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# Modeling surface roughness when grinding SB410 steel

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***ABSTRACT :*** *Surface roughness has a great influence on the workability as well as the life/lifetime of the machine part surfaces. Developing surface roughness model is a useful method to predict surface roughness when machining as well as determine the value of technological parameters in the machining process in order to achieve surface roughness as required. This article presents a study on modeling surface roughness when surface grinding SB410 steel. From the experimental results, a surface roughness model was established. This model indicates the relationship between surface roughness and three cutting parameters of the grinding process including workpiece velocity, feed rate, and depth of cut. The Box-Cox transformation method was also used to improve the accuracy of the surface roughness model. In addition, the influence of cutting parameters as well as their interaction influence on the surface roughness has also been discussed. The tasks to be done in the future has also been mentioned in this study.*

***KEYWORDS:*** *Surface roughness, SB410 steel grinding, surface roughness model, Box-Cox transformation*

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## I. INTRODUCTION

Grinding is a commonly used finishing machining method in the machine building industry. Products that require high precision, small surface roughness are often made by grinding method [1, 2]. Many parameters can be used to evaluate the grinding process such as machining productivity, precision, surface quality, etc. [1,3]. Of which, surface texture is the most commonly used parameter to evaluate the grinding process. Two reasons can be given to explain this statement: *first* – surface roughness has a great influence on the workability, life/lifetime of products [4, 5], and *second* – It is more convenient to measure surface roughness than when measuring other parameters (such as residual stress, cutting force, cutting heat, etc.) [6]. Machining the surface of machine parts by grinding method to achieve small roughness is always the goal set in most cases. To achieve this goal, many studies have been carried out to develop a surface roughness model. Surface roughness model can be used to predict surface roughness under specific conditions, and moreover, it can also be used to determine the value of parameters in a machining process to ensure that the surface roughness reaches a specified value [7]. The development of surface roughness models when grinding can be done based on theoretical studies of the grinding process [8], or based on experimental studies. In particular, because of the simplicity and closeness to reality, the surface roughness models built by the experimental method account for an overwhelming number compared to the ones built by the theoretical method. After building the roughness model, several studies have applied the Box-Cox transformation, and the Johnson transformation to improve the precision of the model [9,10].

In this study, the surface roughness model was built when grinding SB410 steel on a surface grinder. SB410 steel is the one commonly used in grinding technology to manufacture machine parts with high requirement for hardness, wear resistance as well as corrosion resistance. Testing the grinding process with a total of eighteen experiments, at each experiment three parameters will be changed including the workpiece velocity, the feed rate, and the depth of cut. The reason for selecting these three parameters is that the machine operator will easily adjust their values [11]. A surface roughness model was established after analyzing the experimental results. To improve the precision of the surface roughness model, this study, used the Box-Cox transformation method. The influence of each parameter (workpiece velocity, feed rate, and depth of cut) as well as the influence of the interaction among these parameters on surface roughness have also been discussed in detail. Finally, the development direction for further studies has also been mentioned in the last part of this work.

## II. EXPERIMENT OF GRINDING SB410 STEEL

The experiments were carried out on a surface grinder SG-5010AHR (Taiwan) as shown in figure 1. SB410 steel samples with dimensions of 90 mm long, 40 mm wide and 10 mm high were used during the experiment. After the finish milling, the steel samples are heat treated to a hardness of 64 HRC.

$Al_2O_3$ grinding wheel was used during the experiment. The outer diameter, inner diameter and height of the grinding wheel are 240 mm, 90 mm and 22 mm, respectively. The dressing of grinding wheels is carried out by a dressing tool with a feed rate of 100 mm/min, a depth of cut of 0.01 mm.

**Fig 1.** Grinding machine SG-5010AHR

The values of cutting parameters have been selected as shown in Table 1. These values have been selected on the basis of reference to related works [12-14], as well as based on the ability to adjust such parameters of the experimental machine.

**Table 1**. Cutting parameters

| Parameter | Unit | Code | Symbol | Value at level | | |
|---|---|---|---|---|---|---|
| | | | | -1 | 0 | 1 |
| Workpiece velocity | m/min | x1 | v | 10 | 15 | 20 |
| Feed rate | mm/stroke | x2 | f | 6 | 8 | 10 |
| Depth of cut | mm | x3 | t | 0.005 | 0.01 | 0.015 |

The experimental matrix was developed by the Box–Behnken method. This method is widely used and has proven to be effective when developing an experimental matrix with the goal of optimizing the machining process [15,16]. The experimental matrix was developed with eighteen experiments as shown in Table 2.

