting. Observing the data in Table 2 and in Figure 3 shows that the surface roughness in the experiment and the prediction is very close, the average deviation between the predicted and experimental results is only about 2.09%. This once again confirms the accuracy of the model (1), as well as the reliability of the experimental system and the experimental method used.

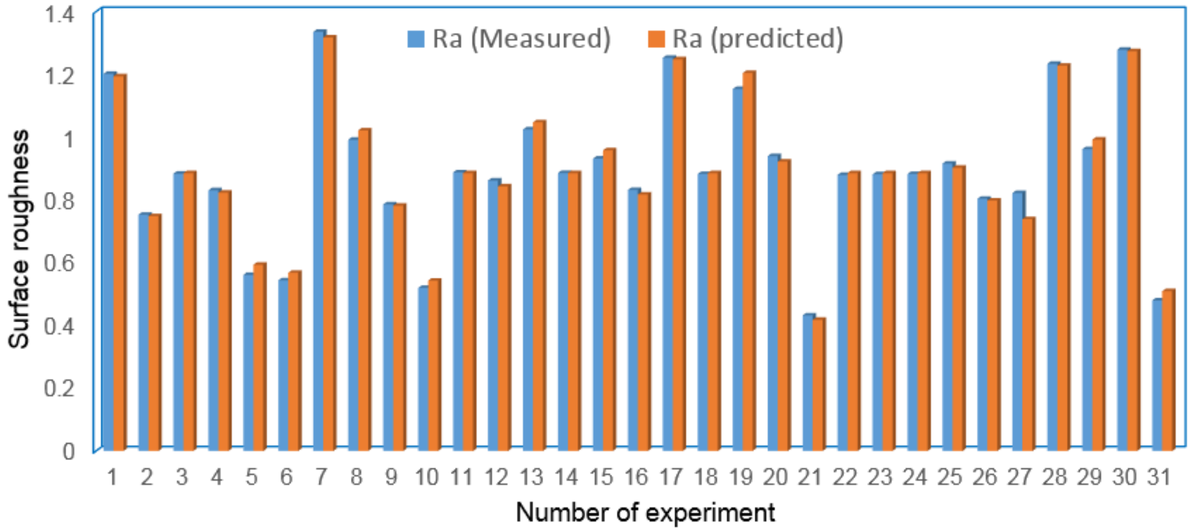

Fig 3. Surface roughness when doing experiment and predicting

In addition to being used to predict the surface roughness, the model (1) is also used to determine the value of the input parameters to ensure that the surface roughness reaches a specific value. This problem is known as optimization problem solving. This is the content that will be presented by the author of this article in the next section of this study.

IV. OPTIMIZATION

The optimization problems in the study of cutting methods in general have been done for a long time by the scientists. In each optimization problem, the scientists have used different algorithms, such as: genetic algorithm (GA), Generalized Reduced Gradient (GRG), Vlse Kriterijumska Optimizacija Kompromisno Resenje (Vikor), Data Envelopment Analysis-based Ranking (Dear), Moora, Topsis, etc. In this study, Genetic Algorithm was used to solve the optimization problem.

Some basic parameters of Genetic Algorithm used in this study include Population number of 100, Hybridization probability of 0.25, Mutation probability of 0.05 [2, 10]. A program to solve the optimization problems by Genetic Algorithm was written in Visual Basic language in Excel. In Figure 4, there is the graph of the adaptation function of the surface roughness. As a result, the optimal value of the input parameters was determined as the cutting speed equal to 129.89 m/min, the feed rate equal to 0.0902 mm/rev, the cutting depth equal to 0.2063 mm and the coolant flow rate equal to 17.99 liters/min. When machining with these values of the input parameters, the surface roughness has the smallest value (0.381 μm).

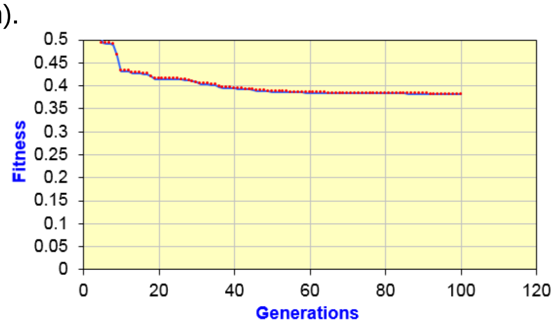

Fig 4. Diagram of the adaptation function of the surface roughness

The optimal values of the input parameters were used to carry out the turning process with three steel samples. Each steel sample was also measured for its surface roughness three times, the results are shown in Table 3.

Table 3. The roughness value when doing experiment according to the optimal value of the input parameters

<table>
<tr><th rowspan="3">No.</th><th rowspan="3">V_c (m/min)</th><th rowspan="3">f (mm/rev)</th><th rowspan="3">a_p (mm)</th><th rowspan="3">F (litre/min)</th><th colspan="4">Surface roughness, Ra (μm)</th></tr>
<tr><th colspan="3">Measured</th><th rowspan="2">Predicted</th></tr>
<tr><th>first</th><th>second</th><th>third</th></tr>
<tr><td>1</td><td rowspan="3">129.89</td><td rowspan="3">0.0902</td><td rowspan="3">0.2063</td><td rowspan="3">17.99</td><td>0.392</td><td>0.396</td><td>0.394</td><td rowspan="4">0.381</td></tr>
<tr><td>2</td><td>0.394</td><td>0.394</td><td>0.391</td></tr>
<tr><td>3</td><td>0.390</td><td>0.397</td><td>0.398</td></tr>
<tr><td colspan="5">Average</td><td colspan="3">0.394</td></tr>
</table>

The experimental data in Table 3 show that when turning with the optimal value of the input parameters, the surface roughness has an average value of 0.394 μm, which is very close to the value predicted by Genetic Algorithm, the deviation is only about 3.29%. This result once again reinforces the confirmation of the accuracy of the model (1) as well as the effectiveness of using Genetic Algorithm in this study.

V. CONCLUSION

An experimental process of turning 35KMH steel with TiAlN coated cutting tools was performed in this study. Some conclusions are drawn as follows:

- All four parameters including the cutting speed, the feed rate, the cutting depth and the coolant flow rate have a significant influence on the surface roughness. In which the feed rate is the parameter that affects the surface roughness to the greatest extent, followed by the influence of the coolant flow rate, the cutting speed and the cutting depth.

- A regression model showing the relationship between the surface roughness and four input parameters has been developed. This model has very high accuracy, the surface roughness value when predicted according to this model only deviates from the experiment by about 2.09%.

- Genetic Algorithm has been applied to solve the optimization problem. The results have shown that in order to have the minimum surface roughness, the optimal values of The cutting speed, the feed rate, the cutting depth and the coolant flow are 129.89 m/min, 0.0902 mm/rev, 0.2063 mm and 17.99 liters/min, respectively.

- The study of the influence of coolant type, its concentration and pressure on the surface roughness as well as the study of determination of the value of these parameters to ensure the minimum surface roughness that is minimum is the task that the authors of this article will carry out in the further studies.

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