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A Study on Surface Roughness when Milling C45 Steel

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ABSTRACT

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In this paper, a study is presented on the milling process of C45 steel by face milling cutters. An experimental process was performed according to an experimental matrix constructed by the Box-Behnken method. At each experiment, three cutting parameters were changed, namely cutting speed, feed rate, and depth of cut. Surface roughness has been selected as a parameter to evaluate the milling process. Analysis of experimental results has determined the influence of cutting parameters as well as their interactions on surface roughness. Two regression models for surface roughness have been proposed. In which one model uses the Johnson transformation. These two models were used to predict the surface roughness and then compared with the experimental results. The results show that the model using the Johnson transformation has higher accuracy than the model not using the data transformation.

Keywords : Milling, C45 Steel, P6M5 Insert, Surface Roughness, Johnson Transformation

I. INTRODUCTION

Milling is considered to be the most productive of all cutting methods [1]. Like other cutting and machining methods, in the milling method, many criteria can be selected to evaluate the machining process. In which, the surface roughness of the workpiece is often chosen as the criterion to evaluate the milling process. This is easy to understand because surface roughness is a parameter that directly affects the workability and durability of the product. On the other hand, the survey of surface roughness is also a relatively simple thing, which can be applied in many different production or research units. To investigate the surface roughness in milling, the simplest method is to consider changing the cutting parameters because changing the cutting parameters will be easily done by the operator of the machine [2]. C45 steel is considered to be the most common steel in the manufacturing industry, this steel has the advantages of low cost, good machinability. It is used to make many different products such as shafts, forks, gears, etc. P6M5 material (Russian standard) is also one of the widely used materials to make cutting tools in mechanical processing thanks to its low cost and temperature durability and high hardness. This type of cutting tool is used to make a variety of cutting tools such as turning tools, milling cutters, drill bits, both in the case of cast iron and steel processing. In this study, we present experimental results of milling

C45 steel by cutting tool P6M5 to investigate the influence of cutting parameters on surface roughness. The parameters considered in this study include cutting speed, feed rate, and depth of cut. In addition, a regression model of surface roughness has also been proposed. The Johnson transformation method has also been applied to improve the accuracy of the regression model.

2. C45 steel milling test

C45 steel samples were used during the experiment. The steel sample measures 200 millimeter in length, 60 millimeter in width, and 20 millimeter in high. Vertical milling machine 6H82 (Russian Federation) was used during the experiment. In order to adjust the cutting speed to the desired value, the main-shaft motor of the machine is connected to a frequency changer, also known as a frequency converter. The cutting inserts used in the experiment are made from a hard alloy of grade P6M5. They are mounted on the body of the face milling cutter with two symmetrical cutting pieces. The tool body has a diameter of 80 millimeters, which means that it only needs to be carried out once to mill the entire surface of the steel sample. To eliminate the influence of tool wear on surface roughness, each cutting piece is used only once.

An experimental matrix was built by the Box-Benken method with a total of eighteen experiments. At each experiment, three cutting parameters will be changed including cutting speed, feed rate, and depth of cut. Each cutting parameter was selected with three levels corresponding to the coding levels -1, 0, and 1. The values of these parameters were selected according to a published study [3] (Table 1). The experimental matrix is presented in Table 2.

Table 1. Cutting parameters

Parameter	Unit	Code value	Symbol	Value at the level		
				-1	0	1
Cutting speed	m/min	x1	v	140	200	260
Feed rate9	mm/tooth	x2	f	0.1	0.2	0.3
Depth of cut	mm	x3	t	0.28	0.4	0.52

Table 2. Experimental matrix and results

Trial	Code value			Real value			Ra, µm
	x1	x2	x3	v, m/min	f, mm/tooth	t, mm	
1	0	0	0	200	0.2	0.4	1.056
2	-1	0	1	140	0.2	0.52	1.224
3	1	0	-1	260	0.2	0.28	0.804
4	0	0	0	200	0.2	0.4	1.032
5	1	1	0	260	0.3	0.4	1.464
6	-1	0	-1	140	0.2	0.28	0.984
7	0	1	-1	200	0.3	0.28	2.256
8	1	-1	0	260	0.1	0.4	0.864
9	-1	1	0	140	0.3	0.4	1.428

