MODELING AND IMPROVEMENT OF THE SURFACE ROUGHNESS MODEL IN HOLE TURNING PROCESS 3X13 STAINLESS STEEL BY USING JOHNSON TRANSFORMATION

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ABSTRACT

In this paper, a study was performed to improve the accuracy of the surface roughness model when hole turning the 3X13 steel by using response surface methodology (RSM) and Johnson transformation. This study was presented including three contents that were determination of the influence degree of cutting velocity, feed rate, depth of cut, and cutter nose radius on the surface roughness, building the regression model of the surface roughness by a quadratic model of above input parameters, and building the surface roughness model by using Johnson transformation. By experimental data and using analysis of variance (ANOVA), the influence of input parameters on surface roughness was investigated. Feed rate that was a factor has the most influence on the surface roughness, the influence of the cutter nose radius and cutting velocity on the surface roughness was smaller than the influence of feed rate on the that one. Cutting depth has a negligible effect on surface roughness. The interaction between the feed rate and the depth of cutting has the greatest effect on surface roughness, followed by the degree of interaction between the cutting velocity and the cutter nose radius. The interaction between other factors has a negligible influence on the surface roughness. Besides, the surface roughness model was improved to increase the accuracy by using Johnson transformation. These models have been verified and evaluated by comparison process between the predicted and measured surface roughness. The model using the Johnson transformation was more accurate than the model using without the Johnson transformation. Johnson transformations can be applied to improve the accuracy of surface roughness prediction models in the hole turning processes.

KEYWORDS: Hole Turning, 3X13 Steel; Surface Roughness; Modelling & Johnson Transformation

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1. INTRODUCTION

Turning is the most commonly used machining method in cutting machining methods. In a mechanical workshop, the group of turning machines usually accounts for 25% to 35% of the total number of machine tools, the amount of work done by the turning method accounts for about 40% [1].

The roughness of the hole surface when machining has a great influence on the workability and life of the products. Therefore, surface roughness is often chosen as an indicator to evaluate the efficiency of the machining process. There have been many studies that were published to determine the influence of machining process parameters on the surface roughness as well as develop the surface roughness models to predict the surface roughness of the machined holes in the different conditions.

Amrifan Saladin Mohruni et al. [2] studied the process of turning AISI D2 steel by using the CBN cutting insert. Two parameters of the cutting parameters that were selected as the input parameters to design the experimental process during the experimental process of this study include the cutting velocity and feed rate. The

experiments have been designed according to the response surface method (RSM), based on the design of a Central Composite design (CCD). Their research has shown that both cutting velocity and feed rate have a significant effect on surface roughness. A quadratic polynomial model of surface roughness was also established in this study.

Nguyen Hong Son et al. [3] used a coated PVD insert to hole turning the SCM400 steel. The parameters of cutting velocity feed rate, and depth of cut that were selected as input parameters when constructing the experimental matrix according to the Box-Behnken type. Their research has shown that the feed rate is the parameter that has the greatest influence on surface roughness, followed by the degree of influence of the depth of cut and the interaction between the feed rate and the depth of cut. The cutting velocity and the remaining interactions have a negligible effect on the surface roughness.

In another study, Nguyen Hong Son et al. [4] conducted the experiments in the turning process of SKD11 steel. The cutting velocity, feed rate, and depth of cut were selected as three input parameters to design the experimental process. The experiments in this study were designed according to a 2k experimental matrix type (where $k = 3$ that is the number of input parameters), and added 3 points at the central experiments. This study has determined that the feed rate that is a parameter greatly effects on the surface roughness, the interaction between the feed rate and the depth of cutting also has a significant effect on the surface roughness. The cutting velocity and the remaining interactions between these parameters have a negligible effect on the surface roughness. This study has also developed a roughness model as a quadratic polynomial function of the above three cutting mode parameters to predict surface roughness when turning SKD11 steel.

