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Exploratory Investigation on the Influence of Machining Parameters on Surface Roughness and Tool Wear in the Turning Process of Steel ST-42

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A B S T R A C T

This study aims to investigate the influence of the conventional lathe machine's cutting parameters in the turning process of ST-42 steel material on surface roughness and tool wear by employing an HSS tool. The examined cutting parameters encompass the spindle speed and the depth of cut, while maintaining a consistent feed rate. Each cutting parameter was evaluated at three different levels, spindle speed of 330 rpm, 360 rpm, and 500 rpm, and depth of cut 0.2 mm, 0.5 mm, and 1 mm, all with a uniform feed rate of 0.3 mm/minute. The findings of this research demonstrate that alterations in spindle speed and depth of cut exert a discernible influence on both surface roughness and tool wear. Elevated spindle speeds are associated with reduced surface roughness, albeit at the expense of increased tool wear. Conversely, deeper depth of cut correspond to heightened surface roughness, yet lead to decreased tool wear, aiming to achieve a uniform final diameter of the workpiece. By synergistic manipulation of these two parameters, the most favorable outcome in terms of surface roughness and tool wear can be identified. The lowest surface roughness was 4.42 µm, found at a spindle speed of 500 rpm coupled with the depth of cut of 0.2 mm. Meanwhile, the least amount of tool wear, quantified at 0.07 mm, was achieved at a spindle rotation speed of 330 rpm along with a cutting depth of 1 mm. The application of ANOVA analysis substantiates the statistical significance of both parameters, affirming their pivotal role in influencing surface roughness and tool wear.

Keywords: turning parameters, steel ST-42, surface roughness, tool wear, built-of-edge

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1. Introduction

Turning process is a primary process in the manufacturing industry using lathe machines for producing machine components and products. Lathes are versatile machines that can be used to create a variety of shapes and features on workpieces. They can be used to turn, drill, and create screw threads on both the inside and outside of workpieces. Lathes can also be used to work on workpieces with non-circular cross-sections [1]. Most of lathes used to create a variety of cylindrical shapes, some common examples include axles, rods, cones, cylinders, and spheres [2].

Turning is also one of the essential skills that students of vocational high schools (SMK) must have. Every student is required to be able to operate a lathe machine, which is done through turning machining practice. The most common problem is that the workpiece produced is only for practice and is less useful because the practice planning is not market-oriented, that is to make products that can be sold. To be able to make a marketable product, quality is a primary requirement. One of the quality aspects of turning machined products is surface roughness. In addition, tool wear is also another problem faced in turning process. Improper parameter configuration leads into wasteful materials and tools.

These problems can be overcome by determining the right machining parameters. Therefore, this study conducted an experiment to obtain the best combination of parameters that can minimize surface roughness and minimize tool wear. Cutting parameters on a lathe machine include cutting speed (Cs), which can be adjusted through spindle speed (N), depth of cut (DoC), and feedrate (f). The cutting speed is the speed at which the workpiece rotates, the depth of cut is the amount of material that is removed with each pass, and the feed rate is the speed at which the tool moves across the workpiece [3]. In the turning process, these parameters are interdependent in producing the turning process speed that affects surface roughness and tool wear. In addition, if using coolant, the appropriate type of coolant can be selected.

This study was conducted on a conventional machine that is used as a learning medium at a vocational high school (SMK). The purpose of this study was to determine the best parameter setting in the turning process of steel ST-42, which will later be used as a reference in the practice that will be carried out by students. The parameters that were varied were spindle speed and depth of cut, while the feed rate was kept constant. The quality variables of the turning results that were tested were surface roughness and tool wear.

Surface roughness is a measure that describes the non-smoothness or unevenness of the surface of the cutting. Poor surface roughness can affect

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product quality, dimensional accuracy, and the ability to repair the surface (such as finishing). The surface roughness of a lathed workpiece is influenced by a number of factors, including machining parameters (cutting speed, depth of cut, and feed rate), tool macro and micro-geometry (the nose radius, rake angle, and side cutting edge angle (SCEA)), mechanical properties of the workpiece material (hardness, strength, and ductility), auxiliary tools, lubricants, and vibration [4]. Vibrations can cause the cutting edge to skip across the workpiece, which can lead to a rough surface.Small changes in any of the above factors can have a significant effect on the surface that is produced.