10	0	0	0	200	0.2	0.4	1.044
11	0	0	0	200	0.2	0.4	0.984
12	-1	-1	0	140	0.1	0.4	0.996
13	0	-1	1	200	0.1	0.52	0.864
14	1	0	1	260	0.2	0.52	0.744
15	0	-1	-1	200	0.1	0.28	0.828
16	0	0	0	200	0.2	0.4	0.984
17	0	0	0	200	0.2	0.4	1.116
18	0	1	1	200	0.3	0.52	2.424

II. Experimental results and discussion

The tests were carried out in the order shown in Table 2. Each test was performed on three steel samples. After testing, the steel samples were washed with alcohol and made to dry before measuring the surface roughness. Surface roughness gauge SJ-301 (Japan) was used to measure surface roughness. Each steel sample was measured at least three times. Thus, the roughness value at each experiment is the average of at least nine measurements. The surface roughness measurement results at each experiment are also presented in Table 2

Minitab statistical software was used to analyze the results. In Figure 1 and Figure 2, respectively, the graph show the influence of cutting parameters and the interaction effect between cutting parameters on surface roughness.

Observe Figure 1 for the feed rate which is the parameter that has the greatest influence on the surface roughness. When the feed rate increases, the surface roughness increases rapidly. The cutting speed and depth of cut have no significant influence on the surface roughness. However, if considered in detail, it is shown that the cutting speed affects the surface roughness more than the influence of the depth of cut

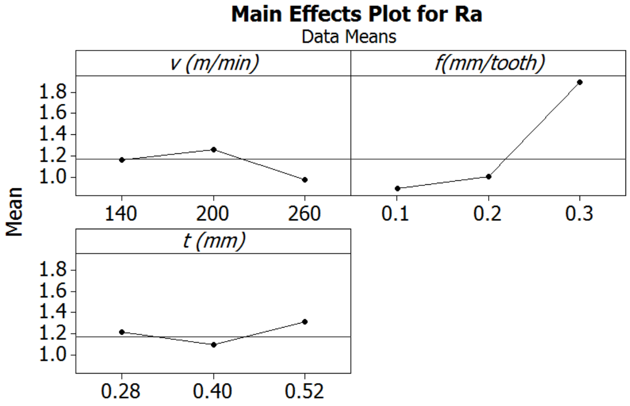

Figure 1. Effect of cutting parameters on surface roughness

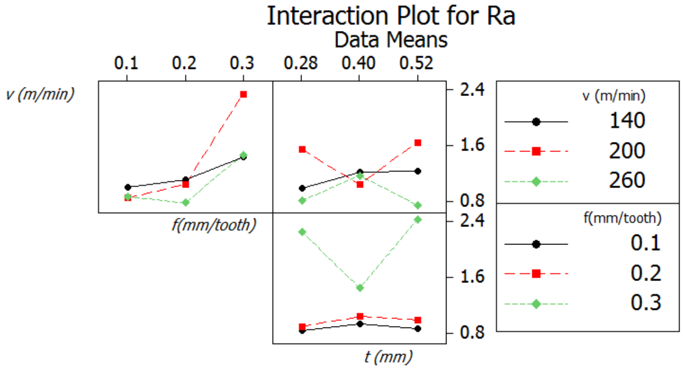

Figure 2. Interaction effects of cutting parameters on surface roughness

Observing the chart in Figure 2 shows:

- For all three values of cutting speed (140 m/min, 200 m/min, and 260 m/min), if the feed rate increases, the surface roughness increases. This result is also consistent with the content analyzed in Figure 1.
- When the cutting speed is 140 m/min if the cutting depth increases from 0.28 mm to 0.40 mm, the surface roughness will increase. However, if the cutting

depth is further increased from 0.40 mm to 0.52 mm, the surface roughness is almost unchanged.

- When the cutting speed is 200 m/min, if the cutting depth increases from 0.28 mm to 0.40 mm, the surface roughness will decrease rapidly. However, if the cutting depth increases from 0.40 mm to 0.52 mm, the surface roughness will be increased rapidly.
- When the cutting speed is 260 m/min, if the cutting depth increases from 0.28 mm to 0.40 mm, the surface roughness will increase, but if the cutting depth continues to increase, the surface roughness will decrease
- For both values of feed rate (0.1 mm/tooth and 0.2 mm/tooth), when the cutting depth changes, there is almost no change in the surface roughness.
- In the case of a feed rate of 0.3 mm/tooth, the surface roughness will decrease rapidly if the cutting depth increases from 0.28 mm to 0.40 mm. But if the cutting depth is increased from 0.40 mm to 0.52 mm, the surface roughness will increase rapidly.