Taraman et al. [5] used a coated carbide - tungsten cutting insert in turning processes of the ASE 1018 steel The input parameters were chosen to design the test matrix including the cutting velocity the feed rate, and the depth of cutting. The experimental matrix was built by the RSM method based on the CCD matrix. From the experimental results, surface roughness was modeled as a quadratic polynomial to predict surface roughness. Besides, this study also showed that when the cutting velocity increased, the surface roughness decreased, when the feed rate and the depth of cut increased the surface roughness also increased.

Dilbag Singh et al. [6] used the RSM method based on the CCD experimental matrix type in the turning process of the AISI 52100 by using ceramic-coated cutting insert. The cutting velocity feed rate, relief angle, and insert nose radius were selected as input parameters during the experiments. The results of their study have determined that the feed rate is the parameter that has the most influence on surface roughness, followed by the influence of the insert nose radius and cutting velocity, and the relief angle of the insert had negligible influence on surface roughness. A quadratic polynomial equation showing the relationship between surface roughness and the four parameters that were mentioned above was also established in this study.

Manan Kulshreshtha [7] investigated the effect of workpiece rotation speed (cutting velocity), feed rate, and cutting depth on surface roughness when using Tungsten carbide-coated cutting insert in turning process of EN 36 steel. He determined that all three parameters have a significant effect on surface roughness. When the cutting velocity increased, the surface roughness increased. Meanwhile, if the feed rate and depth of cut increased, the surface roughness decreased.

Salah Gasim Ahmed [8] used carbide-coated cutting insert to machine aluminum alloy by using a turning process. Cutting velocity, feed rate, and depth of cut were the three parameters that were selected as input parameters when designing the experimental matrix. From the research results, a model of surface roughness was developed in the form of an exponential

function. The influence of parameters on surface roughness has also been shown: The feed rate had a great influence on the surface roughness. When increasing the feed rate, the roughness of the machining surface increased rapidly. Cutting velocity and depth of cut have a negligible effect on surface roughness.

Feng et al. [9] used cutting tools coated with Ti (C, N) - Al₂O₃ - TiN mixtures in the turning process of two materials (8620 steel and aluminum 6061T). The type of experimental plan they used was a 2k-1 part design form (where k = 5 is the number of input parameters). Five input parameters are used to develop the experimental matrix, including the workpiece hardness, the feed rate, the rake angle of the tool, the depth of cutting, and the cutting velocity. Their research has identified that all five parameters as well as the interaction between them had a significant effect on surface roughness. A model of quadratic polynomial roughness was also proposed in this study.

Doniavi et al. performed the experimental research in the turning process of the AISI 1060 steel by using carbide-coated cutter insert [10]. Cutting velocity, feed rate, and cutting depth that were three parameters were selected in the designing process of the experimental matrix. The experimental matrix was designed in the Box-Behnken type with 20 experiments (L20). This study had shown that the cutting velocity and the feed rate had a great influence on the surface roughness, in which the influence of the feed rate on the surface roughness is greater than the influence of the cutting velocity. When the cutting velocity increased, the surface roughness decreased, and if the feed rate increased, the surface roughness increased. Cutting depth had a negligible effect on surface roughness. Besides, in this study, the surface roughness was modeled as an exponential function.

Dinesh et al. [11] conducted the turning process of the EN 24 alloy steel by using Cemented - coated cutter insert. The experimental matrix of type 2k (L16) was applied to develop the experimental matrix with four input parameters: cutting velocity, feed rate, cutting depth, and cutter nose radius. The results of their study showed that only the feed rate was a parameter that significantly affected on the surface roughness. When the feed rate increased surface roughness increased. The remaining three parameters had a negligible influence on surface roughness. A quadratic polynomial model of surface roughness was also developed in this study.

El-Axir et al. [12] applied the RSM method and Taguchi technique to machine (turn) the 6061-T6 aluminum alloy. The parameters that were selected during the design of the experimental matrix include the tool overhang, the cutting velocity, the feed rate, and the depth of cut. Their research had shown that cutting velocity and feed rate were two parameters that had a significant effect on surface roughness. Tool overhang and cutting depth had a negligible influence on surface roughness. This study has also modeled the surface roughness in the quadratic polynomial form.

