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Optimizing the Surface Roughness AISI 4340 Steel on Turning Process under Minimum Quantity Lubrication (MQL)

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Abstract. Application of cutting fluids in machining can improve machinability but it may danger to the environment. An alternative to reduce this bad effect is by using minimum quantity lubrication (MQL). This study aims to determine the most optimal parameters in the AISI 4340 steel turning machining process to produce the best surface roughness with MQL condition. The design method used is the Taguchi orthogonal array L9 (3^4). The combined parameters are depth of cut, cutting speed, method of giving cutting fluid and feed rate. Based on the mean response value, it can be concluded that to get the most optimal results of surface roughness, the parameters are depth of cut 1.8 mm, cutting speed 120.89 m/min, method of giving cutting fluid by MQL method and feed rate 0.122 mm/rev. While the percentage contribution of the feedrate has the largest percentage, namely 57,02% and cutting fluid method 41,33%.

Introduction

In the era of globalization, the manufacturing industry is required to be able compete in regional and international markets. The Factors that becomes focus of attention among other things, improving product quality, speed of processes, reduction of production costs, secure, and environmental friendly. The product quality for results is always associated with precision machining dimensional tolerance and the surface roughness value for the results the machining process. Therefore, surface roughness is one of the product standards [1].

The results of a good turning process have the characteristics of good shape, precise size and lower surface roughness [2] There are several factors that affect the surface roughness of the workpiece during the turning process. Apart from the factors influencing operator skill, depth of cut and cutting speed also affects the value of surface roughness [3]. According to [4] that quality in turning is determined by the cutting speed and feedrate, but also by the depth of cut. In fact, these three factors are very important in the turning process to obtain a suitable surface result and a small level of roughness.

According to [5], in the metal turning process, the workpiece will experience high heat level as a result of friction between the chisel and the workpiece being cut. If the temperature that occurs in the workpiece is not controlled, then the metal surface between the cutting tool and workpiece will tend to converge. Only one to obtain the desired surface roughness specification is to use cutting fluids during the machining process, so that it can make the temperature becomes lower than before. There are various types of cutting fluids, including dry method, flood method, automated MQL (minimum quantity lubrication) [6].

MQL is a lubrication technique to reduce friction between the tool and the workpiece, therefore it will reduce the rate of increase in tool temperature. First advantage method compared with the flood, MQL and dry cutting is economical [7][8] and environmentally friendly [7][9][10]. This research is a continuous attempt to develop an MQL system which can be both time- and temperature-controlled. The first attempt has successfully establish the control system [11] and it proofed to increase the quality of machined surface [12]. However, at this first achievement the spray was around 2000 ml/h, which not comply to MQL criteria that require maximum of 500 ml/h. The second effort has achieved the spray up to 900 ml/h [13] which according to another literature it has fulfill the MQL criteria [14]. The recent trial by the same research group has succeeded to achieve 500 ml/h. Therefore, this paper aim is to observe the impact of this new developed MQL system to the machined surface roughness in straight turning.

Method

The method used was to compare the effect of several variables, namely the depth of cut, cutting speed, feed rate and method of spraying the coolant for the value of surface roughness.

Tools and Materials. Figure 1 represents all the machine and equipment used in this research. The tools used in this research are GUT type C6236 x 1000 lathe (Fig. 1a), MQL cooling system controller based on Arduino UNO (Fig. 1b), surface roughness tester machine (Fig.1c), and a microscope (Fig.1d).

