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THE EFFECT OF TURNING CUTTING PARAMETERS ON THE SURFACE ROUGHNESS OF MILD STEEL ST 41

M. Sobron Yamin Lubis[1]*, Silvi Ariyanti[2]
[1]Mechanical Engineering Department, Engineering Faculty, Universitas Tarumanagara, Jakarta, Indonesia
[2]Industrial Engineering Department, Engineering Faculty,University of Mercu Buana Jakarta, Indonesia
Email: sobron@untar.ac.id[1]

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Coresponding Author

ABSTRACT

Surface roughness is one of the important parameters in determining the quality of turning process results. This study aims to analyze the cutting parameters, namely cutting speed (Vc) and feed rate (f) on the surface roughness value (Ra) in the turning process of ST41 steel. Variations in cutting parameters include five levels of cutting speed (200, 215, 230, 245, and 260 m/min), three variations of feed rate (0.1, 0.2, 0.3 mm/rev) at a depth of cut of 0.5 mm, Surface roughness measurements were carried out using a Mitutoyo surface roughness tester. The results showed that increasing the feed rate had the most significant effect on increasing the surface roughness value. Parameter interactions showed that the combination of low feed rate and medium–high cutting speed (230–245 m/min) produced the best surface quality. In contrast, the combination of high feed and low cutting speed produces the highest roughness due to the simultaneous contribution of large feed marks, BUE formation, and increased cutting forces.

Keywords : *ST41 Steel, Cutting Speed, Feed, Surface Roughness, Turning Process*

1. Introduction

Machining is the most widely used manufacturing method in the production of steel machine components because it is capable of producing precise dimensions and surface quality that meets functional standards. One of the dominant machining processes is turning, in which the workpiece rotates on a spindle and the tool moves translationally to form a cylindrical geometry according to the design. The quality of the turning results is greatly influenced by the cutting parameters used during the process, especially in relation to cutting stability and chip formation.

Surface roughness is a key indicator of machining quality because it directly relates to wear resistance, friction coefficient, assembly accuracy, and component service life. Theoretically, surface roughness is influenced by feed rate, tool nose radius of cutting tools, plastic deformation in the shear zone, and dynamic phenomena such as vibration and built-up edge (BUE) formation. Cutting speed and feed rate parameters play a crucial role in controlling the chip formation mechanism, cutting temperature, and the stability of the tool-workpiece interaction. In general, increasing feed rate will increase the geometrical surface wave height, while increasing cutting speed can improve surface quality to a certain extent before the effect of tool wear becomes dominant. Low carbon steel ST41, which has identical characteristics to AISI 1018, is widely used in industry for the manufacture of shafts, machine frames, and structural components due to its good machinability and adequate mechanical strength. However, variations in cutting parameters during the turning process of this material can produce significant differences in surface roughness values. Previous studies evaluated the effect of variations in cutting speed on the surface roughness of AISI 1018 steel during dry turning and found that increasing cutting speed tends to decrease the Ra value with better process stability. [1].[2],[3].

The novelty of this research lies in the direct experimental analysis approach to evaluate the simultaneous influence of cutting speed and feed rate on the surface roughness of ST41 steel. This research not only identifies the most influential parameters but also formulates recommendations for optimal and applicable cutting parameter combinations in industrial practice.The objectives of this study are: to analyze the effect of variations in cutting speed and feed rate on the surface roughness value of ST41 steel in the turning process; to determine the parameters that most dominantly affect surface quality; and to obtain a combination of cutting parameters that produce optimum surface quality. The results of this study are expected to provide scientific contributions in controlling the quality of the turning process and become a practical reference in selecting cutting parameters for low carbon steel materials.

2. Literature Review

Turning is one of the most widely used conventional and modern machining processes in the manufacturing industry. Lathes operate on the basic principle of rotating a workpiece and cutting it using a cutting tool to achieve dimensions and shapes that meet specifications. The development of modern turning technology leads to the optimization of cutting parameters to improve surface quality, productivity, and tool life. Research by Gupta et al. (2021) shows that in the CNC turning process, the stability of cutting speed and feed rate parameters significantly determines the final surface quality and surface integrity of low-carbon steel materials. [4]. Another study by Mia & Dhar (2020) emphasized that CNC systems provide precise control over machining parameter variations, thus enabling quantitative analysis of the effect of cutting speed and feed rate on surface roughness. [5]. The main parameters in the turning process include cutting speed (Vc), feed rate (f), and depth of cut (a).