Tool wear is the wear of the tool tip due to friction with the workpiece. In general, tool failure can lead to wear, plastic deformation, or fracture [5]. The occurrence of wear depends on the material or workpiece being used in the cutting conditions, especially on the cutting speed. Tool wear can be grouped into several types, including adhesive wear, abrasive wear, diffusion wear, and fracture wear. The forms of wear that occur on the tool are generally identified as nose wear, flank wear, notch wear, and crater wear. Nose wear occurs due to the abrasion mechanism at the tip of the tool, which results in a decrease in the rake angle [6]. Factors such as improper cutting speed, incorrect cutting feed, or dull tools can cause tool wear. Minimizing tool wear is one of the targets that want to be achieved in the turning process, because minimal tool wear is one of the indicators of turning quality [7].

This study aims to determine the influence of turning process parameters, which include spindle speed and depth of cut, on the level of surface roughness and tool wear in the turning process using a conventional machine, on the turning process of ST-42 steel using HSS tools. The benefits that can be taken from this study are to provide information to students or lathe machine operators in determining turning parameters, namely spindle speed and depth of cut, so that smooth workpiece results are obtained and tools can be used for a longer period of time.

2. Methods

This study is an experimental research conducted in the laboratory. In this research, steel ST-42 is used as test specimen which is a commonly used material in the automotive industry (Figure 1). In total 27 steel ST-42 cylinders were prepared. The steel had a diameter of 1 inch (25.40 mm) and a length of 100 mm.

Figure 1. The specimen Steel ST-42

The material undergoes turning process with variations in spindle speed and depth of cut. Each of the parameters is having 3 levels of variation. Subsequently, surface roughness test and tool wear analysis were performed to evaluate the quality of the specimens. To proceed the surface roughness test and tool wear analysis, the specimens are formed and dimensioned as shown in Figure 2.

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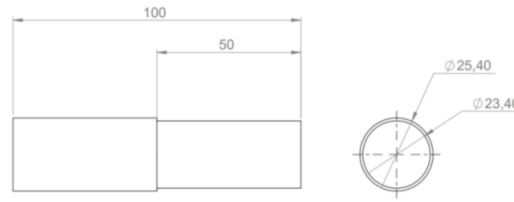

Figure 2. Design of the specimen (in mm)

The turning process is conducted on the Bech Lathe Westco CQ6230 A. This lathe is a manual lathe that can be used for a variety of turning operations, including turning, drilling, threading, and forming workpieces with non-circular cross sections. This machine has spindle diameter of 38 mm, which allows it to be used to work on workpieces with large diameters. Spindle rotational speed of up to 1500 rpm, which allows it to be used for various types of materials. The tool used in this study is a High-Speed Steel (HSS) tool with a 90° cutting edge angle.

The parameters on a lathe are set based on the type of tool and its standard table, as well as the specifications of the machine in use. Setting parameters include spindle rotation speed and depth of cut, while feed rate of 0.3 mm/minute is remain fixed. Table 1 shows the factors and levels of each turning parameters. On the other hand, the variables investigated were surface roughness and tool wear.

Table 1. Turning parameters and levels

Parameter	Symbol	Level 1	Level 2	Level 3
Spindle speed (rpm)	N	330	360	500
Depth of Cut (mm)	DoC	0.2	0.5	1

To ensure unbiased results, 27 specimens were marked with symbols which represent the parameter combination as listed in Table 1 into nine experiment number. Then, the workpiece materials were randomly machined based on the order recommended by Minitab 19 software.

3. Results and Discussions

After specimens underwent a rigorous turning process based on the randomized run order, all specimens were conducted surface roughness test using surface roughness tester (Figure 3). Subsequently, all tools were inspected using stereo microscope (Figure 4) for any signs of wear and tear.

Figure 3. Surface roughness tester

Figure 4. Stereo microscope

3.1. Data Acquisition

Table 2 shows the results of surface roughness test and tool wear for each parameter combination. The values represent the average value of the three replication for each combination of parameter experiment number.

Table 2. The experimental design and results

Exp. Number	Run Order	N (rpm)	DoC (mm)	Ra (µm)	Vb (mm)
1	8	330	0.2	5,36	0,14
2	2	330	0.5	5,67	0,10
3	3	330	1	5,69	0,07
4	7	360	0.2	5,05	0,19
5	5	360	0.5	5,32	0,13
6	4	360	1	5,36	0,10
7	6	500	0.2	4,42	0,21
8	1	500	0.5	4,44	0,17
9	9	500	1	4,67	0,13

On Table 2, it can be seen that the lowest surface roughness is 4.42 µm , while the highest one is 5.69 µm. Meanwhile, the lowest value for tool wear is 0.07 mm, and the highest one is 0.21 mm..