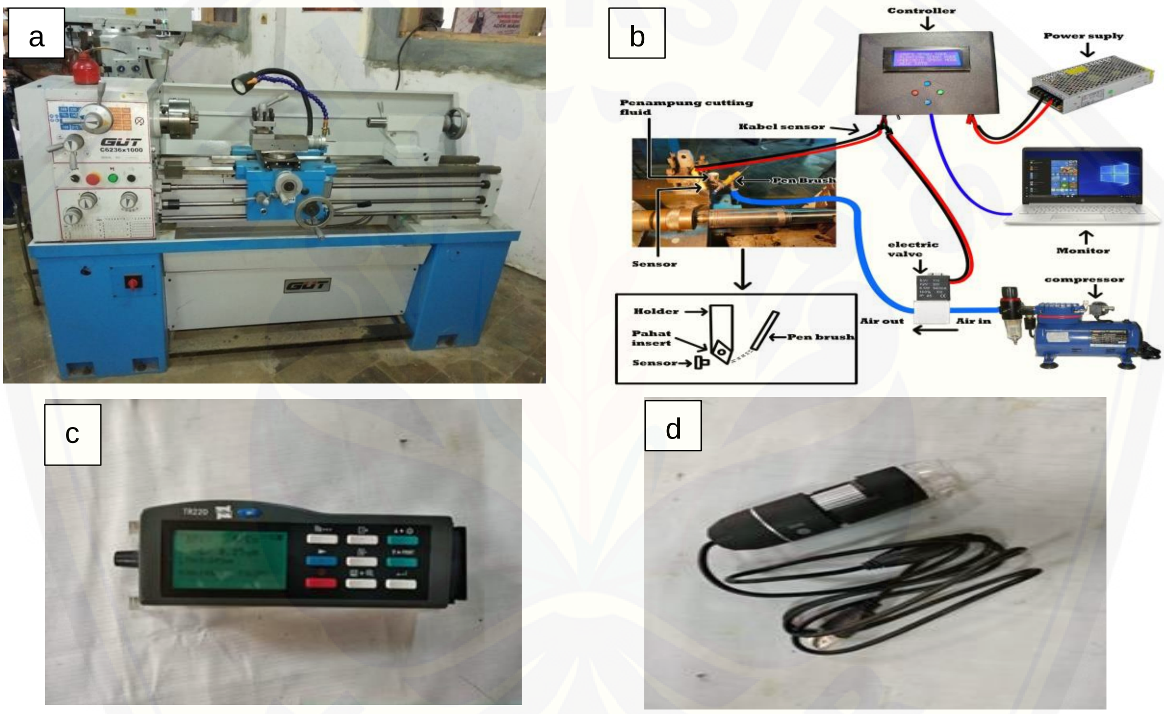

Fig. 1. Experimentations used: (a) Lathe machine tool (b) MQL controller (c) Surface roughness tester (d) Digital microscope

The materials used in this research are AISI 4340 steel in form of a bar with 20 mm in diameter and 250 mm long Fig. 2a. The tool used is a TiAlN coated carbide insert tool Fig. 2b.

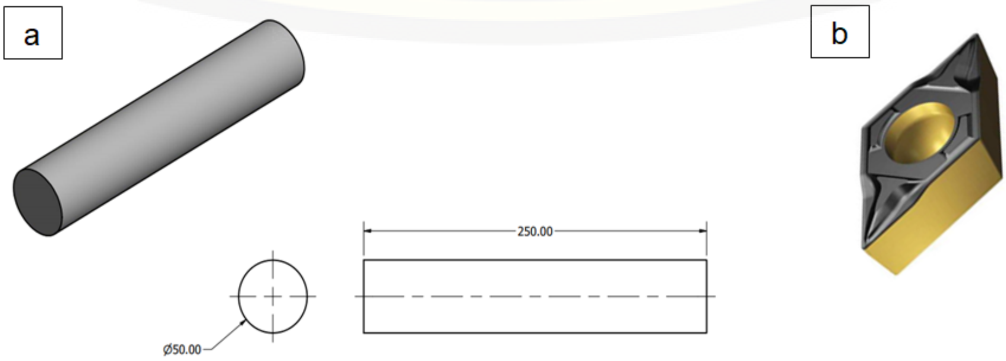

Fig. 2a. AISI 4340 of work piece dimension Fig. 2b carbide insert tool

Research Variables. Variables are factors that become the focus of research and determined by researchers with variations to support the research studied as to obtain the information needed and conclusions can be drawn. The independent variable is a variable whose value is independently determined by the researcher. The variables used in this research are depth of cut, cutting speed, variations of cutting fluid spraying method and feed rate. The independent variables and levels can be seen in following Table 1.