Dejan Tanikić et al. [13] studied the turning process of Cold Rolled Alloyed (type Č.4732) by using a tungsten-carbide coated cutter insert. The study used cutting velocity, feed rate, and cutting depth were three input parameters that were used to build the experimental matrix. The experimental matrix was constructed with 27 experiments. Each cutting parameter receiving three levels of values. This study had determined that all three parameters had a great influence on the surface roughness. Where the cutting velocity is the parameter that had the most influence on the surface roughness, followed by the influence of the feed rate and the depth of cut. The interaction between these above parameters had a negligible influence on surface roughness. This study also built the relationship between surface roughness and cutting parameters in the form of a quadratic mathematical function.

Nitin Ambhore et al. [14] conducted experiments to investigate the effect of cutting velocity, feed rate, and cutting depth on surface roughness when turning AISI 52100 steel by using a cutter insert with the sign of CNMG120408-MF5. The experimental process was performed by the RSM method based on the CCD matrix. This study had shown that the

feed rate was the parameter that has the greatest influence on the surface roughness, followed by the degree of influence of the cutting velocity. The depth of cut has a negligible influence on the surface roughness. A quadratic polynomial model of surface roughness was also established in this study.

Shahabi et al. [15] carried out the turning process of AISI 304 steel by using cemented carbide - coated with the symbol of CNGP-12-04-04_H13A. The experiments were conducted by the RSM method based on the CCD experimental matrix. Cutting velocity, feed rate, cutting depth, and machining time were selected as 4 parameters to build the experimental matrix. Research results had shown that cutting velocity, feed rate, and machining time had a significant effect on surface roughness. Cutting depth has a negligible effect on surface roughness. A model of surface roughness in quadratic polynomial form was also established in this study.

Maohua Xiao et al. [16] used a cutter insert with the symbol of 41305A to turn the 1Cr18Ni9Ti stainless steel. The experiments were performed using the RSM method based on the central composite face-central design (CCF). Three cutting parameters including cutting velocity, cutting depth, and feed rate were selected as input parameters when designing the experimental matrix. Research results had shown that the feed rate was the parameter that had the most effect on surface roughness. Increasing the feed rate the surface roughness was quick increased. The cutting velocity was also a parameter that significantly affected on surface roughness. When increasing the value of cutting velocity, sometimes, the surface roughness increased, sometimes, the value of surface roughness was decreased. When the value of the cutting depth increased, the surface roughness also increased, but the influence of depth of cut on the surface roughness is not much. This study has also modeled the surface roughness in the quadratic polynomial form.

In hole machining processes, turning method has many advantages in comparing to some other machining methods (drilling, boring, broaching, etc.) because the turning processes are highly versatile, easy to clamp the workpiece when machining the hole surfaces on the complex structure parts, especially when machining the holes with non-standard sizes [1].

3X13 steel (GOST standard - Russian Federation) is common steel that is often used for manufacturing the parts in shipbuilding, oil and gas, chemical technology, food processing, and medical industries, and so on. Up to now, research documents on the influence of machining process parameters on surface roughness when turning this steel are still quite limited. Besides, it seems that using the Johnson transformation to improve the accuracy of prediction model of surface roughness have not been mentioned. Thus, the studies in the turning processes of 3X13 steel and improvement of prediction model are necessary.

In this paper, the influence of the cutting velocity, feed rate, cutting depth, and insert nose radius on the surface roughness when hole turning the 3X13 steel was investigated. RSM basing on the experimental matrix CCD type was applied to build the surface roughness model. The Johnson transformation was applied to improve the accuracy of the model in prediction of surface roughness. The evaluation process of the accuracy of these prediction models (with or without application of Johnson transformation) was also performed.

2. MATERIAL AND METHOD

2.1. Experimental Workpiece

The workpiece that was used in this study was 3X13 steel. Before performing the experiments, the workpiece had heat treated for archived 56 HRC in hardness. The dimensions of the workpiece were 80 mm x 50 mm x 52 mm. The chemical

composites of 3X13 steel were described in table I.

