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Factors Affecting Optimal Surface Roughness of AISI 4140 Steel in Turning Operation Using Taguchi Experiment

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Abstract. This paper presents the result of using Taguchi method in turning process of medium carbon steel of AISI 4140. The primary concern is to find the optimal surface roughness after turning process. The taguchi method is used to get a combination of factors and factor levels in order to get the optimum surface roughness level. Four important factors with three levels were used in experiment based on Taguchi method. A number of 27 experiments were carried out during the research and analysed using analysis of variance (ANOVA) method. The result of surface finish was determined in Ra type surface roughness. The depth of cut was found to be the most important factors for reducing the surface roughness of AISI 4140 steel. On the contrary, the other important factors i.e. spindle speed and rake side angle of the tool were proven to be less factors that affecting the surface finish. It is interesting to see the effect of coolant composition that gained the second important factors to reduce the roughness. It may need further research to explain this result.

1. Introduction

Various machine tools i.e. lathes, millings, grindings, and drilling are used in conventional machining. Hence, the turning operation by using a lathe machine is one process that includes in traditional or conventional machining [1]. It removes material form a work piece by cutting and produce finished part and chips as the waste.

The friction during the turning process is created amount of heat that can shorten to the tool life [1-3]. The wear of tool raise the vibrations that increase the surface roughness of the finished product. The coolant or lubrication lately reported to be used in conventional machining to increase the tool life [1, 4]. Mineral based oil can be used as coolant or lubrication during turning process. However, this type of coolant may increase the pollution to the environment [1, 4, 5]. Recently, the development of the water-based lubricant becomes favourable to the researcher worldwide. Aqueous copolymer solutions can be used as lubricants that not harm the environmental [6-8].

The AISI 4140 steel is subject commonly in turning process [4, 9]. Aslan et al. and Asiltürk and Akkußs conducted study using AISI 4140 steel in turning operation in dry condition. Taguchi method was chosen to do various experiments with the surface roughness as their final parameter of the turning performance. Both of authors firstly increased the hardness of the AISI to approximately above 55 HRC. The counterpart hardness during turning was approximately above 63 HRC [10, 11]

Determine the untreated AISI 4140 steel quality after turning process is found less attracted to the researcher. However, the composition of AISI 4140 that contains Cr and Mo permitted this steel to have good toughness and ability to create surface harder [9, 12, 13]. Hence, it is interesting to see the lowest possible roughness by combining kinds of cutting parameter and comparing between dry and wet turning condition.

2. Taguchi Method

The Taguchi method for engineering has the goal for improving the quality of the product and the process, simultaneously [11, 14-16]. It also can be used for optimizing cost and resources. It makes the product and the process have robust properties against the noise factor. The noise factor identified as the cause of a large number of output variation of a process. Therefore, this method is also referred to as robust design.

In a process using turning machine, surface roughness and tolerance, are playing important role to determine the quality of the part [14-16]. The smaller number of roughness as initial roughness also confirmed as one factor to reduce wear when the two parts is used as tribo-pairs. Therefore, smaller is the better is used in this study. The further research in lubricated surface of copolymer on bare surface of metal also mention that the surface finish created different thickness and behavior of the layer [6-9].

3. Methods

3.1. Experiments

This study used work piece made from AISI 4140 steel. The condition of the material was proceed without any further processes e.g. heat treatment. It has carbon content of 0.380% - 0.430%, the hardness of the material is 197 BHN and has tensile strength approximately of 655 Mpa [17]. It is a solid cylinder work piece with the dimensions of each work piece was 30.0 mm long and 32.5 mm in diameter.

Table 1 shows the important factor levels that consists of three level of depth of cut, three levels of spindle speed, three levels of coolant and three levels of side rake angle. Common coolant namely Shell Dromus B is used in this research. The combination of the coolant that mixed with demineralized water shown in Table 1 was get from Shell recommendation. The $L_9(3)^4$ was assigned as orthogonal array for Taguchi experiment.

Due to the experiments were carried out in lubricated condition, the work piece was cleaned prior the roughness test. The metal was rinsed using demineralized water followed by cleaning using mild soap to remove the oil dirt. The work piece was dried in room temperature condition. Prior the test, it swabbed with acetone in order to make sure the surface free form any dust.

Table 1. Important factor levels.