Mild steel ST41 material is included in the low carbon steel category with a carbon content of around 0.08–0.20% C. This material is widely used in machine components such as shafts, gears, and light structures because it has good ductility and machinability.[6]. Micro structurally, low-carbon steel is dominated by ferrite and a small amount of pearlite, making it relatively easy to shape its surface contours through machining processes. According to research by Pramanik et al. (2020), low-carbon steel exhibits high surface roughness sensitivity to feed rate variations compared to medium- or high-carbon steel. Micro structurally, low-carbon steel is dominated by ferrite and a small amount of pearlite, making it relatively easy to shape its surface contours through machining processes. [7]. According to research by Pramanik et al. (2020), low-carbon steel exhibits high surface roughness sensitivity to feed rate variations compared to medium- or high-carbon steel. Research by Singh & Sharma (2021) shows that in low carbon steel, increasing cutting speed tends to improve surface quality to a certain extent, before a significant increase in temperature occurs which can accelerate tool wear.[8].

Cemented carbide tools are widely used in turning carbon steel due to their high hardness, wear resistance, and good thermal stability. DCMT type carbide inserts (such as the Kyocera DCMT11T304HQ) have a positive cutting angle geometry suitable for finishing cuts. According to research by RAo et al. (2023), tool nose radius directly affects the theoretical value of surface roughness. A larger nose radius tends to produce a smoother surface but can increase radial cutting forces.[9]. In addition, a study by Abbas et al. (2024) showed that the combination of high cutting speed and low feed on carbide tools was able to minimize BUE formation and produce lower Ra values on low carbon steel.[10].Surface roughness is a micro geometric parameter that describes the surface irregularity resulting from the machining process. A commonly used parameter is Ra (arithmetical mean roughness). Practically, the Ra value of finishing turning results is usually in the range of 0.4–3.2 µm depending on the cutting parameters and tool conditions. Research by Kumar et al. (2025) shows that in turning low-carbon steel, feed rate contributes 60–75% to the variation in Ra based on ANOVA analysis, while cutting speed contributes around 15–25%. [11].Surface characteristics play a crucial role in the design of machine components. Many situations require explicit surface characteristics related to friction, wear, lubrication, fatigue resistance, and the bonding of two or more machine components. Surface testers work by using a stylus that moves along a straight line at a predetermined distance. The stylus detects the surface condition of the work piece and converts it into a surface roughness value. Surface roughness can be represented on a graph that has the same shape as the measured profile. The graph represents an enlargement of the surface roughness of that profile. [12].

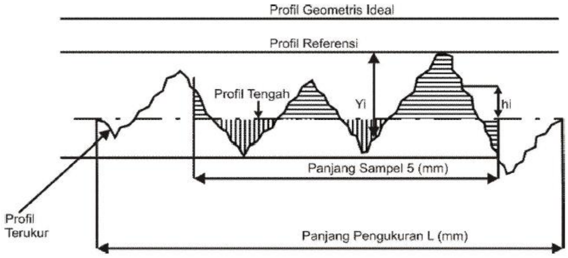

Figure 1. Surface Roughness Contour Graph. [13]

The following is an explanation of the types of surface roughness profiles: [13]

1) Geometrically Ideal Profile
   This profile represents an ideal surface geometry that is impossible to achieve due to the many factors that influence its manufacturing process. The shape of this ideal geometric profile can be a straight line, a circle, or a curved line.
2) Reference Profile
   This profile is used as a basis for analyzing the characteristics of a surface. Its shape is the same as the ideal geometric profile, but it precisely touches the highest peak of the measured profile at the sample length taken during the measurement.
3) Measured Profile
   A measured profile is a profile of a surface obtained through a measurement process. This profile is used as data for analyzing the surface roughness characteristics of machined products.
4) Root Profile
   The root profile is a reference profile shifted downward to precisely the lowest point of the measured profile.
5) Center Profile
   The center profile is the profile located in the middle, positioned such that the sum of the areas from the top of the center profile to the measured profile is equal to the sum of the areas from the bottom of the center profile to the measured profile. This center profile is essentially a reference profile shifted downward perpendicular to the ideal geometric profile to a certain limit that divides the surface cross-sectional area into two equal parts: the top and the bottom.

The average roughness (Ra) value of the surface is presented in Table 1

Table 1. Tolerance of Average Surface Roughness Value Ra. [14].