Table 1. Independent variables

Code	Factor control	Level		
		1	2	3
A	Depth of cut [mm]	1.8	2.0	2.2
B	Cutting speed [m/min]	120.89	141.3	200
C	Method	Periodic[1]	MQL[2]	*Flood*
D	Feed rate [mm/rev]	0.107	0.122	0.137

[1] Periodic: a shortened term of time-controlled MQL; in which the cutting fluid was sprayed periodically 4s off followed by 1s on.
[2] MQL: a shortened form of temperature-controlled MQL; in which cutting fluid was set to spray when the monitored tool achieved temperature of 150 ^{0}C and automatically shut off when its temperature down below this temperature

The dependent variable is the result variable that can be visually searched and calculated or its value. The dependent variable in this study is the surface roughness value. The controlled variables used in this study the composition of cutting fluid and water 1:9.

Research Design. This study uses orthogonal array (orthogonal matrix) L9(3^4) design with 4 control factors and 3 levels for each control factor. Three replications were used in each combination. The designed experiment was presented in Table 2 column 1- 6. The analysis used in this study using the Taguchi method. The Taguchi method is a new methodology in statistical engineering that aims to improve product quality and process execution at the same time keeping production costs and resources to a minimum. This method seeks to improve product quality without being sensitive to interference factors such as materials, manufacturing equipment, human labor and conditions [15].

Data Collection Method. The data that has been obtained using a surface roughness tester in form the value of arithmetic surface roughness value (Ra). Measurements were carried out at three different places: at the beginning, at the middle, and at the end of machined surface as shown in Fig 3. Observation was carried out to each replication workpiece. The result is presented in Table 2 column 7-9.

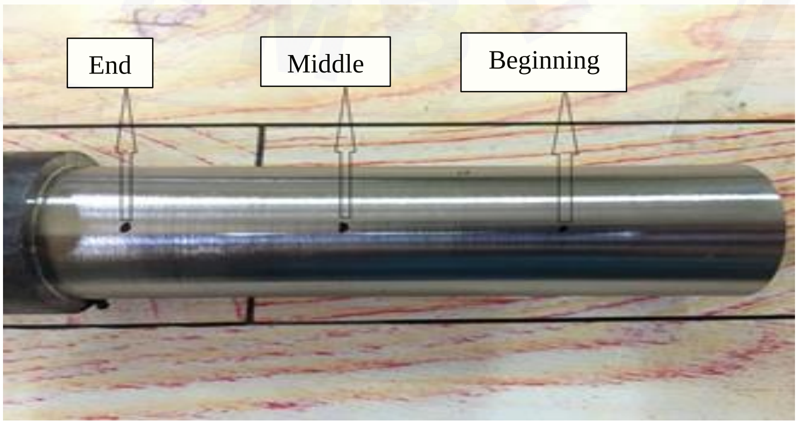

Fig. 3. How to measure the surface roughness

Furthermore, the data that has been entered into the table is displayed in the form of a graph to see the characterization of each factor. The roughness tester was placed horizontally in line with the measured bar, then measurement was carried out at near right end of the bar as the representation of beginning area of turned part. Then roughness tester shifted to the middle position and measured this area. It repeated for the end area.

Results

The surface roughness value that has been taken is then observed and the average surface roughness value is calculated. The surface roughness value data can be seen in Table 2.

