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An Investigation on Surface Roughness and Tool Wear In Milling Operation of XW-41 Steel

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KEYWORDS

Surface roughness
Tool wear
Response surface method
ANOVA method

ABSTRACT

The project has focused on the comparison of cutting parameters for XW-41 (SKD11) tool material using Deckel Maho DMU 50 Computer Numerical Control (CNC) Milling Machine. The tool wear and surface roughness are measured in order to assess the surface quality of the workpiece after the milling process. The objective of this research is to determine the effects of machining parameters (spindle speed, depth of cut and feed rates) on the surface roughness and tool wear using respond surface method (RSM) on the CNC Milling Machine. This paper presents an optimization method of the cutting parameters (spindle speed, feed rate and depth of cut) in XW-41 steel to achieve minimum the surface roughness and tool wear. The experimental layout was designed based on the Respond surface methodology (RSM) and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The results showed that spindle speed, feed rate and depth of cut are the most important parameter influencing the surface roughness and tool wear. The optimum condition for obtaining the lowest value of surface roughness and tool wear were using the spindle speed of 2000 RPM, feed rate at 50 mm/min and depth of cut of 0.12 mm.

1.0 INTRODUCTION

The project has focused on the comparison of cutting parameters for XW-41 (SKD11) Tool material using Deckel Maho DMU 50 CNC Milling Machine. In industries, milling operation is a very basic type of machining.

Traditionally, the selection of cutting conditions for machining was left to the manufacturing engineer, machine operator or machine setup technician is often expected to utilize the experience and published shop guidelines for determining the proper machining parameters to achieve a specified level of requirement condition like surface roughness and tool wear. (U. Natarajan, et al., 2014) have examined surface roughness is an important criteria to find the quality of a surface. It is an important response parameter. Surface roughness of work parts plays an important role on mechanical properties.

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Specifically, the tool wear and surface roughness are measured in order to assess the surface quality of the workpiece after the milling process. (M. Nurhaniza et al., 2016) said, machining parameters and the process used are important to produce the necessary part for geometrical shapes and dimensional tolerances required. (Kant, Girish, et al, 2014) The optimization of machining parameters for minimum power requirement is expected to lead to the application of lower rated motors, drives and auxiliary equipment and hence save power not only during machining but as well as during build-up to machining, post machining and idling condition. In addition to the machining parameters, the power requirement during machining also depends upon workpiece properties and cutting tool properties.

Machining technique with the combination of high cutting speed, high feed rate and shallow depth of cut using CNC milling machine is one of the wide production technology used (Sutarmanet al., 2014). By comparing this high productivity machine with conventional machine has a number of advantages, such as high efficiency, accuracy, quality of final workpieces, eliminate the secondary or semi-finishing process, increase of productivity, cut off of costs and machining time, better surface finish, eliminates the needs of coolant, reduce tool load for finishing operation and last but not least small chips are produced for easy cleaning purposes.

The materials are used in this experiment, namely; XW-41 Tool Steel, (Rachmadi Norcahyo, Bobby O.P Soepangkat, 2017) which is widely used in the manufacturing industry. XW-41 tool steel is recommended for tool insert which requires a very high wear resistance, combined with moderate toughness (shock resistance). XW-41 is versatile tool steel, which can be used for a wide variety of cold work applications including blanking and other cutting processes, and several forming processes.

The machining parameters need to be considered for this project. For this project, the experiment made are based on the Design of Experiment (DOE) that had been made regarding the variable and parameter needed to be considered in this experiment. The experimental work will be designed using the Response surface methodology (RSM) and will be analyzed using the ANOVA method. By designing the experiment, a major and minor error such as random error can be minimized and also can be avoided. With this, the data and result that come out from the experiment is reliable and trusted. (Aggarwal et al, 2008) used RSM and Taguchi's technique to investigate the effect of cutting speed, feed, depth of cut, nose radius, and cutting environment during turning of AISI P20 tool steel on the power consumption. Results show that the cutting speed is the most significant factor followed by depth of cut and feed.