Roughness Class	C.L.A (μm)	R_a (μm)	Tolerance N +50% –25%	Sample Length (mm)
N1	1	0.0025	0.02 – 0.04	0.08
N2	2	0.05	0.04 – 0.08	
N3	4	0.0	0.08 – 0.15	0.25
N4	8	0.2	0.15 – 0.3	
N5	16	0.4	0.3 – 0.6	
N6	32	0.8	0.6 – 1.2	
N7	63	1.6	1.2 – 2.4	
N8	125	3.2	2.4 – 4.8	0.8
N9	250	6.3	4.8 – 9.6	
N10	500	12.5	9.6 – 18.75	2.5
N11	100	25.0	18.75 – 37.5	
N12	2000	50.0	37.5 – 75.0	8

Theoretically, the ideal surface roughness value in the turning process can be estimated using the equation: [14].

$$Ra = \frac{0{,}032\ 1 \, . \, f^2}{r_e}$$

where:
Ra: Surface roughness (µm)
f: Feed rate (mm/rev)
re: Tool bit radius (mm)

This equation shows that feed rate has a quadratic effect on the Ra value, so theoretically, feed rate is the dominant parameter in determining surface roughness. Research by Sahoo et al. (2022) on turning carbon steel showed that increasing feed rate significantly increases the Ra value compared to increasing cutting speed.[15]. Research by Kumar et al. (2023) stated that in low-carbon steel, the combination of high cutting speed and low feed produces smoother surfaces due to reduced cutting forces and stabilization of plastic deformation in the primary shear zone.[16].

3. Research Methods

This research was conducted in the Mechanical Engineering Laboratory using a Mazak Quick Turn 8N CNC machine with Kyocera DCMT11T304HQ carbide cutting tools.[17]. The focus of the research was to analyze the effect of cutting speed and feed rate on the surface roughness value of ST41 steel, while other parameters were conditioned to maintain the validity of the experimental results. Surface roughness measurements were carried out using a surface roughness tester to obtain the average roughness value (Ra) as a quality indicator.

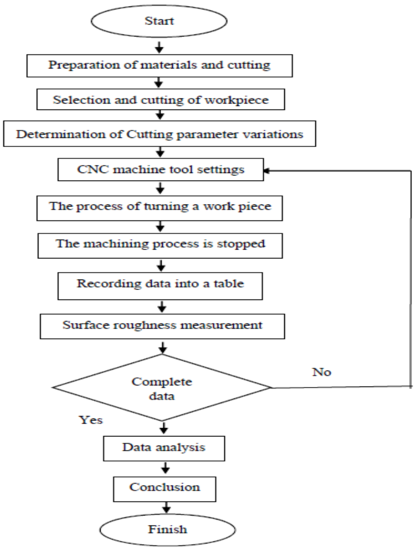

Figure 2. Experiment Flowchart

3.1 Equipment and Materials

The equipment and materials used are as follows:

1) CNC Lathe, Quick Turn 8N Type
2) Vernier Caliper
3) Surface Roughness Measuring Tool

Figure 3. Mitutoyo Roughness Measuring Device

1) ST 41 Low Carbon Steel Workpiece

Figure 4. Low Carbon Steel ST 41

Table 2. Chemical composition of ST 41 Steel

Chemical Composition	Percentage %
Ferrum (Fe)	99,158
Carbon (C)	0,084
Silicon (Si)	0,135
Manganese (Mn)	0,278
Nickel (Ni)	0,005
Sulfur (S)	0,0035
Chromium (Cr)	0,298

2) Kyocera Carbide cutting tool DCMT11T304HQ

Table 3. Characteristics of Kyocera DCMT11T304HQ Carbide cutting tool

Cutting speed ($^{m}/_{min}$)	120-260
Feeding ($^{mm}/_{rev}$)	0,08 – 2,00
Depth of Cut (mm)	0,5 – 2

3.2 Experimental Procedure

The cut workpiece was then placed in the workpiece chuck, and the cutting parameters, including cutting speed, feed rate, and depth of cut, were set. The cutting tool was placed on the edge of the workpiece, and the turning process was performed. After the turning process was completed, the surface tester was placed on the workpiece, and the stylus was scratched on the turned surface to measure the surface roughness. The roughness values were then recorded and entered into a table for further graphing and analysis.

4. Results and Discussions

4.1 Result

The results of the workpiece surface roughness measurements can be seen in Table 4.

Table 4. Surface Roughness Values with a depth of cut of 0.5 mm

Feeding	Cutting speed (Vc, m/min)				
(f, mm/rev)	200	215	230	245	260
0,1	1,1 µm	0,77 µm	0,92 µm	0,97 µm	1,16 µm
0,2	2,68 µm	2,67 µm	2,73 µm	2,42 µm	2,83 µm
0,3	6,76 µm	5,85 µm	6,12 µm	9,85 µm	10,74 µm

Based on Table 4. for each cutting speed, it can be seen that with each increase in feed speed, the surface roughness value increases.