The statistical software Minitab was once again used to build the regression model of the surface roughness. The results have determined the regression model as in formula (1).

$$\begin{aligned} R_a = 1.0360 - 0.0945x_1 + 0.5025x_2 \\ + 0.0480x_3 \\ -0.0750\, x_1x_2 + 0.0330x_1x_3 - 0.2510x_1^2 \\ + 0.4030x_2^2 + 0.1540x_3^2 \end{aligned} \qquad (1)$$

This equation has *R-Square* coefficient is 0.8552, and adjusted coefficient of determination *R-Square(adj)* is 0.6154. The significance of these coefficients has been analyzed in detail in many documents, the closer these coefficients are to 1, the higher the accuracy of the regression model [4]. Since *R-Square(adj)* is 0.6154, it means that the change in surface roughness is only reflected by 61.54% of the change in the cutting parameters. The rest of the surface roughness variation is due to other factors that are not known (confounding factors). Therefore, improving the accuracy of the surface roughness regression model is presented in the next part of this paper

III. Improve the accuracy of the surface roughness model

To improve the accuracy of the regression model, a known solution is to use the Box-Cox metric transformation [5, 6] and the Johnson metric transformation [3, 7]. The condition to perform either of these transformations is that the initial data set must not be normally distributed [4]. The distribution rule of the surface roughness data is presented in Figure 3, in which the significance level was chosen as 0.05. Observing the graph in Figure 3 the surface roughness data set is relatively far from the standard line (the middle line). Especially *P-value* < 0.005, which is much smaller than the significance level. That confirms that the dataset on surface roughness is not distributed according to normal rules. Thus, it is enough to convert this dataset.

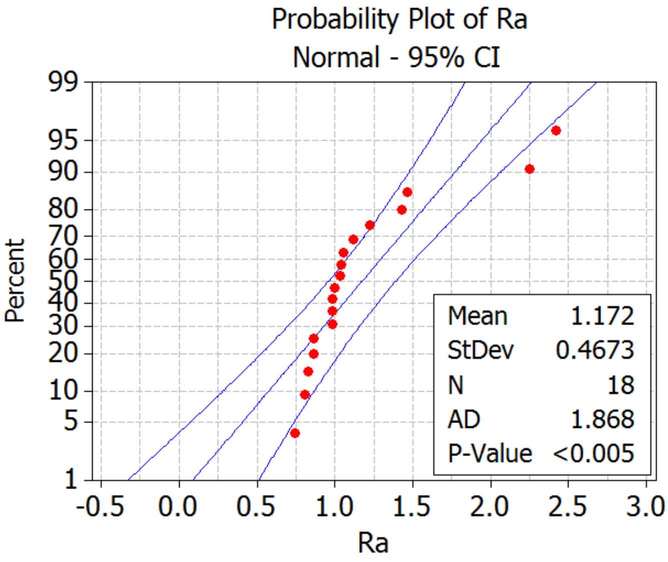

Figure 3. The surface roughness distribution rule

In this study, the Johnson transformation was used. Figure 4 shows the graph of the data transformation. The upper left figure is the surface roughness distribution rule without conversion (above analyzed). The figure on the right is the distribution of the data after converting. We see that the data has been distributed in the form of a bell. That is a normal distribution. Observing the figure below shows that the converted data are close to the standard line, and especially the *P-value* = 0.594 is much larger than the significance level. This confirms that the data set after performing the Johnson transformation has a normal distribution. The lower right corner of Figure 4 shows the mathematical relationship between the data set before and after the transformation.