Table I: Chemical Composites of 3X13 Steel

C [%]	Si [%]	Mn [%]	Cr [%]	S [%]
0.42	1.00	1.00	13.00	0.005

2.2. Machine and Cutter

The experiments were conducted in the CNC Doosan Lynx 220L turning machine. The cutter that was used in this study was coated PVD insert of Korloy (Korea) with five different values of the nose radius (0.1mm, 0.2mm, 0.3mm, 0.4mm, and 0.5mm). Five inserts that has the sign DNC250 1EA19C28 0.1R, DNC250 1EA19C28 0.2R, DNC250 1EA19C28 0.3R, DNC250 1EA19C28 0.4R và DNC250 1EA19C28 0.5R.

2.3. Measurement System

The SI-301 surface roughness tester (Mitutoyo - Japan) was used to measure the surface roughness in this study. In each experiment, the surface roughness were measured at least three time. The surface roughness value at each experiment is the average of successive measurements.

2.4. Experimental Design

The experiments were designed following the RSM basing on the CCD matrix type. According to these experimental types, each input parameter was designed by five code levels including $-\alpha$, -1, 0, 1 and α . Where $\alpha = (2k)^{1/4}$, with k is the number of the input parameters. The input values at their levels were listed in the Table II. Experimental matrix included 2k origin experimental points (at level -1 and 1), 2k axial experimental points (at level $-\alpha$ and α), and 6 center experimental points (at level 0). The detail of experimental matrix was expressed in Table III.

Table II: The Input Parameter Values and Levels

Parameter	Unit	Symbol	Values at the Levels				
			-2	-1	0	1	2
Cutting velocity	m/min	v	100	140	180	220	260
Feed rate	mm/rev	f	0.02	0.04	0.06	0.08	0.1
Cutting depth	mm	t	0.05	0.1	0.15	0.2	0.25
Cutter nose radius	mm	r	0.1	0.2	0.3	0.4	0.5

Table III: The Experimental Matrix and Results

No.	Code Values				Actual Values				Ra (μ m)
	v	f	t	r	v (m/min)	f (mm/rev)	t (mm)	r (mm)	
1	-1	-1	1	-1	140	0.04	0.2	0.2	1.12
2	1	1	1	1	220	0.08	0.2	0.4	4.08
3	-1	-1	-1	1	140	0.04	0.1	0.4	2.88
4	1	-1	1	1	220	0.04	0.2	0.4	1.4
5	0	0	0	0	180	0.06	0.15	0.3	2.18
6	0	0	0	0	180	0.06	0.15	0.3	2.34
7	1	-1	-1	-1	220	0.04	0.1	0.2	1.7
8	1	1	-1	-1	220	0.08	0.1	0.2	2.16
9	1	-1	1	-1	220	0.04	0.2	0.2	1.24
10	0	0	0	0	180	0.06	0.15	0.3	2.18
11	1	1	1	-1	220	0.08	0.2	0.2	3.32
12	-1	1	1	1	140	0.08	0.2	0.4	5.22

Table III: Contd,...									
13	0	0	0	0	180	0.06	0.15	0.3	2.2
14	-1	-1	1	1	140	0.04	0.2	0.4	2.08
15	-1	1	1	-1	140	0.08	0.2	0.2	3.04
16	-1	1	-1	-1	140	0.08	0.1	0.2	2.84
17	1	1	-1	1	220	0.08	0.1	0.4	2.88
18	-1	1	-1	1	140	0.08	0.1	0.4	5.66
19	-1	-1	-1	-1	140	0.04	0.1	0.2	2.16
20	1	-1	-1	1	220	0.04	0.1	0.4	2.22
21	-2	0	0	0	100	0.06	0.15	0.3	2.8
22	0	2	0	0	180	0.1	0.15	0.3	3.94
23	2	0	0	0	260	0.06	0.15	0.3	1.44
24	0	-2	0	0	180	0.02	0.15	0.3	2.09
25	0	0	-2	0	180	0.06	0.05	0.3	1.92
26	0	0	2	0	180	0.06	0.25	0.3	2.32
27	0	0	0	-2	180	0.06	0.15	0.1	2.66
28	0	0	0	2	180	0.06	0.15	0.5	2.84
29	0	0	0	0	180	0.06	0.15	0.3	2.22
30	0	0	0	0	180	0.06	0.15	0.3	2.12

3. RESULTS AND DISCUSSIONS

Conducting the experimental process in the same order as in Table III, the measured surface roughness for each experiment was also listed in this table. ANOVA analysis results and regression model information for surface roughness were analysed, obtained, and shown in Table IV.

