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Prediction of surface roughness in turning of 40Cr steel

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ABSTRACT: *The paper presents the study of turning process of 40Cr steel, which is a type of alloy steel commonly used in machining processes to make various kinds of parts subjected to relatively high static and impact loads such as shafts, gears, and so on, using two types of cutting tools. The comparison experiments were conducted to evaluate the obtained values of surface roughness compared to the formula of other studies. The results indicate the appropriate formula to calculate surface roughness in turning of 40Cr steel corresponding to each different value of the nose radius. Also, this study also shows the regression equations representing the relationship between striations with the amount of longitudinal feed rates during turning of 40Cr steel with different values of nose radius.*

Keywords: *Prediction, surface roughness, turning, 40Cr steel, nose radius.*

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I. INTRODUCTION

In mechanical processing, turning operation is one of the most popular methods, accounting for the highest proportion compared to others. Surface quality of machined parts after turning is evaluated through many parameters, in which surface roughness is one of the important parameters, which has a great influence on the working quality of machined parts. Surface roughness is often chosen to evaluate the results of turning process. There are many factors that affect surface roughness during turning operation, in which many studies have shown that the amount of longitudinal feed rate and nose radius are two of the factors that greatly affect surface roughness. The study of turning process with different values of longitudinal feed rate and nose radius for machining part with small surface roughness has been done by various experimental studies. In these studies, the relationship between surface roughness and cutting parameters is based on the data of experimental studies. However, experimental research is often costly and time-consuming, and it affects the operation efficiency. In addition, the results of experimental researches are usually only applied to a few specific cases, limiting the meaning of the studies. In order to solve this disadvantages of experimental research method, some scientists have conducted studies to predict surface roughness in turning by different methods: Application of artificial neutron network to predict surface roughness when turning is done by the NR Abburi and U.S. Dixit [1], Baris Buldum and colleagues [2], ...; Jean-Philippe Costes [3] conducted part surface spectroscopic analysis after turning, then performed Fourier transform to give a model to predict surface roughness when turning; The Adaptive Neuro-Fuzzy Inference System application for predicting surface roughness was made by B. Sidda Reddy et al. The production process often has many limitations, because in the units producing the application of solutions for artificial intelligence, spectral analysis - Fourier analysis or fuzzy things are often difficult. A number of scientists in the world have also studied the way to build of formulas that allow to calculate surface roughness of part surface in each specific case: G. Boothroyd and W.A. Knight [5] proposed a formula for determining surface roughness as in equation (1):

$$R_a = 1000\frac{f^2}{18r\sqrt{3}} \approx 1000\frac{0.0321f^2}{r} \tag{1}$$

Where:
f: longitudinal feed rate (mm/round)
r: nose radius (mm).

In turning with the feed rate less than 2 times of nose radius, J-E.Ståhl et al [6] proposed the formula (2):

$$R_a \approx 770\left[1 - \frac{\frac{f}{2r}}{\arcsin\left(\frac{f}{2r}\right)}\right] r \qquad (2)$$

Groover [7] introduced the roughness formula as in expression (3):

$$R_a \approx 1000\frac{f^2}{32.r} \qquad (3)$$

METALWORKING SOLUTIONS COMPANY MITSUBISHI MATERIAL - METALWORKING SOLUTIONS COMPANY [8] also gave an expression of the relationship between surface roughness and longitudinal feet, nose radius in turning as in formula (4):

$$R_a = 1000\frac{f^2}{8.r} \qquad (4)$$

Custom partnet company [9] introduced the formula (5) to calculate surface roughness for each specific case when changing the longitudinal feed rate or nose radius:

$$R_a = 1000\frac{f_I^2}{24.r_I} \qquad (5)$$

Where:
f: longitudinal feed rate (inch/round)
r: nose radius (inch).

Thus, the relationship between surface roughness, the amount of longitudinal feed rates and the nose radius in turning has been proposed by many studies. However, the above formulas when applied to a specific case for surface roughness are quite different. To demonstrate this observation, the cutting condition with the feed rate 0.097 (mm/rev), the nose radius 0.4 (mm) was chosen. When changing these two values into expressions (1), (2), (3), (4), (5), five values of surface roughness 0.76; 1.89; 0.74; 2.94 and 0.98 μm are obtained repsectively. Thus, although one of the five formulas from (1) to (5) is applied to predict surface roughness, it is possible to reduce machine adjustment time and trial machining time, and contribute to improve the efficiency of machining process. Choosing the formula to ensure predictable results close to the actual value requires specific experimental studies to assess the suitability in each specific condition.