3.2. Surface Roughness Analysis

Figure 5 shows the surface roughness level corresponding to various depths of cut. The graph in this figure illustrates the correlation between the depth of cut (DoC) and surface roughness (Ra) at different spindle speeds (N) of 330 rpm, 360 rpm, and 500 rpm. Specifically, at a spindle speed of 330 rpm, the surface roughness value rises with an increase in the depth of cut. This trend is similarly observed for spindle speeds of 360 rpm and 500 rpm. Consequently, it can be concluded that at the same spindle rotation speed, an increase in the depth of cut results in a higher surface roughness (Ra). Conversely, at the same depth of cut, higher spindle rotation speeds lead to lower surface roughness.

Figure 5 displays surface roughness as a function of depth of cut. From Figure 5, it is evident that the lowest surface roughness value is obtained at a spindle speed of 500 rpm and a depth of cut of 0.2 mm, resulting in a surface roughness of 4.42 µm. In contrast, the highest surface roughness value is attained at a spindle rotation speed of 330 rpm and a depth of cut of 1.00 mm.

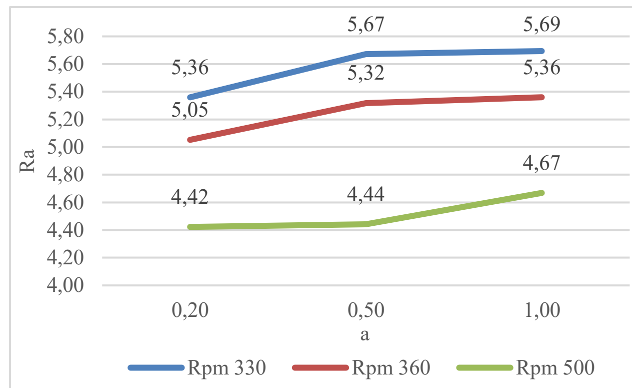

Figure 5. Surface roughness as a function of depth of cut

Figure 6 shows the relationship between spindle rotation speed and surface roughness at depths of cut of 0.20 mm, 0.50 mm, and 1 mm. The graph reveals a significant impact of changes in spindle rotation speed on surface roughness values. Increasing the spindle rotation speed results in a reduction in surface roughness. At a depth of cut of 0.20 mm and a rotation speed of 330 rpm, the surface roughness value is 5.36 µm. At the same depth of cut but with a higher rotation speed of 360 rpm, the surface roughness value decreases to 5.05 µm, and at 500 rpm, it further reduces to 4.42 µm. Similar trends are observed at depths of 0.50 mm and 1 mm. As the spindle rotation speed increases, the surface roughness values decrease.

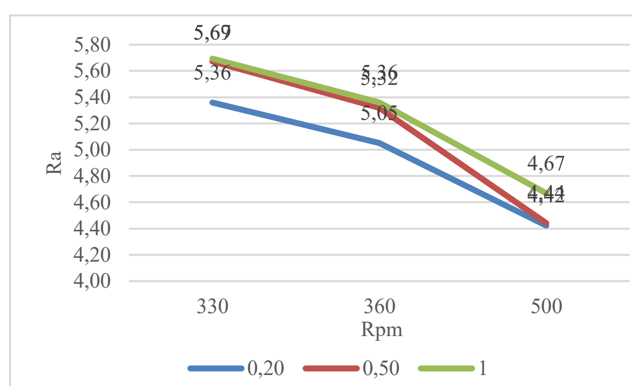

Figure 6. Surface roughness levels based on spindle rotation speed

3.3. Tool Wear Analysis

Figure 7 shows tool wear rate based on the cutting depth.. The relationship between cutting depth (a) and tool wear (Vb) is shown in Figure 7 at different spindle speeds (N), specifically 330 rpm, 360 rpm, and 500 rpm. At a spindle rotational speed of 330 rpm, the surface roughness decreases with increasing cutting depth. Similarly, for spindle speeds of 360 rpm and 500 rpm, it can be concluded that at the same spindle speed, a greater cutting depth results in a lower tool wear rate. Conversely, at the same cutting depth, it is observed that higher spindle speeds lead to increased tool wear.