2.0 EXPERIMENTAL PROCEDURE

This experiment will identify the optimum machining parameters used for machining on tool steel material which is XW-41 (SKD11) grade using end mill 2 flutes tool in wet cutting condition. Customer always prefer the quality of product and the quality of work piece cutting surface procedure and the same time prolonged the life of tool. That is one of the main reasons of these project to compare the behaviour of the cutting parameters.

The stages of experimental:

1) The data of surface roughness and tool wear will be collected using surface roughness tester and the optical microscope respectively.
2) The CNC milling machine will be used is Deckel Maho DMU 50 CNC Milling Machine. Computer Numerical Control (CNC).
3) The Material used is Tool Steel Grade; XW-41 (SKD11) Tool.
4) The machining parameters for maximum and minimum value be considered are spindle speeds (RPM), feed rate (mm / min) and cutting depth (mm).
5) Two flutes end mill be used as a cutting tool and the wear of the cutting tool will be measured using an optical microscope.
6) The experimental work will be designed using Respond surface methodology (RSM) and will be analyzed using ANOVA method.

The experiment used the Response Surface Method (RSM) to arrange the selected parameters before conducting the process of getting the sample part. For both cutting operations, the machining parameters were set into three variables which were cutting speed, feed rate and depth of cut. The details of the machining parameters are provided in Table 1 below:

Table 1: The parameters considered for conducting the experiment

Machining parameters	Units	Values
Spindle speed	(RPM)	2000 - 3500
Feed rate	(mm/min)	50 - 100
Depth of cut	(mm)	0.1 – 0.5

The Response Surface Method (RSM) is exploring the relationships between several explanatory variables and one or more response variables. It is a dynamic, important tool of the design of experiment (DOE) and is based on fitting empirical models with experimental data. These data are obtained from the relationship between the response and input decision variables to maximize or minimize response properties. RSM is a set of statistical technique that employs linear or square polynomial function to describe and explore experimental conditions of a study system until its optimization. This method is useful for any field of engineering.

To run the experiment, the table of machining parameters that needed to be investigated during the experiment should be completed. Table 2 shows of Response Surface Method (RSM) for the experiment. The table can get from the analysis of variance (ANOVA) after the parameter had been keyed in the software.

Table 2: Table of Response Surface Method (RSM) for the experiment

No.	Spindle speed (RPM)	Feed rate (mm/min)	Depth of cut (mm)	Surface roughness(Ra)	Tool wear(mm)
1	2750.00	75.00	0.30	0.163	0.130
2	2000.00	50.00	0.50	0.179	0.123
3	2000.00	75.00	0.30	0.224	0.125
4	3500.00	75.00	0.30	0.314	0.114
5	2750.00	75.00	0.30	0.261	0.139
6	2750.00	75.00	0.10	0.400	0.102
7	2750.00	75.00	0.30	0.263	0.183
8	2750.00	75.00	0.50	0.335	0.140
9	2750.00	75.00	0.30	0.250	0.195
10	3500.00	50.00	0.50	0.332	0.413
11	2000.00	100.00	0.50	0.339	0.256
12	2000.00	50.00	0.10	0.151	0.072
13	2750.00	75.00	0.30	0.229	0.163
14	2750.00	75.00	0.30	0.290	0.077
15	3500.00	50.00	0.10	0.179	0.134
16	2000.00	100.00	0.10	0.151	0.131
17	3500.00	100.00	0.10	0.142	0.396
18	3500.00	100.00	0.50	0.439	0.397
19	2750.00	50.00	0.30	0.238	0.195
20	2750.00	100.00	0.30	0.284	0.131

3.0 RESULTS AND DISCUSSION

In this section, the full result of experimental work on the machining of XW-41 (SKD11) tool steel material using different of cutting parameters in order to assess the surface roughness and tool wear for the best understanding and legitimization.

The machining operation was set up on CNC milling machine (CNC) that is Deckel Maho DMU 50. From this study, the variables investigated was different machining parameter (spindle speed, feed rate and depth of cut) by using 2 flutes carbide end mill tool with diameter of 6 mm on the workpiece. All of the data for the surface roughness and tool wear were recorded for analysis purpose.