Some other conditions of the grinding process such as: cutting speed 34 m/s, Tectyl-cool 1240 oil of 3.5% concentration was used, the pressure of the coolant supplied to the grinding zone was 4 atm with a flow rate of 6.8 liters/min

**Table 2**. Box-Behnken experimental matrix and result

| No. | Code value | | | Real value | | | Ra, µm |
|---|---|---|---|---|---|---|---|
| | $x_1$ | $x_2$ | $x_3$ | v, m/min | f, mm/stroke | t, mm | |
| 1 | 0 | 0 | 0 | 15 | 8 | 0.01 | 0.498 |
| 2 | -1 | 0 | 1 | 10 | 8 | 0.015 | 0.577 |
| 3 | 1 | 0 | -1 | 20 | 8 | 0.005 | 0.379 |
| 4 | 0 | 0 | 0 | 15 | 8 | 0.01 | 0.487 |
| 5 | 1 | 1 | 0 | 20 | 10 | 0.01 | 0.691 |
| 6 | -1 | 0 | -1 | 10 | 8 | 0.005 | 0.464 |
| 7 | 0 | 1 | -1 | 15 | 10 | 0.005 | 1.064 |
| 8 | 1 | -1 | 0 | 20 | 6 | 0.01 | 0.408 |
| 9 | -1 | 1 | 0 | 10 | 10 | 0.01 | 0.674 |
| 10 | 0 | 0 | 0 | 15 | 8 | 0.01 | 0.492 |
| 11 | 0 | 0 | 0 | 15 | 8 | 0.01 | 0.464 |
| 12 | -1 | -1 | 0 | 10 | 6 | 0.01 | 0.470 |
| 13 | 0 | -1 | 1 | 10 | 6 | 0.015 | 0.408 |
| 14 | 1 | 0 | 1 | 20 | 8 | 0.015 | 0.351 |
| 15 | 0 | -1 | -1 | 15 | 6 | 0.005 | 0.391 |
| 16 | 0 | 0 | 0 | 15 | 8 | 0.01 | 0.464 |
| 17 | 0 | 0 | 0 | 15 | 8 | 0.01 | 0.526 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 18 | 0 | 1 | 1 | 15 | 10 | 0.015 | 1.143 |

## III. EXPERIMENTAL RESULTS AND DISCUSSION

The experiments were carried in the order shown in Table 2, each experiment was conducted with three steel samples, the surface roughness was also measured three times on each steel sample. The value of surface roughness at each experiment is the mean one of measurements and has been summarized in Table 2. Mintab 16 software was used to analyze the experimental results. Accordingly, the influence of input parameters on surface roughness is shown in Figure 2. Figure 3 shows the interaction influence between input parameters and output parameters.

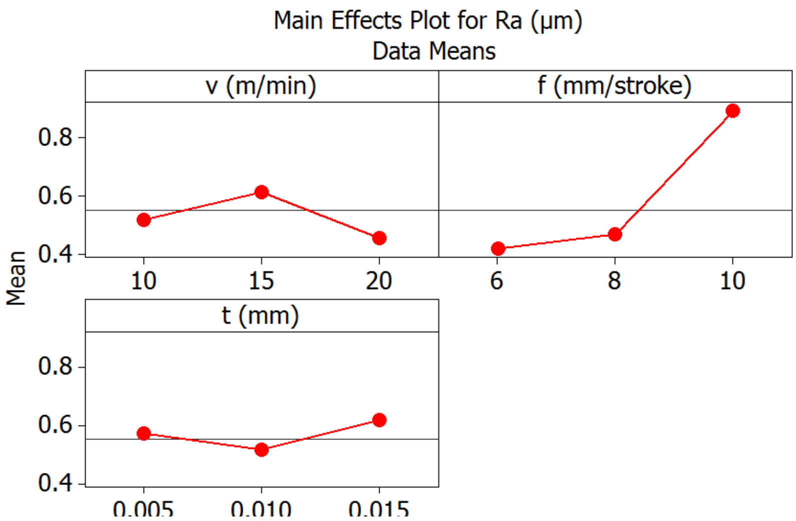


**Fig 2.** Influence of cutting parameters on surface roughness

In figure 2, we can see that:

- When the workpiece velocity increases from 10 m/min to 15 m/min, the surface roughness increases slowly, then if the workpiece velocity continues to increase, the surface roughness will decrease. This is explained that when the workpiece velocity increases, the cuts of abrasive particles on the surface of the part will decrease, leading to an increase in surface roughness. However, if the workpiece velocity continues to increaset, it will cause the cutting heat to decrease, reducing the plastic deformation of the part, which is an opportunity to reduce surface roughness.
- As the feed rate increases, the cuts of abrasive particles on the surface of the part is reduced, which results in an increase in surface roughness.
- The depth of cut has negligible influence on surface roughness. This is explained that SB410 steel has a very high hardness (64HRC), so the cutting heat generated when grinding is very large, the metal layer of the surface reaches the melting state, ie passing the plastic deformation stage, making the depth of cut have negligible influence on the surface roughness.