II. EXPERIMENTAL WORK

2.1. Machine tool

Experiments were performed on CNC lathe Mazak QTS 200 (Fig. 1).

Fig. 1. Mazak QTS 200

2.2. Work pieces

An experimental study of turning of 40Cr steel was conducted, and the obtained values of surface roughness were compared with those calculated by the above formulas to select the suitable model stuitable for surface roughness prediction. The sample is steel 40Cr with hardness of 280 HB, dimension workpiece are 80 in length, 40 in diameter.

Table 1. Chemical composition of 40Cr steel

C	Si	Mn	P	S	Cr	Ni	Mo	Other
0,38-0,43	0,15-0,35	0,6-0,85	0,03	0,03	0,9 – 1,2	< 0,25	-	0,3

2.3. Cutting tool

The two types of inserts are used in this study including the insert with the radius of 0.2 mm, with the designation of TNMG160402GP of KYOCERA (made by Japan) and the insert with the radius of 0.4 mm with the designation of TNMG160404MA (made by Korea).

2.4. Surface roughness measure

Surface roughness equipment is Mitutoyo SJ-210 (made by Japan) as Fig.2. At each value of the feed rates, the experiment trial is carried out with 03 samples, and surface roughness for each sample was measured by 03 times and taken by the average value.

Fig 2. Mitutoyo SJ-210 for surface roughness.

III. RESULTS AND DISCUSSION

The experiments were conducted with two types of inserts with the amount of feed rates each type of insert selected according to the manufacturer's recommendation. Specifically, the feed rate values are 0.04 ÷ 0.18 (mm/rev) and 0.1 ÷ 0.4 (mm /rev) corresponding to TNMG160402GP and TNMG160404MA inserts.

Table 2. Surface roughness obtained by calculating and experiments with nose radius of 0.2 mm

Runs	f(mm/rev)	R_a(μm)					
		Calculation					Experiment
		Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	
1	0.04	0.26	1.29	0.25	1.00	0.33	0.59
2	0.05	0.40	2.01	0.39	1.56	0.52	0.77
3	0.06	0.58	2.91	0.56	2.25	0.75	0.95
4	0.07	0.79	3.96	0.77	3.06	1.02	1.24
5	0.08	1.03	5.19	1.00	4.00	1.33	1.51
6	0.09	1.30	6.59	1.27	5.06	1.69	1.46
7	0.1	1.61	8.17	1.56	6.25	2.08	1.66
8	0.11	1.94	9.92	1.89	7.56	2.52	1.87
9	0.12	2.31	11.86	2.25	9.00	3.00	2.26
10	0.13	2.71	13.98	2.64	10.56	3.52	2.58
11	0.14	3.15	16.30	3.06	12.25	4.08	2.74
12	0.15	3.61	18.82	3.52	14.06	4.69	3.30
13	0.16	4.11	21.55	4.00	16.00	5.33	4.20
14	0.17	4.64	24.49	4.52	18.06	6.02	4.69
15	0.18	5.20	27.66	5.06	20.25	6.75	5.15

The TNMG160402GP insert is used to turning 40Cr steel with 15 different values of longitudinal feed rate, the depth of cut of 0.1 (mm) and cutting speed of 250 (m/min) respectively. The surface roughness results of each experimental site are presented in Table 2. Surface roughness calculated according to the formula (1) to (5) is also presented in Table 2. Fig. 2 shows the comparison of the values of surface roughness between experimental calculation using TNMG160402GP insert.

TNMG160404MA insert was used for turning 40Cr steel with 7 different values of longitudinal feed rate, the depth of cut of 0.1 mm and cutting speed of 250 m/min respectively. The surface roughness results of each experimental site are presented in Table 3. Surface roughness calculated according to the formula (1) to (5) is also presented in Table 3.Fig. 3 shows the comparison of the values of surface roughness between experiment and calculation using TNMG160404MA insert.