The results from Table IV showed that:

Cutting velocity, feed rate, and tool nose radius are the parameters that greatly influenced on the surface roughness. Feed rate is the parameter that has the greatest influence on the surface roughness, followed by the influence of the tool nose radius and the cutting velocity. Cutting depth has a negligible effect on surface roughness. When the value of the cutting velocity increased, the surface roughness decreased. The surface roughness value will increase when the value of the feed rate increased. When the radius of the tip increased, sometimes the roughness increased sometimes the roughness decreased. Observing Figure 1 about the effect of parameters on surface roughness will shed more light on these claims.

Table IV: The Anova Analysis and Regression Information for Surface Roughness

Multiple R			0.9397			R Square		0.8831
Adjusted R Square			0.7740			Standard Error		0.4948
ANOVA								
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>			
Regression	14	27.7436	1.9817	8.0930	0.0001			
Residual	15	3.6730	0.2449					
Total	29	31.4166						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95.0%</i>	<i>Upper 95.0%</i>
Intercept	2.2067	0.2020	10.9232	0.0000	1.7761	2.6373	1.7761	2.6373
v	-0.3633	0.1010	-3.5971	0.0026	-0.5786	-0.1480	-0.5786	-0.1480
f	0.7542	0.1010	7.4664	0.0000	0.5389	0.9695	0.5389	0.9695

t	-0.0083	0.1010	- 0.0825	0.9353	-0.2236	0.2070	-0.2236	0.2070
r	0.3833	0.1010	3.7951	0.0018	0.1680	0.5986	0.1680	0.5986
v ²	0.0198	0.0945	0.2095	0.8369	-0.1816	0.2212	-0.1816	0.2212
f ²	0.2435	0.0945	2.5776	0.0210	0.0422	0.4449	0.0422	0.4449
t ²	0.0198	0.0945	0.2095	0.8369	-0.1816	0.2212	-0.1816	0.2212
r ²	0.1773	0.0945	1.8764	0.0802	-0.0241	0.3787	-0.0241	0.3787
v*f	-0.1650	0.1237	- 1.3338	0.2022	-0.4287	0.0987	-0.4287	0.0987
v*t	0.1975	0.1237	1.5965	0.1312	-0.0662	0.4612	-0.0662	0.4612
v*r	-0.2825	0.1237	- 2.2836	0.0374	-0.5462	-0.0188	-0.5462	-0.0188
f*t	0.3275	0.1237	2.6473	0.0183	0.0638	0.5912	0.0638	0.5912
f*r	0.2575	0.1237	2.0815	0.0549	-0.0062	0.5212	-0.0062	0.5212
t*r	-0.0450	0.1237	- 0.3638	0.7211	-0.3087	0.2187	-0.3087	0.2187

However, in detail, the influence degree of the interactions on the surface roughness decreased gradually according to the orders of the interaction between feed rate and insert nose radius, the interaction between cutting velocity and depth of cut, the interaction between cutting velocity and feed rate, the interaction between depth of cut and insert nose radius.

Figure 2 illustrated the interaction influence between parameters on surface roughness: The interaction between the feed rate and the depth of cut has the greatest impact on surface roughness, followed by the interaction influence between the workpiece velocity and the cutter nose radius on the surface roughness. The interaction between other factors had a negligible influence on the surface roughness.

Figure 1: Influence of Input Parameters on the Surface Roughness.