Table 2. Design of experiments and the result

No.	Control Parameters				Replication	Surface Roughness Value of Each Replication			Means [µm]	Means of Replication [µm]	Ratio S/N
	Depth of cut [mm]	Cutting speed [m/min]	Method	Feed rate [mm/rev]		Beginning	Middle	End			
1	2	3	4	5	6	7	8	9	10	11	12
1	1.8	120.89	Periodic	0.107	1	5.218	9.192	7.073	7.161	6.668	-16.502
					2	5.236	1.15	4.017	6.800		
					3	5.244	8.864	4.025	6.044		
2	1.8	141.3	MQL	0.122	1	3.114	3.214	3.301	3.209	***3.16***	-9.996
					2	2.954	3.157	3.132	3.081		
					3	3.231	3.327	3.015	3.191		
3	1.8	200	Flood	0.137	1	7.009	7.413	7.434	7.383	7.306	-17.275
					2	7.304	7.429	7.369	7.367		
					3	7.129	7.009	4.897	7.168		
4	2.0	120.89	MQL	0.137	1	6.392	6.592	6.286	6.423	6.418	-16.149
					2	6.33	6.809	6.356	6.498		
					3	6.178	6.552	6.274	6.334		
5	2.0	141.3	Flood	0.107	1	4.95	4.887	4.897	4.911	4.921	-13.841
					2	4.86	4.925	4.95	4.911		
					3	4.925	4.934	4.961	4.940		
6	2.0	200	Periodic	0.122	1	5.521	6.742	7.203	6.488	6.361	-16.072
					2	5.435	6.31	7.117	6.287		
					3	5.55	5.55	7.065	6.308		
7	2.2	120.89	Flood	0.122	1	3.897	3.767	3.791	3.818	3.793	-11.581
					2	3.727	3.722	4.059	3.835		
					3	3.703	3.736	3.738	3.725		
8	2.2	141.3	Periodic	0.137	1	9.601	9.125	8.906	9.210	***9.344***	-19.412
					2	9.599	10.04	8.987	9.542		
					3	8.892	9.962	899	9.281		
9	2.2	200	MQL	0.107	1	4.614	4.269	4.09	4.324	4.715	-13.518
					2	4.369	4.351	4.492	4.403		
					3	4.59	7.321	4.344	5.418		

Table 2 above shows that experiment number 2 produces a low average surface roughness value. While, experiment number 8 resulted in the highest average surface roughness. It is obvious from photos using an optic microscope that experiment no 8 showing rougher surface than that of experiments no 2 (Comparison between Fig. 4a and 4b). In Fig. 4b thy are clear between the peaks and the valleys, while Fig. 4a they are rather blur due to less contras.

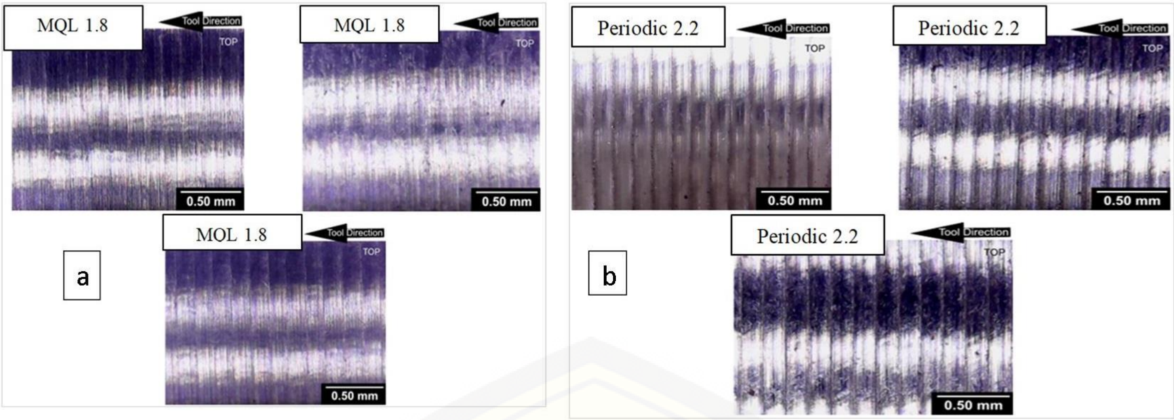

Fig 4. Photo of surface roughness using an optic microscope: 4a of experiment no. 2, 4b of experiment no. 8

The Taguchi method uses a signal to noise ratio calculation to check for interference with variations that occur. In this study, the lower the surface roughness value, the better is the quality of surface roughness. Therefore, what is used to optimize the data is the smaller is better type. The value of the S/N ratio can be seen in Table 2 and the matemathic method to calculate S/N rasio can be seen in below.