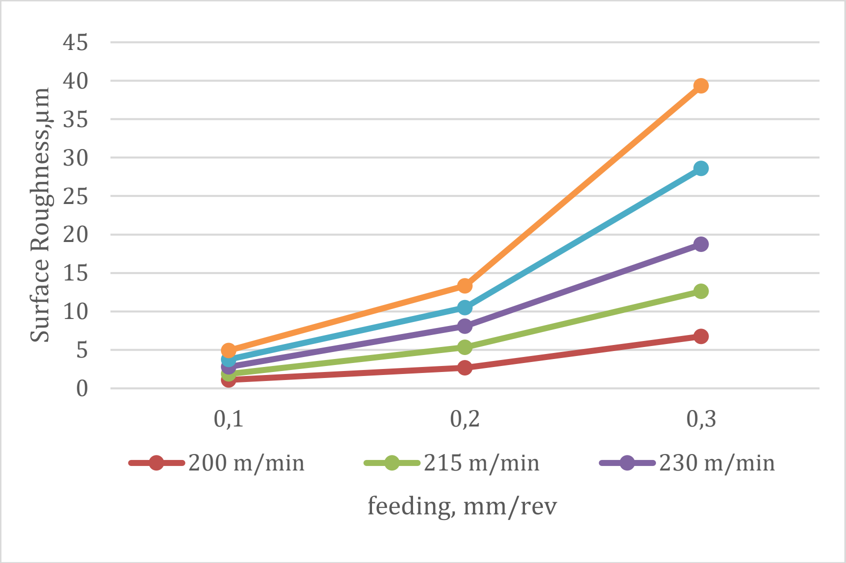

Figure 5. Effect of feeding on surface roughness

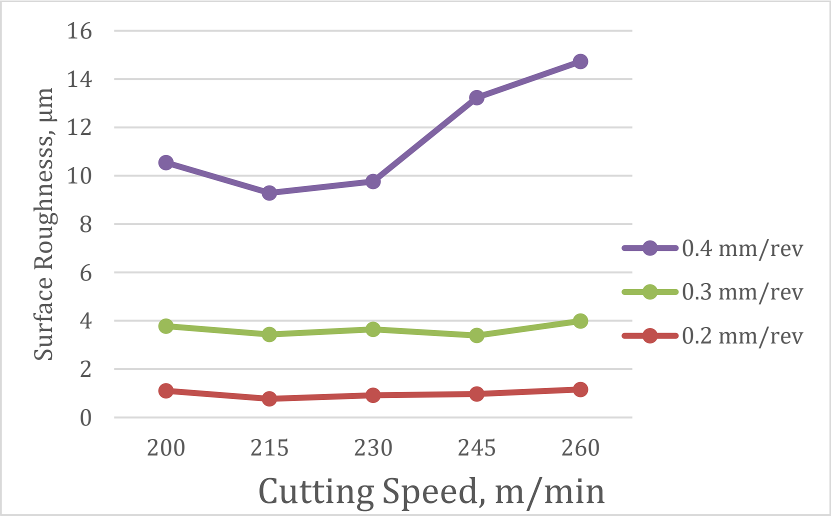

Figure 6. Effect of Cutting Speed on surface roughness

4.2 Discussions

Based on Figure 6. it is known that increasing cutting speed linearly increases surface roughness due to the increased feed rate. The influence of feed rate significantly contributed to this test.There are three types of cutting forces generated in the turning process: tangential force, axial force, and radial force. Tangential force is the force generated in the direction of the cutting speed. Axial force is the force generated in the direction of the feed rate. Radial force is the force directed toward the plane normal to the cutting speed. The magnitude of the cutting force is influenced by several parameters: cutting speed, feed rate, depth of cut, cutting tool, and workpiece material. The influence of the cutting tool includes the type of cutting tool material, the geometry of the tool angle, and the position of the cutting tool in the tool holder on the lathe.

The results of the workpiece surface roughness measurements show that variations in cutting speed and feed have a significant effect on the surface roughness (Ra) value in the turning process of ST41 steel using a carbide tool. ST41 steel, which is included in the low carbon steel category with characteristics close to AISI 1018, has ductile properties and is easy to experience plastic deformation, so the response to changes in cutting parameters is greatly influenced by mechanical and thermal phenomena in the cutting zone.