This chapter will describe the procedure for this analysis is as stated in the methodology in tern of affected on the surface roughness and tool wear on XW-41 (SKD11) Tool Steel material. They were measured by using Surftest SJ-210- Series 178-Portable Surface Roughness Tester for the surface roughness shown in Figure 1, while for the tool wear by using Zeiss Stemi 2000-C Microscope Profile Optical Measuring System shown in Figure 2.

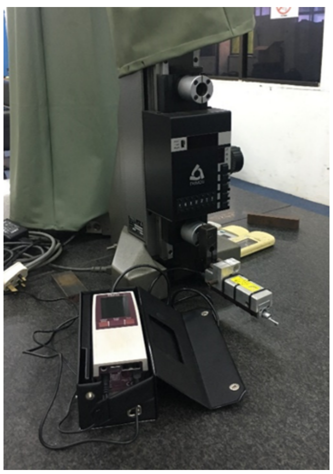


Figure 1: Portable Surface Roughness Tester

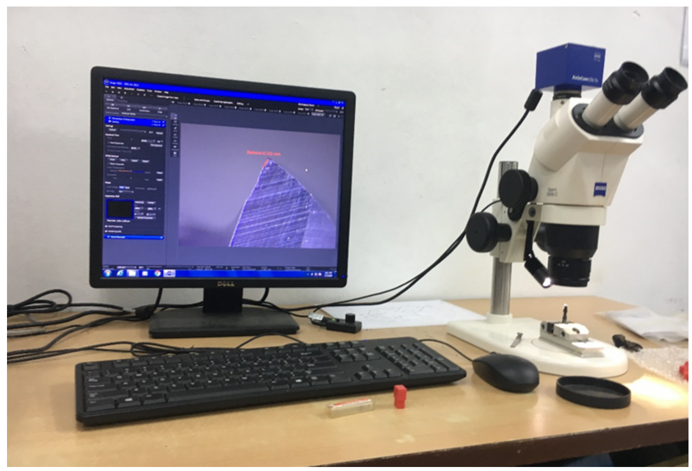


Figure 2: Zeiss Stemi 2000-C Microscope Profile Optical Measuring System

3.1 Surface roughness

The data of surface roughness on workpiece that checked using Surftest SJ-210- Series 178-Portable Surface Roughness Tester. From the Table 2 showed the design layout and experimental results for surface roughness for this experiment. The unit of surface roughness is micrometer (Ra). From the table, the lowest result of surface roughness is 0.142 Ra. The lowest result were from the machining parameter of (spindle speed: 3500 RPM, feed rate: 100 mm/min, depth of cut: 0.10 mm). The highest result of surface roughness is 0.439 Ra. The highest result were from the machining parameter of (spindle speed: 3500 RPM, feed rate: 100mm/min, depth of cut: 0.50 mm).

For the analysis, the ANOVA automatically generated from the Design Expert software. Table 3 listed the ANOVA results of the surface roughness for this experimental. The Model F-value of 15.94 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. The F-value of less than 0.0500 indicates that the selected models are significant, in this case A, C are significant model terms. The lack of fit F-value of 1, 05 implies not significantly relative to the pure error.

Table 3: ANOVA of the surface roughness

ANOVA for Response Surface Linear Model
Analysis of variance table[Partial sum of squares - Type III]

Source	Sum of squares	df	Mean square	F value	p-value Prob>F	
Model	0.095	3	0.032	15.94	< 0.0001	significant
A-spindle speed	0.013	1	0.013	6.63	0.0203	
B-feed rate	7.618E-003	1	7.618E-003	3.86	0.0672	
C-Depth of cut	0.074	1	0.074	37.34	< 0.0001	
Residual	0.032	16	1.976E-003			
Lack of Fit	0.022	11	2.003E-003	1.05	0.5160	not significant
Pure Error	9.577E-003	5	1.915E-003			
Cor Total	0.13	19				

Table 4: shows the table for final equation of linear models of surface roughness in terms of coded factors and actual factors is given below.