S/N Ratio

Eq.1 $$\eta = -10 \log\left(\frac{1}{3}\sum_{i=1}^{r}\left((7.161^{2}) + (6.800^{2}) + (6.044^{2})\right)\right)$$

$$\eta = -16.5020$$

Means

Eq.2 $$\bar{y} = \frac{\Sigma y}{n}$$

$$\bar{y} = \frac{(6.668)+(3.160)+(7.306)+(6.418)+\cdots+(4.715)}{9} = 5.853$$

The calculating of means for each controlled factor can be seen in the following Table 3.

Table 3. Response of means for each controlled factors

Symbol	Control Factors	Means [μm]		
		Level 1	Level 2	Level 3
1	Depth of Cut	***5.711***	5.9	5.950
2	Cutting Speed	*5.626*	5.808	6.127
3	Method	7.457	***4.764***	5.340
4	Feed rate	5.434	***4.438***	7.689
	Total means		5.853	

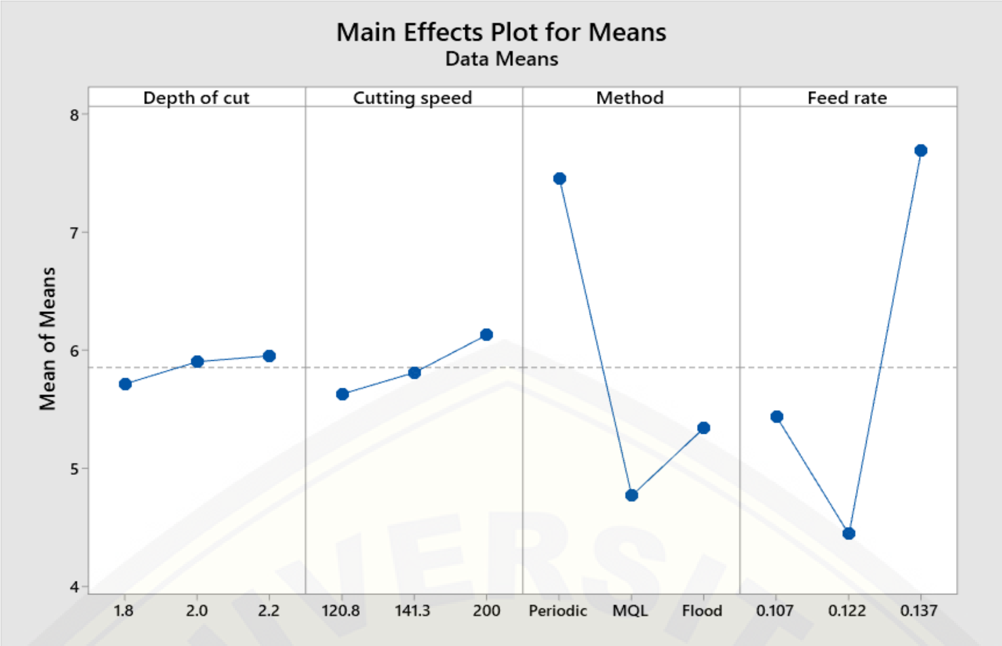

Fig. 5. The plot value of means

Fig. 5 shown the plot means from the parameters. From Fig. 5 it can be concluded that the combination of optimum response parameters in this study is presented in the following Table 4.

Table 4. The optimum parameters

Parameters	Level	Value
Depth of cut	1	1.8 [mm]
Cutting speed	1	120.0 [m/min]
Method	2	MQL
Feed rate	2	0.122 [mm/rev]

Analysis of Variance (ANOVA). ANOVA is an analytical technique used to estimate the value of the quantitative effect of each factor on all measurements of the response. Table 5 below is the result of the ANOVA calculation of the control factor on the response of the surface roughness value.