The influence of feeding appears to be the most dominant factor in the formation of surface roughness. At a feeding rate of 0.1 mm/rev, the Ra value tends to be lowest because the distance between cutting tool traces (feed marks) is relatively small and the resulting cutting force is still within the stability limits of the machine system. Plastic deformation that occurs on the surface is relatively minimal, resulting in a smoother surface profile. When the feeding rate is increased to 0.2 and 0.3 mm/rev, the chip thickness increases so that the cutting force, especially the radial force, increases significantly. This condition causes an increase in plastic deformation and clarifies the feed wave. At a feeding rate of 0.35 mm/rev, roughness increases sharply due to the combined influence of the feed geometry and the possibility of micro vibrations (chatter), which deteriorates the surface quality through tearing and excessive deformation mechanisms.

Variations in cutting speed show a nonlinear relationship pattern to surface roughness. At a speed of 200 m/min, the cutting zone temperature is relatively low so that the tendency for Built-Up Edge (BUE) formation is quite high. The presence of BUE causes fluctuating changes in the effective cutting angle and produces a non-uniform surface. When the speed is increased to 215–230 m/min, the cutting temperature increases so that BUE decreases and the chip flow becomes more stable. This condition reduces the surface roughness value because the contact of the cutting tool with the workpiece becomes more consistent. At a speed of 245 m/min, the cutting condition is in the optimum zone, where BUE is almost not formed and the carbide cutting tool works in the ideal temperature range. This results in the lowest Ra value.However, at a speed of 260 m/min, a significant increase in temperature occurs, accelerating flank wear (V_B). This wear increases friction between the flank plane and the newly formed workpiece surface, resulting in a further increase in roughness. Furthermore, local softening of the material due to heat can increase surface plastic deformation.

The interaction between feed and cutting speed shows that the combination of low feed and medium–high cutting speed (approximately 230–245 m/min) produces the best surface quality. Conversely, the combination of high feed and low cutting speed produces the highest roughness due to the simultaneous contribution of large feed marks, BUE formation, and increased cutting forces.Overall, the mechanism of surface roughness formation in turning ST41 steel is determined by three main aspects, namely feed geometry, chip formation stability, and cutting tool wear conditions. Feed directly influences through the formation of surface wave profiles, while cutting speed plays a role in controlling the thermal and metallurgical phenomena that occur during the machining process.

When viewed from the roughness results of each parameter, the most significant influence is on the feed motion used. At each same cutting speed, it can be seen that each increase in the feed motion used will produce a greater roughness value, then if the feed motion is lower, the roughness results obtained will also be lower, this happens because the slower cutting tool shift will make the surface roughness results in the lathe process will be low, and there are also several factors that influence surface roughness, namely vibration on the cutting tool or the inappropriate proportion of the cutting tool feed in the processing process, then other factors are the center position that is not right / appropriate, the presence of non-linear movement of the feed, machine vibration, unbalanced cutting tool lathe.

5. Conclusion

Based on the results of the discussion, it can be concluded that variations in cutting speed and feeding have a significant influence on the surface roughness value (Ra) in the turning process of ST41 steel which has characteristics close to AISI 1018 using carbide tools.

1) Feed is the most dominant parameter in determining surface roughness. Increasing feed from 0.1 mm/rev to 0.35 mm/rev consistently increases Ra values across all cutting speed variations. This is due to the larger feed marks, increased chip thickness, and increased cutting forces, particularly radial forces, which trigger plastic deformation and potential vibration.
2) Cutting speed exhibits a nonlinear relationship to surface roughness. At low speeds (200 m/min), the formation of built-up edges (BUE) results in surface non-uniformity and relatively high Ra values. Increasing the speed to 230–245 m/min produces more stable

cutting conditions and minimizes BUE, resulting in the lowest roughness. However, at 260 m/min, surface roughness increases due to accelerated flank wear (VB), increased temperature, and increased friction on the workpiece surface.

3) Parameter interactions indicate that the combination of low feed and medium–high cutting speeds (230–245 m/min) produces the best surface quality. Conversely, the combination of high feed and low cutting speed produces the highest roughness due to the simultaneous contribution of large feed marks, BUE formation, and increased cutting forces.
4) The primary mechanism of surface roughness formation is determined by three aspects: feed geometry, chip formation stability, and tool wear conditions. In addition to these primary parameters, contributing factors such as machine vibration, center position inaccuracy, tool imbalance, and nonlinear feed motion also contribute to increased surface roughness.

Overall, feed control is a key factor in achieving good surface quality in the turning process of ST41 steel, while still considering the optimum cutting speed to minimize BUE formation and tool wear.

Suggestion

The suggestion from this research is that experimental testing can be strengthened by comparing ST 41 material with other materials, with the same parameters, so that the comparison of experimental results using the same parameters can be seen in the surface roughness results.

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