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	0.25	1	9.939E-003	0.22	0.27	
A-Spindle speed	0.036	1	0.014	6.402E-003	0.066	1.00
B-Feed rate	0.028	1	0.014	-2.198E-003	0.057	1.00
C-Depth of cut	0.086	1	0.014	0.056	0.12	1.00

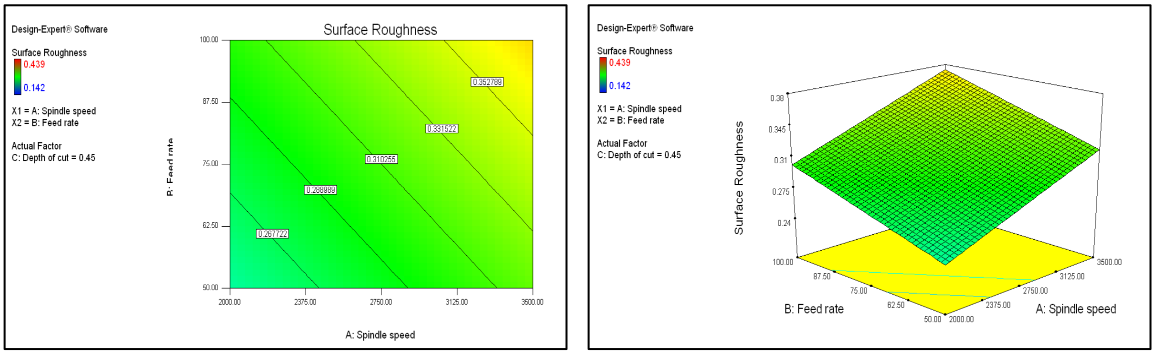
Final Equation in Terms of Coded Factors:

Surface Roughness =+0.25 +0.036* A +0.028* B +0.086* C … Eqn. (1)

Final Equation in Terms of Actual Factors:

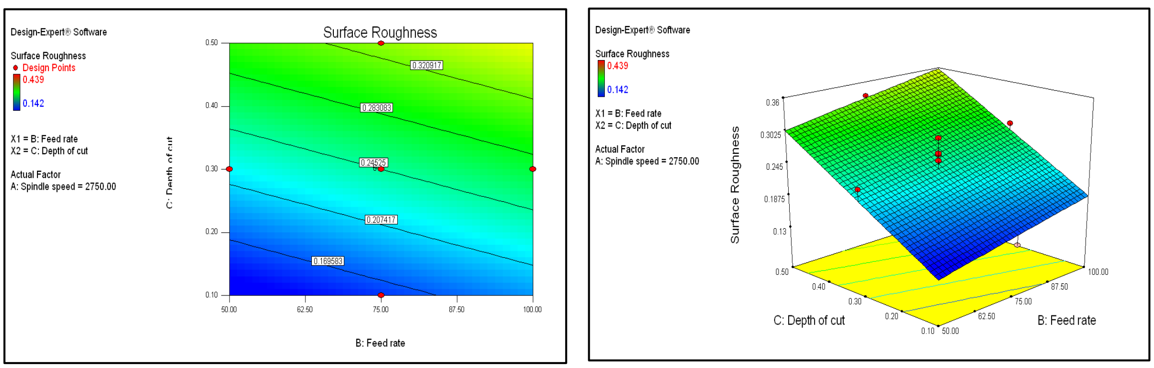
Surface Roughness =-0.099133+4.82667E-005* Cutting Speed +1.10400E-000* Feed rate +0.42950* Depth of cut … Eqn. (2)

Figure 3 shows response surface graph of (a) contours and (b) 3D Surface, as representation the effect of the surface roughness of interaction between spindle speed and feed rate. Then, Figure 4 shows response surface graph of (a) contours and (b) 3D Surface of interaction between feed rate and depth of cut. The maximum value was 0.439 Ra. It was found that the surface roughness of the material was maximum at maximum value of spindle speed, 3500 RPM, feed rate, 100 mm/min and maximum value of depth of cut, 0.50 mm. For the minimum value, the reading was 0.142 Ra. The surface roughness are minimum when the maximum spindle speed, 3500 RPM and feed rate,100 mm/min but with the minimum depth of cut, 0.10 mm used. Therefore, for the result of analysis, the surface roughness increased when the feed rate and depth of cut are increased.