Items	Factor Levels		
	1	2	3
Depth of cut [A]	0.125 mm	0.25 mm	0.375 mm
Spindle speed [B]	420 rpm	620 rpm	1000 rpm
Coolant combi. [C]	20:1	30:1	40:1
Side rake angle [D]	5°	10°	15°

3.2. Turning

This research conducted at Industrial Engineering System Manufacturing Laboratory of Faculty of Engineering, Universitas Brawijaya. The experiment used equipment, a manual lathe, Krisbow KW15-604 type. The maximum swing over bed of the lathe is 210 mm and the maximum swing over gap is 320 mm. It can be used to create metric thread approximately of 0.4 until 3 mm. The spindle bore is 20 mm with the range of its speed approximately of 125 to 2000 rpm, longitudinal feed per spindle revolution is 0.1 to 0.2 mm, tool post cutting area is 14 mm square, a motor of 550 W and 220 V-380 V used as a prime mover to the lathe.

A 7.5 mm turning process is performed to each of work piece with the size of the end product was 30 mm long and 25 mm in diameter. The tool was made from High Speed Steel with three different side rake angle (see Table 1); 5°, 10° and 15°.

3.3. Surface roughness

Surface roughness is a surface that has irregular shortwave patterns occurring due to the vibration of the cutting tool or the improper proportion of the cutter feed in the process [10, 11, 14-16]. Surface roughness measurement is aided by a device called surface roughness tester. The data is obtained from a diamond-shaped stylus motion signal to move along a straight line on the surface. The working principle of this tool is to use a transducer and processed with a microprocessor. The value is expressed in micrometer (μm).

In addition, data collection for roughness conducted at the Industrial Metrology Laboratory of Mechanical Engineering of Engineering Faculty of Universitas Brawijaya. It using SFT-210 Series portable surface roughness tester Mitutoyo brand with the following specifications: measuring range (17.5 mm in X axis and 360 μm in Y axis). The measuring speed is varied from 0.25 mm/s, 0.5 mm/s and 0.75mm/s. The stylus tip force is 0.75 mN/2 μm with radius of 60°. It can be used with the skid force less than 400 mN. The manufacturer's mention that it applicable to the various standards e.a. JIS '82, JIS '94, JIS '01, ISO ' 97, ANSI and VDA. The sampling length is 0.08, 0.25, 0.8, and 2.5mm.

Three types of surface finish were used in this research. The first one is arithmetic average deviation surface roughness. It is an arithmetic average of the absolute value between the measured profile value and the middle profile. The value of the average arithmetic roughness (Ra) has a tolerance price. Each roughness price has a roughness class from N1 to N12.

4. Results and Discussion

There were 27 specimens produced that refers to the number of experiments and replication given by orthogonal array matrices. The surface roughness, Ra, results from experiment is presented in Table 2. The equation to measure the Ra is shown in equation below [16, 18]:

$$R_a = \frac{1}{L}\int_0^L |y(x)|\, dx \qquad (1)$$

Arithmetic average deviation surface roughness is denoted with Ra, L is the sampling length and y is the coordinate of the profile. The Microsoft Excel was used to analysis the data to get Analysis of Variance (ANOVA) table as shown in Table 3.

The Sum of Square denoted as SS in Table 3, while the Degree of Freedom is DF and MS is for mean square. Experiments can be assumed to be good when the percentage of contribution value (Rho %) generated is lesser than 50%. It means that there was no significant factor missing from the experiment. On the other hand, if the value is more than 50% means that it can be assumed if there were several factors that have a significant effect on the experiment being lost [19]. In Table 3 it can be seen that the error value generated of 37,45%, which means there is no significant factor missing from the experiment.

After processing data with ANOVA from the data, which applies either to mean value or value of Signal to Noise Ratio, got a result that there are two factors from four factors that have an influence and big contribution to the level of surface roughness. Meanwhile the other two factors have an impact but in small quantities.

Table 2. Results of the Taguchi experimental surface roughness measurements.

Depth of Cut (A)	Spindle Speed (B)	Coolant Composition (C)	Side Rake Angle (D)	R1	R2	R3
0,125 mm	420 rpm	1:20	5º	2,879	2,139	2,627
0,125 mm	620 rpm	1:30	10º	2,815	2,894	2,797
0,125 mm	1000 rpm	1:40	15º	1,785	1,913	2,214
0,25 mm	420 rpm	1:30	15º	2,301	1,835	2,339
0,25 mm	620 rpm	1:40	5º	1,801	1,792	1,758
0,25 mm	1000 rpm	1:20	10º	1,089	1,118	0,86
0,375 mm	420 rpm	1:40	10º	2,288	1,215	2,706
0,375 mm	620 rpm	1:20	15º	1,202	1,646	1,977
0,375 mm	1000 rpm	1:30	5º	2	2,874	2,366

Table 3. Analysis Of Variance (ANOVA) from experiments.