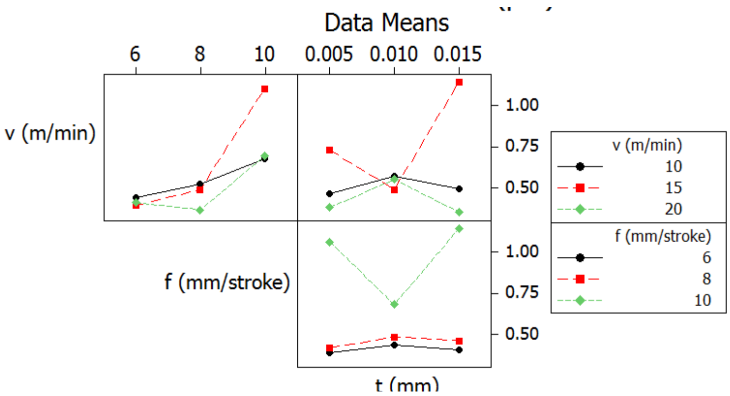


**Fig 3.** Interaction influence of cutting parameters on surface roughness

Figure 3 shows that the interaction mong the parameters affecting the surface roughness is very complex. The following comments will further clarify this statement.

- Corresponding to all three values of the workpiece velocity, when increasing the value of the feed rate, then the surface roughness increases.

- When the velocity of the workpiece is equal to 10 m/min and 20 m/min: if the depth of cut increases from 0.005 to 0.01 mm, the surface roughness will increase, if the depth of cut continues to increase, the surface roughness will decrease. In contrast, when the velocity of the workpiece is equal to 15 m/min: if the depth of cut is increased from 0.005 to 0.01 mm, the surface roughness will decrease, but the surface roughness will increase if the depth of cut continues to increase.

- If the feed rate is equal to 6 mm/stroke and 8 mm/stroke, the change in the depth of cut hardly changes the surface roughness. Conversely, when the feed rate is 10 mm/stroke, increasing the depth of cut from 0.005 to 0.01 mm will cause the surface roughness to decrease rapidly, if further increasing the depth of cut, the surface roughness will increase rapidly.

Also from the analysis of experimental data in Table 2, a surface roughness model has been built as shown in formula (1). This formula has a coefficient of determination ($R^2$) and an adjusted coefficient of determination *(R-Square(adj))* of 0.8575 and 0.6972, respectively. The significance of such coefficients has been analyzed in detail in many documents, the closer such coefficients are to 1, the higher the precision of the regression model is [15,16]. Since *R-Square(adj) = 0.6972*, it means that the change in surface roughness is only reflected by 69.72% of the change of the cutting parameters. The rest of the change in surface roughness is due to other factors that are not known (interference factors). Therefore, the problem is here posed to study to improve the precision of the surface roughness regression model. This is the content presented in the next part of this article.

$$\begin{gathered}R_a = 0.4885 - 0.0445x_1 + 0.2369x_2 + 0.0226x_3 + 0.0198x_1x_2 \\ -0.0352x_1x_3 + 0.0155x_2x_3 - 0.1183x_1^2 + 0.1905x_2^2 + 0.0725x_3^2\end{gathered} \quad (1)$$

## IV. IMPROVING THE PRECISION OF THE SURFACE ROUGHNESS MODEL

The Box-Cox transformation has been used to transform the surface roughness data in Table 2. However, before conducting the data transformation, it is required to check the distribution rule of the dataset (*Ra*). Figure 4 is the distribution rule of the surface roughness dataset. We see that the red dots (representing the values of *Ra*) are not distributed close to the middle line, but there are even points exceeding the limit between the two curves, which shows that the surface roughness dataset is undistributed according to standard rules. *P-value < 0.005* is also a parameter to affirm that the dataset (*Ra*) is not distributed according to standard rules [17].

In Figure 5, the graph is obtained when transforming surface roughness data by the Box-Cox method. Accordingly, the exponential factor of the transformation $\lambda$ = *-2.00* has been determined. The data of surface roughness before and after the Box-Cox transformation are presented in Table 3.