(a) (b)

Figure 3: Response Surface Graph of (a) Contours and (b) 3D Surface for Effect Surface Roughness of Interaction between Spindle Speed and Feed Rate



(a) (b)

Figure 4: Response Surface Graph of (a) Contours and (b) 3D Surface for Effect Surface Roughness of Interaction between Feed Rate and Depth of Cut

3.2 Tool wear

The data of tool wear after observed under the Zeiss Stemi 2000-C Microscope Profile Optical Video Measuring System. For the details data of the tool wear for this experiment. Refer to Table 2 showed the design layout and experimental results for tool wear of end mill 2 flutes after each experiment. The unit of tool wear is mm. From the table, the lowest result of tool wear is 0.072 mm. The lowest result are from the machining parameter of (spindle speed: 2000 RPM, feed rate: 50 mm/min, depth of cut: 0.10 mm) shown in Figure 5. The highest result of tool wear is 0.413 mm. The highest result are from the machining parameter of (spindle speed: 3500 RPM, feed rate: 50 mm/min, depth of cut: 0.50 mm) shown in Figure 6.

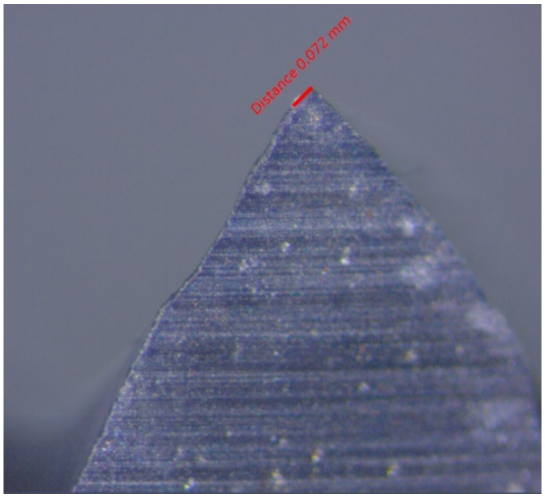


Figure 5

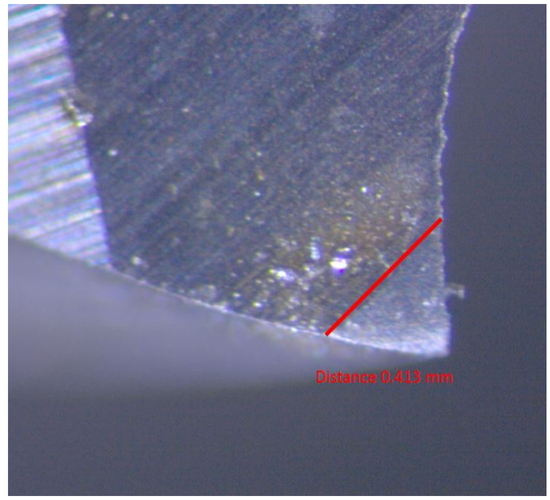


Figure 6

For the analysis, the ANOVA automatically generated from the Design Expert software. Table 5 listed the ANOVA results of the tool wear of end mill 2 flutes carbide cutting tool. The values of Prob>F of less than 0.0500 indicates that the selected models are significant. It can be seen that term A were significant. The F-value for the term A was significant factor of 0.0066. For terms, B, C, A2, B2 and C2 there were no significant factor. The lack of fit F-value of 4.15 implies the lack of fit is that not significantly relative to the lack of fit.