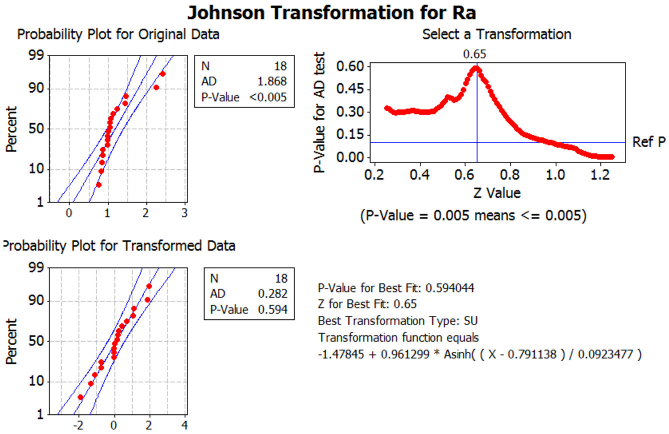

Figure 4. Jouhnson plot for power transformation

From there, we can determine the surface roughness model according to the converted data as in formula (2).

$$-1.47845 + 0.961229 * Asinh\left(\frac{R_a - 0.791138}{0.0923477}\right) = 0.1446 - 0.5818x_1 + 1.0770x_2 + 0.0698x_3 - 0.3355x_1x_2 - 0.0544x_1x_3 - 0.4731x_1^2 + 0.6704x_2^2 - 0.3377x_3^2 \quad (2)$$

Or:

$$R_a = 0.791138 + 0.0923477 * Sinh\ (X) \quad (3)$$

With:

$$X = 1.6885 - 0.6053x_1 + 1.1204x_2 + 0.0726x_3 - 0.3490x_1x_2 - 0.0566x_1x_3 - 0.4922x_1^2 + 0.6974x_2^2 - 0.3513x_3^2$$

This model has an R-Square coefficient of determination and an adjusted R-Square(adj) coefficient of determination of 0.8591 and 0.6227, respectively.

Using formulas (1) and (3) to calculate the roughness, then compared with the roughness value when testing, the results are presented in Table 3

Table 3. Surface roughness when measured and calculated according to models

TT	x_1	x_2	x_3	Ra (measured)	Ra (calculated – without transformation	Ra (calculated – Johnson transformation
1	0	0	0	1.056	1.036	1.032
2	-1	0	1	1.224	1.049	1.004
3	1	0	-1	0.804	0.764	0.811
4	0	0	0	1.032	1.036	1.032
5	1	1	0	1.464	1.521	1.145
6	-1	0	-1	0.984	1.019	0.951
7	0	1	-1	2.256	2.048	1.796
8	1	-1	0	0.864	0.666	0.840
9	-1	1	0	1.428	1.860	3.216
10	0	0	0	1.044	1.036	1.032

11	0	0	0	0.984	1.036	1.032
12	-1	-1	0	0.996	0.705	0.903
13	0	-1	1	0.864	1.139	0.898
14	1	0	1	0.744	0.926	0.814
15	0	-1	-1	0.828	1.043	0.878
16	0	0	0	0.984	1.036	1.032
17	0	0	0	1.116	1.036	1.032
18	0	1	1	2.424	2.144	1.954

From the data in Table 3, we can calculate the mean difference between the predicted results and the experimental results. It is called *F* as follows: for the surface roughness model without data transformation, this value is 14.51%, for the model using Johnson transformation, it is 12.93%. Table 4 presents some comparison parameters between two surface roughness models, one is the model that does not use the data transformation and the other is the model that uses the Johnson transformation.

Table 4. Comparison of some parameters of two roughness roughness models

Model	*R-Square*	*R-Square(adj)*	*F*
Without transformation	0.8552	0.6154	14.51%,
Johnson transformation	0.8591	0.6227	12.93%

The data in Table 4 shows that both parameters *R-Square* and *R-Square(adj)* of the model using Johnson transformation is higher than that of the model not using data transformation. Besides, the *F* parameter of the model using the Johnson transformation is smaller than that of the model not using the data transformation. This is enough to confirm that the model using Johnson transformation has higher accuracy than the model not using data transformation.

IV. CONCLUTION

After the experimental process of milling C45 steel with P6M5 tool was carried out in this study, some conclusions are drawn as follows:

1. The feed rate is the parameter that has the greatest influence on the surface roughness. When the feed rate increases, the surface roughness increases rapidly. The cutting speed and depth of cut have no significant influence on the surface roughness.
2. The interaction between cutting parameters and surface roughness is quite complex.
3. Two regression models for surface roughness have been built, one of which does not use data transformation and the other uses Johnson transformation. The results show that the model using Johnson transformation has higher accuracy than the model not using data transformation.

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