Table 5. Value of ANOVA

Source	DF	SS	MS	F Value
Depth of cut	2	0.0953	0.0476	*
Cutting speed	2	0.385	0.192	*
Method	2	12.069	6.03	*
Feed rate	2	16.647	8.32	*
Total	8	29.202	14.583	

Percentage Contribution. The percentage contribution indicates that the influence of the control parameters on the response under study. Table 6 below is the result of percent contribution.

Table 6. Percentage of contribution

Symbol	**Control Factor**	**SS'**	**P**
A	Depth of cut	0.0953	0.33%
B	Cutting speed	0.3858	1.32%
C	Method	12.0709	41,33%
D	Feed rate	16.6509	57.02%
R	Residual	0	0
	Total	29.2029	100 %

Confirmation Experiments. After knowing the optimal results for each parameter in Table 6, the last step is to carry out a confirmation experiment using the most optimum parameters. Confirmation experiments were replicated 3 times to ensure the optimum results. Table 7 presents the data from the confirmation experiment, while the intepretation of surface roughness value can be seen in Table 8

Table 7. The result of confirmation experiment

Replication	Depth of cut [mm]	Cutting speed [m/min]	Method	Feed rate [mm/rev]	Means of Replication [µm]	*Means* [µm]
1	1.8	120.89	MQL	0.122	5.152	5.469
2					5.392	
3					5.864	

Table 8. Intepretation of surface roughness value

Respon of Surface Roughness	*Means*
Taguchi Experiment	5.853 µm
Confirmation Experiment	5.469 µm

Based on the interpretation Table 8 above, the value of the confirmation experiment is greater than the value of the Taguchi experiment. Thus, it can be concluded that the combination of these parameters is proven to produce a lower chance of forming surface roughness due to the reduced value of surface roughness.

Discussion

In this study, the cooling with the MQL method produce low surface roughness values due to the periodic spraying. The system using compressed air in order the attached chips to the workpiece are carried away by the cutting fluid periodically. This process results in a lower surface roughness value compared to other cutting fluid spraying parameters.

Depth of cut. Depth of cut with a value of 1.8 mm is the most optimal parameter that produces the lowest surface roughness value with a surface roughness value of 5.711 µm. When using a low depth of cut it causes a smooth machining result. This is in accordance with the result of [12] and [16], that the greater the depth of cut, the higher the surface roughness value.

Cutting fluid applying method. The automated MQL method produces a surface roughness value of 3.160 µm. It may because the automated MQL spraying method has been given a special touch where the addition of compressed air makes the chips attached to the workpiece wasted along with the cutting fluids. The percentage contribution value of 41.33% is obtained by the automated MQL spraying method. According to [12] and [17], the use of the cutting fluid spraying method with MQL is very influential on the decrease in temperature during machining, resulting in a low surface roughness value.

Cutting speed. In this study, the cutting speed of 120.89 m/min resulted in a roughness value of 5.626 µm and the percentage contribution value was 1.32%, that may be abandoned. According to [18] in their research, the higher the cutting speed, the smoother the workpiece surface tends to be. In data retrieval with high cutting speed, the lathe vibrates strongly, causing the gripped rod to shift frequently and cause the cutting to be not optimal.

Feed rate. Feedrate 0.122 mm/put produces a surface roughness value of 4.438 µm and gets a large percentage contribution value in this study of 57.02%. According to [1] the higher the feed rate, the better the roughness value. However, the higher the feedrate may creates more damage to the tool [19].

Conclusions

The most optimum parameter is the variation of depth of cut 1.8 mm; cutting speed 120.89 m/minute; MQL automation method and feed rate 0.122 mm/put. The biggest influence of the parameter is feedrate with the percentage contribution of 57.02% and the smallest influence of the parameter is the depth of cut with the percentage contribution of 1.32%. The MQL automation tool with the addition of a compressor greatly affects the results of the surface roughness value because it causes a more even spray and a decrease in temperature in the machining process. In this study, the parameters of high depth of cut, cutting speed, and feedrate resulted in high surface roughness values.

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