Table 3. Surface roughness between calculation and experiment with nose radius of 0.4 mm

Runs	f(mm/rev)	R_a(μm)					
		Calculation					Experiment
		Eq. 1	Eq.2	Eq.3	Eq. 4	Eq.5	
1	0.1	0.80	2.01	0.78	3.13	1.04	1.00
2	0.15	1.81	4.56	1.76	7.03	2.34	2.23
3	0.2	3.21	8.17	3.13	12.50	4.17	4.03
4	0.25	5.02	12.90	4.88	19.53	6.51	6.06
5	0.3	7.22	18.82	7.03	28.13	9.38	8.76
6	0.35	9.83	26.05	9.57	38.28	12.76	11.61
7	0.4	12.84	34.70	12.50	50.00	16.67	16.05

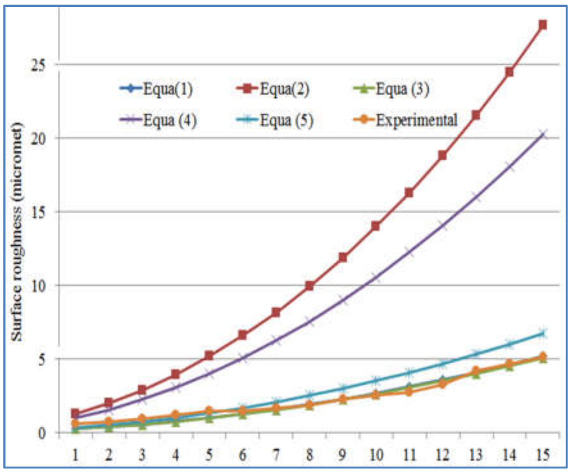

Fig. 2. Surface roughness with TNMG160402GP insert.

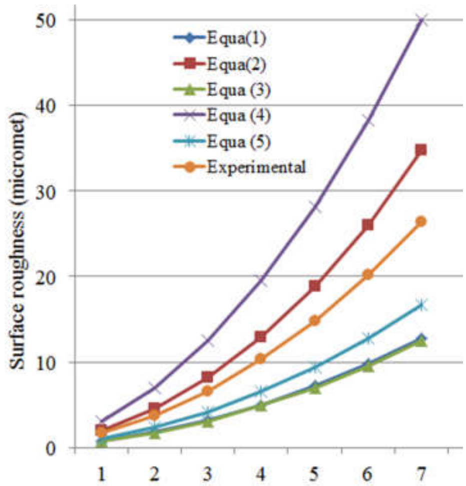

Fig. 3. The value of surface roughness between between experiment and calculation using TNMG160404MA insert.

From Table 2-3, Figure 2-3, it can be observed as following:

- When increasing the feed rate, surface roughness will increase for both different inserts. This is also consistent with comments in many other studies.
- The surface roughness value calculated according to formula (2) and formula (4) is always much larger than that of experiment. This suggests that the formula (2) and (4) are not suitable for predicting surface roughness in turning 40Cr steel.
- In case of using the tool with a nose radius of 0.2 mm, the surface roughness value of experiment is very close to that calculated by formula (1), (3). This shows that it is possible to use formula (1) or (3) for predicting surface roughness in turning 40Cr steel.
- The surface roughness value is relatively consistent with the results calculated by the formula (2) using the tool with a radius of 0.4 mm.

From Tables 2, 3, the relationship between surface roughness and the amount of feed rate was built up for two cases as follows:

- For the insert with nose radius of 0.2 mm, that relationship is as in equation (6) with a determination coefficient $R^2 = 0.9703$.

$$R_a = 47.04S_d^{1.3886} \quad (6)$$

- For the insert with nose radius of 0.4 mm, that relationship is as in equation (7) with a determination coefficient $R^2 = 0.9996$.

$$R_a = 95.569S_d^{1.9798} \quad (7)$$

In addition to using formula (1) or (3) to calculate the surface roughness in turning 40Cr steel with the tool with nose radius of 0.2 mm and using formula (2) to calculate surface roughness using the insert with nose radius of 0.4 mm, it is possible to use expressions (6) and (7) to calculate surface roughness for the two corresponding cases of the nose radius of 0.2 mm and 0.4 mm.

IV. CONCLUSIONS

In this study, the appropriate formula is selected to predict the surface roughness in turning of 40Cr steel. The experimental regression equation exhibiting the relationship between surface roughness and the feed rate in two different cases of the nose radius is also formed. The machine adjustment time and test machining time much reduce by using these equations to predict the surface roughness in turning 40Cr steel, which contributes to improve the economic and technical efficiency of the machining process.

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