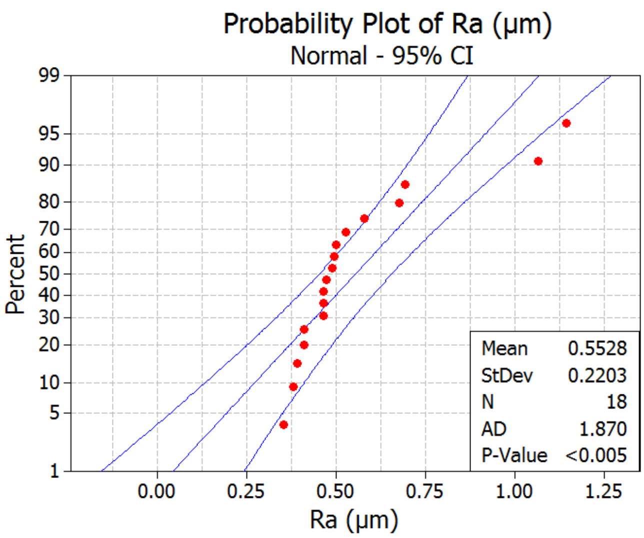


**Fig 4.** Distribution rules of the surface roughness dataset

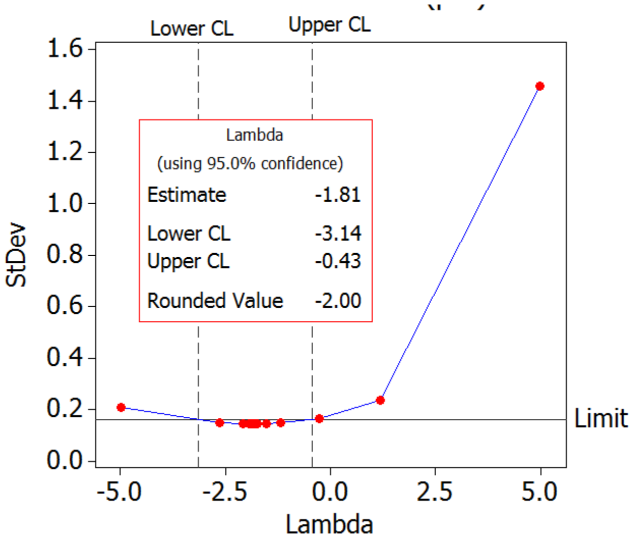


**Fig 5**. Box-Cox plot of Ra

**Table 3.** Surface roughness data before and after the Box-Cox transformation

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Before | 0.498 | 0.577 | 0.379 | 0.487 | 0.691 | 0.464 | 1.064 | 0.408 | 0.674 | 0.492 | 0.464 | 0.470 | 0.408 | 0.351 | 0.391 | 0.464 | 0.526 | 1.143 |
| After | 4.032 | 3.004 | 6.962 | 4.216 | 2.094 | 4.645 | 0.883 | 6.007 | 2.201 | 4.131 | 4.645 | 4.527 | 6.007 | 8.117 | 6.541 | 4.645 | 3.614 | 0.765 |

From the values of surface roughness after the Box-Cox transformation (table 3) and $\lambda$ = *-2.00*, we can develop a surface roughness model as indicated in formula (2).

$$R_a^{-2} = \begin{matrix} 4.2139 + 1.1004x_1 - 2.1423x_2 - 0.1422x_3 - 0.3968x_1x_2 \\ +0.6990x_1x_3 + 0.1040x_2x_3 + 0.8130x_1^2 - 1.3195x_2^2 + 0.6548x_3^2 \end{matrix} \quad (2)$$

Or:

$$R_a = \begin{Bmatrix} 4.2139 + 1.1004x_1 - 2.1423x_2 - 0.1422x_3 - 0.3968x_1x_2 \\ +0.6990x_1x_3 + 0.1040x_2x_3 + 0.8130x_1^2 - 1.3195x_2^2 + 0.6548x_3^2 \end{Bmatrix}^{-0.5} \quad (3)$$

The coefficient of determination ($R^2$) and adjusted coefficient of determination *R-Square(adj)* of equation (3) are 0.8823 and 0.7498, respectively. Thus, both parameters ($R^2$ and *R-Square(adj))* of (3) are larger than that of (1). That proves that model (3) has a higher precision than model (1). In other words, the Box-Cox transformation has been successfully applied to improve the precision of the surface roughness model in this study.

## V. CONCLUSION

In this study, the process of flat-surface grinding SB410 steel was experimented using an $Al_2O_3$ grinding wheel. The influence of the workpiece velocity, feed rate and depth of cut on surface roughness has been analyzed in detail. Two surface roughness models were established, one of which used the Box-Cox transformation. The results have shown that two parameters to evaluate the precision of the model (including $R^2$ *and R-Square(adj)*) using the Box-Cox transformation are larger than that of the model not using the data transformation. In other words, if using the Box-Cox transformation, the surface roughness model can be built with higher precision than when not using the data transformation. In the future, the author of this article will use the Johnson transformation to build a surface roughness model when grinding SB410 steel.

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