Table 5: ANOVA results of the tool wear of end mill 2 flutes

ANOVA for Response Surface Reduced Quadratic Model						
Analysis of variance table[Partial sum of squares - Type III]						
Source	Sum of squares	df	Mean square	F value	p-value Prob>F	
Model	0.14	6	0.023	4.25	0.0137	significant
A-spindle speed	0.056	1	0.056	10.42	0.0066	
B-feed rate	0.014	1	0.014	2.61	0.1300	
C-Doc	0.024	1	0.024	4.56	0.0524	
A^2	1.080E-003	1	1.080E-003	0.20	0.6607	
B^2	0.011	1	0.011	2.06	0.1749	
C^2	1.250E-003	1	1.250E-003	0.23	0.6370	
Residual	0.070	13	5.353E-003			
Lack of Fit	0.060	8	7.561E-003	4.15	0.0668	not significant
Pure Error	9.105E-003	5	1.821E-003			
Cor Total	0.21	19				

Table 4.6: shows the table for final equation of linear models of tool wear in terms of coded factors and actual factors is given below.

	Coefficient		Standard	95% CI	95% CI	
Factor	Estimate	df	Error	Low	High	VIF
Intercept	0.13	1	0.025	0.074	0.18	
A-Spindle speed	0.075	1	0.023	0.025	0.12	1.00
B-Feed rate	0.037	1	0.023	-0.013	0.087	1.00
C-Depth of cut	0.049	1	0.023	-5.853E-004	0.099	1.00
A^2	0.020	1	0.044	-0.076	0.12	1.82
B^2	0.063	1	0.044	-0.032	0.16	1.82
C^2	0.021	1	0.044	-0.074	0.12	1.82

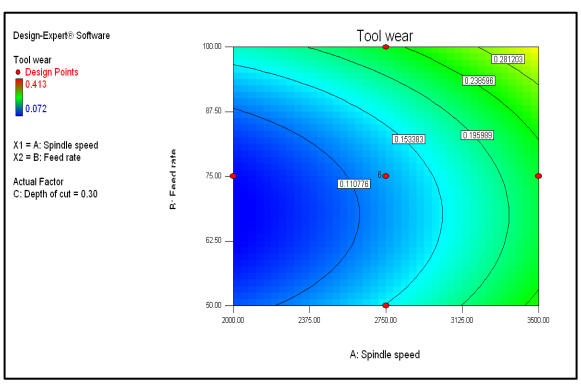
Final Equation in Terms of Coded Factors:

Tool wear =+0.13+0.075A+0.037B+0.049C+0.020A2+0.063B2+0.021C2 ... Eqn. (3)

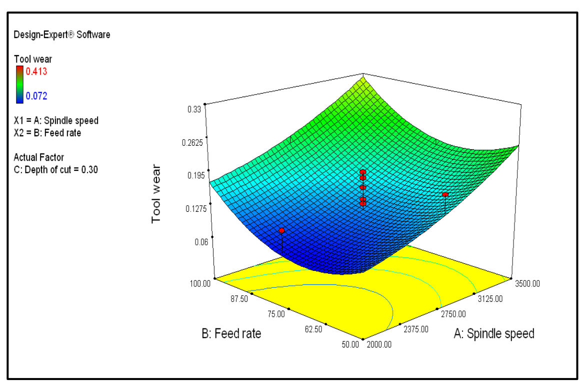
Final Equation in Terms of Actual Factors:

Tool wear =+0.55265 -9.41778E-005* Spindle speed -0.013700* Feed rate -0.072773* Depth of cut +3.52323E-008* Spindle speed2 +1.01309E-004* Feed rate2 +0.53295* Depth of cut2 ... Eqn. (4)

Figure 7 shows the graph (a) contour and (b) 3D graph representation the effect of the tool wear of interaction between Spindle speed and feed rate for the tool wear. Then, figure 8 shows the graph (a) contour and (b) 3D graph representation the effect of the tool wear of interaction between feed rate and depth of cut for the tool wear. The maximum value was 0.413 mm. It was found that the tool wear of the cutting tool was maximum value of spindle speed, 3500 RPM and depth of cut, 0.50 mm but with minimum value of fate rate, 50 mm/min. For the minimum value, the reading was 0.072 mm. The tool wear are minimum when the minimum value of spindle speed, 2000 RPM, feed rate, 50 mm/min, and depth of cut, 0.10 mm were used. The data shows the result of the experiment that the feed rate and depth of cut have more effect on tool wear than the spindle speed.