Figure 2: Interactive Influence of the Input Parameters on the Surface Roughness

4. REGRESSION OF THE SURFACE ROUGHNESS

4.1. The Quadratic Model of the Surface Roughness

From the experimental data in Table 5, the regression equation that described the relationship between surface roughness and cutting velocity, feed rate, depth of cut, and insert nose radius was expressed in Eq. (1) with the determination coefficient R^2 of 0.8831. By this method, the surface roughness model was modelled by quadratic function of the cutting velocity, feed rate, depth of cut, and insert nose radius.

$$\begin{aligned}
 Ra = & 2.2067 - 0.3633 * v + 0.7542 * f - 0.0083 * t + 0.3833 * r + 0.0198 * v^2 + 0.2435 * f^2 + 0.0198 \\
 & * t^2 + 0.1773 * r^2 - 0.1650 * v * f + 0.1975 * v * t - 0.2825 * v * r + 0.3275 * f * t + 0.2575 * f * r - 0.0450 * \\
 & t * r
 \end{aligned} \quad (1)$$

4.2. Regression of the Surface Roughness by Using Johnson Transformation

The Johnson transformation, also known as the Johnson transform that is used to convert a dataset of non-normal distribution into the normal distribution form. The results of the Johnson transformation of measured surface roughness in Table 4 that were performed by the Minitab 16 statistical software. The transformation results were shown in figure 3.

Figure 3: The Johnson Transformation Results for Surface Roughness.

Observations in Figure 3a showed that the measured data was quite far from the standard distribution line. On the other hand, the probability value P is <0.005, which is much smaller than the significance level (the significance level is usually chosen as 0.05). Therefore, it can be asserted that the roughness value set was not distributed according to the standard distribution.

The observation in Figure 3b showed that the post-transformation data was close to the standard distribution line. On the other hand, the probability value P has a value of 0.309, much larger than the significance level. Therefore, it can be asserted that the dataset after the Johnson transformation was distributed according to the normal distribution. This showed that applying the Johnson transformation to perform surface roughness data transformation was appropriate.

Figure 3 showed that the roughness data after using Johnson transformation was distributed in the form of a standard curve. Figure 3d described the relationship between the dataset after using Johnson transformation and before using Johnson transformation. Since then, the roughness model was expressed in Eq. (2), this is a reverse parabola model with the determination coefficient R^2 of 0.8939.

$$\begin{aligned} \text{Asinh}((Ra - 2.09526)/0.457943) = & 0.2382 - 0.4388 * v + 0.8685 * f - 0.0355 * t + 0.3574 * r - 0.0400 \\ & * v^2 + 0.2137 * f^2 - 0.0352 * t^2 + 0.2399 * r^2 + 0.0152 * v * f + 0.2039 * v * t - 0.1506 * v * r + 0.4731 * f * \\ & t + 0.0251 * f * r - 0.1010 * t * r \end{aligned} \quad (2)$$

4.3. Comparison of the Surface Roughness Models

The measured surface roughness and the predicted surface roughness by using model 1 and model 2 were stored in Table V. In order to evaluate the accuracy of two above surface roughness models, the comparing process of mean absolute error (MAE), mean square error (MSE), and the determination coefficients of two models was implemented. The MAE and MSE were determined by Eq. (3) and Eq. (4).

$$\%MAE = \left(\frac{1}{n} \sum_{i=1}^n \left| \frac{e_i - p_i}{e_i} \right| \right) * 100\% \quad (3)$$

$$\%MSE = \left(\frac{1}{n} \sum_{i=1}^n |e_i - p_i|^2 \right) * 100\% \quad (4)$$

Where e is the experimental values, p is the predicted values, n is the number of experiments.