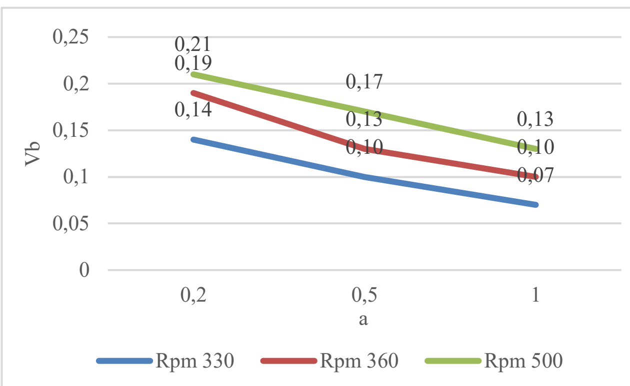

Figure 7. Tool wear rate as a function of depth of cut

From the above graph, it can be seen that the lowest tool wear rate is obtained at a spindle rotational speed of 330 rpm and a cutting depth of 1.0 mm, yielding a tool wear rate of 0.07 mm. Conversely, the highest tool wear rate is obtained at a spindle rotational speed of 500 rpm and a cutting depth of 0.20 mm, amounting to 0.21 mm.

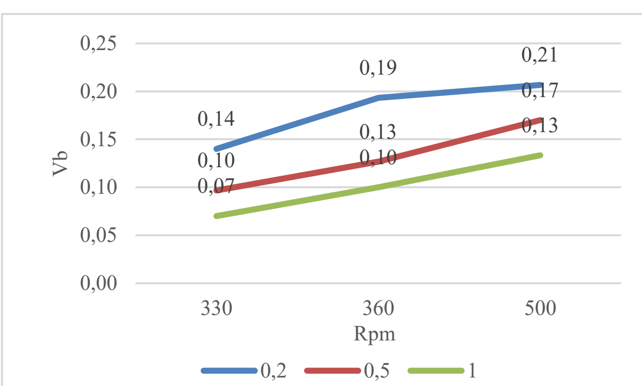

Figure 8. Tool wear based on spindle speed

The graph in Figure 8 illustrates the correlation between spindle rotation speed and tool wear at cutting depths of 0.2 mm, 0.5 mm, and 1 mm. As observed in the graph, an increase in spindle rotation speed results in a corresponding elevation in the tool wear rate. For instance, at a cutting depth of 0.2 mm and a spindle rotation speed of 330 rpm, the measured tool wear is 0.07 mm. With a higher spindle rotation speed of 360 rpm, the tool wear increases to 0.10 mm, and at the highest spindle rotation speed utilized in this study, namely 500 rpm, the tool wear reaches its maximum value of 0.13 mm. Similar trends are observed at cutting depths of 0.5 mm and 1 mm, indicating that higher spindle rotation speeds lead to greater tool wear.

3.4. Analysis of Variance (ANOVA)

An analysis of variance (ANOVA) is conducted at a 95% confidence interval to assess the main effects of input parameters on individual responses. The results of the ANOVA for surface roughness and tool wear are presented in Table 3 and Table 4, respectively. A parameter or factor is considered significant or significantly influence the response parameter when its P-value is less than α 0.05.

The ANOVA analysis on Table 3 indicated that the surface roughness is significantly influenced by the control parameters, as the P-value for all parameters were found to be less than 0.05. It means Table 3 reveals that surface roughness is predominantly influenced by spindle speed and depth of cut. The percentage contribution of spindle speed and depth of cut to surface roughness are 91.56% and 7,08%, respectively, as indicated in Table 3. Then, the percentage contribution of spindle speed and depth of cut to tool wear are 40.40% and 58.53%, respectively, as indicated in Table 4.

Table 3. ANOVA for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
N	2	1.778	0,889	133.75	0.000	91.56%
DoC	2	0.137	0,069	10.34	0.026	7.08%
Error	4	0.027	0,007			1.36%
Total	8	1.941	0,889			100%

Based on the results of the Analysis of Variance (ANOVA) presented in Table 3, it is evident that the spindle speed and depth of cut parameters significantly influence tool wear. This finding aligns with previous research, which indicated that cutting speed and depth of cut have significant impacts on surface roughness [8]. This relationship is visually represented in the graphs in Figure 6, it is observed that higher spindle speed leads to lower surface roughness. Similarly, Figure 7 shows an increase in the depth of cut results in higher surface roughness. These outcomes are consistent with earlier studies, such as the work conducted by [9], which concluded that the best surface roughness is achieved at the highest spindle speed and the lowest depth of cut.