Source	*SS*	DF	MS	*F-Ratio*	*SS'*	*Ratio%*	F tabel 0.05 (2;18)
A	2,86	2	1,43	10,48	2,59	27,32	3,55
B	0,95	2	0,48	3,49	0,68	7,16	3,55
C	2,63	2	1,31	9,64	2,36	24,89	3,55
D	0,57	2	0,29	2,10	0,30	3,18	3,55
Error	2,45	18	0,14	1	3,55	37,45	
SST	9,47	26	4,53		9,47	100	
Mean	112,98	1					
SStotal	122,44	27					

There is only one factor that has value F-Ratio ≥ F-Table (F 0.05 (2:18) = 3.55) (see Table 3). So it can be concluded that depth of cut factor is statistically has an effect on the level of surface roughness of the shaft. The SNR value calculation is done on each experiment with three replication, so that nine SNR data is then processed in ANOVA calculation of Signal to Noise Ratio value.

The depth of cut in this research was proven to be the most factors to reduce the Ra. Similar conclusion was reported from Thamizhmanii et al. [16] that conducted similar experiment. However, they reported that the experiment was carried out using dry condition and the metal was much harder than this research reported. Almost ten times higher of depth of cut value was used for Thamizhmanii et al. [16] compared to this setup. Higher depth of cut may increase heat and wear but proven to be useful to produce better quality of finished part. The chosen parameters and the ability of the lathe used in this research may affect to the results. Other conditions i.e. the hardness of material and the coolant needs to investigate further.

Figure 1 shows one of evaluation profile of Ra, the sixth trial and the third replication with value Ra 0,86 µm. It shows the result of surface roughness testing with the lowest value from the 27 experiments for Ra. It was one and only result below 1. On the contrary, Figure 2 shows a clearly different profile from the first trial and the first replication. It comes from the result of test with the highest roughness value with value Ra 2,879 µm.

A significant variation is detected from the results shown in Figure 1 and Figure 2. It may come from the depth of cut that proves as the most affected factors to surface roughness. However, Asiltürk and Akkußs [11] that was doing similar experiment and similar method with this study have different opinion. The feed rate was mentioned as the most factor affected to the best of roughness when the AISI 4140 is processed with turning machine.

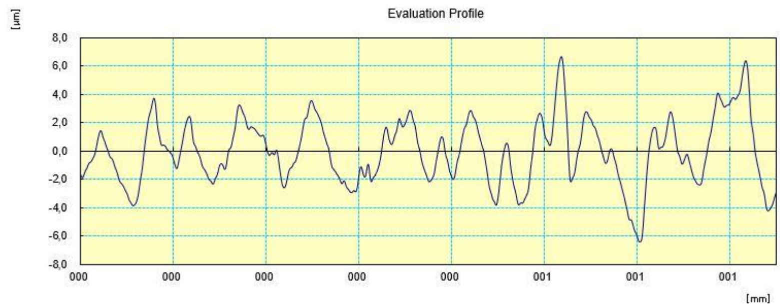

Figure 1. Evaluation profile of Ra 0,86 µm.

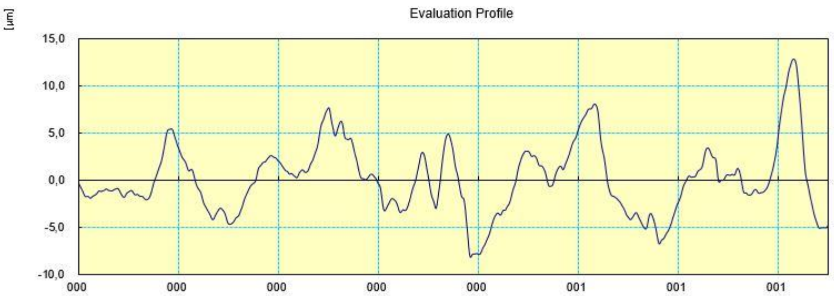

Figure 2. Evaluation profile of Ra 2,879 µm.

It is interesting to see the data of Ra from other researchers. Much lower Ra value was gained during their experiment in dry condition [11, 14-16]. The result shows in their experiment was carried out in the different parameters especially it done without cooling or dry condition. The cooling may not the most affected factor in this paper, however, it is interesting to do future experiment to see the effect of cooling process and the type of coolant to get the smallest value of surface roughness.

5. Conclusions

Based on the results of research conducted, the most factors that have an effect on the roughness during wet condition turning process on AISI 4140 untreated steel is depth of cut factor with a contribution value of 27.32%. Coolant composition factor with a contribution value of 24.89%, spindle speed factor with value contribution of 7.16%, and the last factor depth of cut with contribution of 3.18%.

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