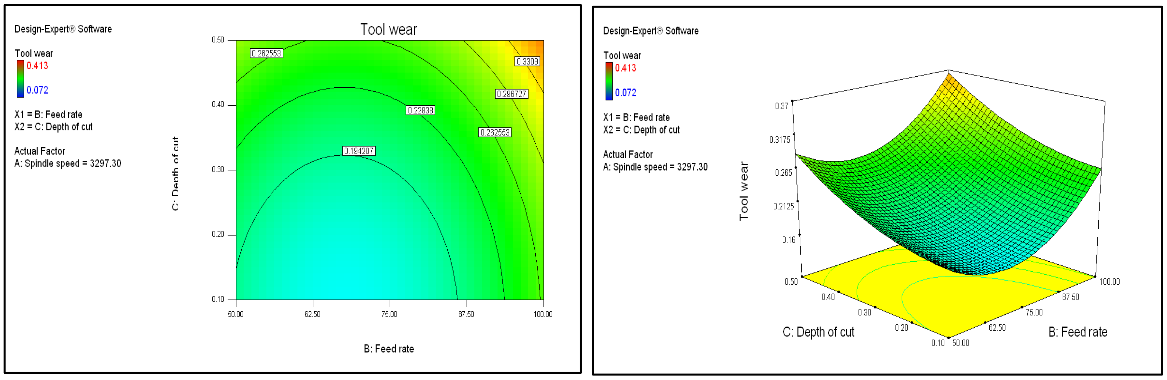


(a)



(b)

Figure 7: The Graph (a) Contour and (b) 3D Graph Representation the Effect of the Tool Wear of Interaction between Spindle Speed and Feed Rate87-Research Materials-215-1-4-20201116 (1)



(a) (b)

Figure 4.4: The Graph (a) Contour and (b) 3D Graph Representation the Effect of the Tool Wear of Interaction between Feed Rate and Depth of Cut

4.0 CONCLUSION

Conclusion, the result of the experiments has shown the importance of proper cutting parameters selection in machining of XW-41 (SKD11) tool. The parameters should be designed optimally in order to reach the prescribed quality of surface workpiece. In this contribution, the influence of selected cutting parameters on surface roughness and tool wear after CNC milling of workpiece has been analysed and examined. Before starting this project, reading needed to be done in order to understand the main point of the project. By making the literature review, it helps in order to further understand the parameter and building up the flow of project. For this project, the experiment made are based on the DOE that have been made regarding to the variable and parameter needed to be considered. By designing the experiment, major and minor error such as random error can be minimized and avoided. From the experiment results, the plotted graphing conclude that the good surface finish and tool wear are depends on the tool geometry of the cutting tool, and machining parameters (spindle speed, feed rate and depth of cut).

As a result of the experiment, the lowest value of surface roughness is 0.142. The lowest value were from the machining parameter of (spindle speed: 3500 RPM, feed rate: 100 mm/min, depth of cut: 0.10 mm). Then, the highest value is 0.439 Ra. The highest result were from the machining parameter of (spindle speed: 3500 RPM, feed rate: 100 mm/min, depth of cut: 0.50 mm). For tool wear, the lowest value is 0.072 mm. The lowest value are from the machining parameter of (spindle speed: 2000 RPM, feed rate: 50mm/min, depth of cut: 0.10 mm). The highest value is 0.413 mm. The highest value are from the machining parameter of (spindle speed: 3500 RPM, feed rate: 50 mm/min, depth of cut: 0.50 mm). Based on the result of analysis, the value of surface roughness increased when the feed rate and depth of cut are increased. Similarly, the value of tool wear are interaction between feed rate and depth of cut. For optimization, the Design Expert software have given suggestion of machining parameter for getting the best lowest value of surface roughness and tool wear for this experiment. The suggestion value were using the spindle speed, 2000 RPM, feed rate, 50 mm/min and depth of cut is 0.12 mm.

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