Table 4. ANOVA for tool wear

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
N	2	0.007	0.003	75.25	0.001	40.40%
DoC	2	0.010	0.005	109.00	0.000	58.53%
Error	4	0.0002	0.0000			1.07%
Total	8	0.017	0.003			100%

Likewise, Table 4 illustrates the significant impact of spindle speed and depth of cut parameters on tool wear. This discovery aligns with prior research, as indicated by previous studies emphasizing the substantial effects of cutting speed and depth of cut on tool wear [10]. The connection is visually depicted in Figure 7, where an increase in the depth of cut results in reduced tool wear. Furthermore, Figure 8 highlights that higher spindle speeds correspond to increased tool wear. These findings are in line with earlier investigations, such as the study conducted by [11], which concluded that optimal tool wear occurs at the lowest spindle speed and the highest depth of cut.

3.5. Build of Edge (BUE)

Figure 9 illustrates a tool experiencing the phenomenon of Build-Up Edge (BUE). This phenomenon occurs due to friction between the tool and the workpiece surface, generating high temperatures capable of melting workpiece chips. These molten chips adhere to the cutting edge of the tool. The elevated temperature is a consequence of an imbalance in the parameters of spindle rotation speed and cutting depth, leading to significant frictional forces and an increase in temperature [12].

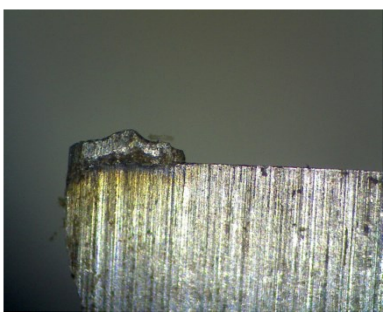

Figure 9. Build of edge (BUE)

3.6. Chipping

Figure 10 represents a cutting tool experiencing chipping, characterized by the detachment of small fragments at the cutting edge due to substantial friction between the workpiece and the tool edge. The occurrence of chipping is closely associated with the Built-Up Edge (BUE) phenomenon, where chipping typically takes place after the formation of BUE. Periodically unstable BUE can detach from the cutting tool edge, carrying small fragments along with it.

Similar to the Breakout Edge (BOE), this phenomenon is caused by inappropriate parameters leading to a rise in temperature due to significant frictional forces between the workpiece and the cutting tool. Additionally, it can result from the repeated use of the tool, causing wear and eventual breakage. Chipping leads to a loss of cutting tool sharpness and a shortened tool lifespan [13].

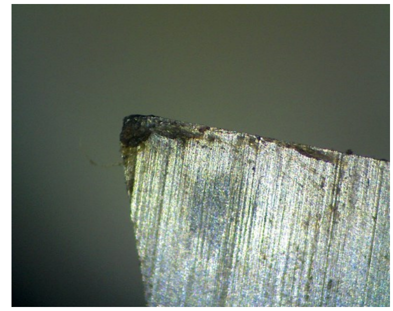

Figure 10. Chipping in Cutting Tool

4. Conclusion

In this study, an analysis was conducted on the influence of ST-42 steel cutting parameters on surface roughness and tool wear during the turning process using High-Speed Steel (HSS) tools. Based on the statistical analysis of ANOVA, the results indicated that surface roughness is significantly affected by spindle speed and depth of cut. The lowest surface roughness value of 4.42 µm was obtained at a spindle speed of 500 rpm with a depth of cut of 0.2 mm, while the highest surface roughness value of 5.69 µm was observed at a spindle speed of 330 rpm with a depth of cut of 1 mm. Also, spindle speed and depth of cut parameters were significantly influence tool wear. Conversely, the lowest tool wear was 0.7 mm which observed at a spindle speed of 330 rpm and a depth of cut of 1 mm, while the highest tool wear of 0.21 mm occurred at a spindle speed of 500 rpm with a depth of cut of 0.2 mm. The findings suggest that higher spindle speed results in smaller surface roughness and greater tool wear, whereas increased depth of cut leads to higher surface roughness and lower tool wear. This study also identified Built-Up Edge (BUE) and chipping as the consequences of high friction between the cutting tool and the workpiece. These particular findings attributed in part to inadequate parameter of settings.

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