Table IV: Comparison of Surface Roughness by Experimental and by using Proposed Models

Order	Experimental Surface Roughness Ra (μm)	Predicted Surface Roughness Ra (μm)		Absolute Error (%)	
		Without Transformation	With Transformation	Without Transformation	With Transformation
1	1.12	1.393	1.630	24.36	45.55
2	4.08	3.901	3.492	4.38	14.42
3	2.88	3.276	3.069	13.75	6.56
4	1.4	1.553	1.605	10.91	14.67
5	2.18	2.207	2.205	1.22	1.17
6	2.34	2.207	2.205	5.70	5.75
7	1.7	2.143	1.757	26.05	3.36
8	2.16	2.151	2.135	0.41	1.15
9	1.24	1.956	1.490	57.76	20.18
10	2.18	2.207	2.205	1.22	1.17
11	3.32	3.275	3.151	1.37	5.10
12	5.22	5.128	5.083	1.77	2.63
13	2.2	2.207	2.205	0.30	0.25
14	2.08	2.119	2.036	1.89	2.10
15	3.04	3.371	3.320	10.89	9.22
16	2.84	3.038	2.663	6.96	6.24
17	2.88	2.958	2.474	2.70	14.11
18	5.66	4.974	4.377	12.11	22.67
19	2.16	2.369	2.249	9.69	4.14
20	2.22	1.919	2.041	13.54	8.07
21	2.8	3.013	2.603	7.59	7.05
22	3.94	4.689	5.962	19.01	51.32
23	1.44	1.559	1.689	8.28	17.29
24	2.09	1.672	1.780	19.99	14.85
25	1.92	3.015	2.173	57.05	13.16
26	2.32	2.982	2.107	28.54	9.17
27	2.66	2.149	2.325	19.20	12.59
28	2.84	3.683	3.612	29.67	27.18
29	2.22	2.207	2.205	0.60	0.66
30	2.12	2.207	2.205	4.09	4.03

Table VI presented the compared results of the surface roughness model without using Johnson transformation and surface roughness model by using Johnson transformation. These results showed that when using the roughness model

with using Johnson transformation (model 2), the MAE of surface roughness between the predicted results and the experimental results was 11.53%, While, in another case without using the Johnson transformation (model 1), the MAE of surface roughness between the predicted result and the experimental result was 13.37%. About the MSE, this value in the case using without Johnson transformation was 3.93. And, it was 2.78 % in the case applying the Johnson transformation. So, if using the Johnson transformation, the MSE was smaller than in the case without using Johnson transformation.

Besides, in the comparison process of determination coefficients, these values that was determined by using Johnson transformation was larger than that one when using without Johnson transformation. These were 89.39 % and 88.13 %, respectively. Moreover, the comparison results of experimental values, predicted values of surface roughness with and without using Johnson transformation were described in Fig. 3. These results showed that in almost case, the surface roughness results that was predicted by using Johnson transformation were close to the experimental results than that one without using Johnson transformation. So, using Johnson transformation that was a good approach to improve the accuracy in prediction of the surface roughness in the hole turning processes.

Figure 3: The Comparison of Predicted and Measured Values of Surface Roughness.

Table VI: Summary of Comparative Criteria of the Surface Roughness Models

Models	Mean Absolute Error (%)	Mean Square Error (%)	R ²
Without Johnson transformation	13.37	3.93	0.8831
With Johnson transformation	11.53	2.78	0.8939

5. CONCLUSIONS

The conclusions that were drawn from this study when turning 3X13 steel were as follows:

- Cutting velocity, feed rate, and insert nose radius were parameters that greatly influence on the surface roughness. In particular, the feed rate was the parameter that had the greatest influence on the roughness, followed by the influence of the insert nose radius, and the influence of the cutting velocity. Cutting depth was a parameter that does not significantly affect on the surface roughness.
- The interaction between the feed rate and the depth of cut had the greatest effect on the surface roughness, followed by the interaction influence between the workpiece velocity and the insert nose radius. The interaction between other factors had a negligible influence on the surface roughness.
- The accuracy of the surface roughness model had been improved when using the Johnson transformation. When

comparing the surface roughness model using the Johnson transformation and without Johnson transformation, the mean absolute errors that were determined between predicted and experimental results decreased from 13.37 % to 11.53%, the means square errors decreased from 3.93 % to 2.78%, the determination coefficients (R²) increased from 0.8831 to 0.8939.

- This approach can be applied for other machining processes such as milling, drilling, ect. These were the research directions in the future.

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