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Effect of Cutting Parameters in the Turning Process towards the Surface Roughness of AISI D3 Materials

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ABSTRACT

The metal forming for manufacturing machine and automotive components can be done using machinery. The surface of the workpiece must meet the requirements for the roughness value according to the design. Factors such as the use of cutting tools and cutting parameters need to be considered because they could affect the surface roughness value. However, it's a problem if the right combination of cutting parameters can't be determined. The use of high cutting speeds could fasten the process, but this shortened the age of the cutting tool. Meanwhile, if the cutting feed is increased, then the process is shorter and the roughness value will be much higher. This study aims to determine the effects of cutting parameters in the turning process on the roughness value of the workpiece. In this study, an experimental turning process of AISI D3 Steel workpieces was carried out. AISI D3 workpieces have high hardness, which is why they require tough, hard and strong cutting tools such as ceramics. The cutting parameters used are varied, such as cutting speed (120-200 m/min), cutting feed (0.1-0.2 mm/rev), and cutting depth of 0.25 mm. The machining process was carried out without using coolant. After each turning process, the surface roughness of the AISI D3 Steel workpiece was measured at five different points. The results of the study showed that the smallest surface roughness value of the workpiece was 0.82 µm at a cutting speed of 180 m/min and a cutting feed of 0.1 mm/rev. The highest surface roughness value of the workpiece was 2.88 µm at a cutting speed of 200 m/min and a cutting feed of 0.2 mm/rev. Increasing the use of cutting speed has an effect on reducing the surface roughness value of the workpiece. Meanwhile increasing the use of cutting feed will increase the surface roughness value. At higher cutting speeds, the temperature in the cutting zone increases, which can reduce cutting forces and reduce surface roughness. To produce the desired surface roughness value, the use of cutting current that is too high or too low must be balanced with the appropriate cutting speed.

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1. Introduction

The formation of metal materials, especially for the manufacture of moulds or dies can be done using machine tools. The moulds generally consist of several parts such as anvil, punch, and dies. The commonly used material is AISI D3 steel. Of course, the process of manufacturing moulds requires the surface condition of the workpiece to have a low roughness value. The formation of these parts was partly done using lathes.

The turning process is used to form the workpiece into a cylindrical shape. In the turning process, there are many factors to consider to determine the surface roughness value. Such as the type of cutting tool, machine, coolant usage and cutting parameters. Cutting parameters in the turning process are important to consider in order to achieve the desired surface roughness condition of the workpiece. In the turning process, there are three main parameters such as cutting speed, cutting feed, and cutting depth. The three cutting parameters are determined based on the type of workpiece to be cut and the material of the cutting tool used.

Variations in feeding speed and L/D ratio significantly affect the surface roughness of the workpiece, parameters that are correctly selected and optimized can produce a smoother surface and better machining quality Pratama, [1]. Changes in cutting feed rate have a significant impact on surface roughness. A higher cutting feed rate tends to produce a rougher surface, meanwhile a lower cutting feed rate tends to produce a smoother surface.

This research provides important insights for the manufacturing industry in improving product efficiency and quality through the adjustment of turning process parameters. This research also provides important insights for the manufacturing industry in optimizing machining parameters to achieve the desired surface quality Hadimi, [2]. Theoretically, surface roughness can be calculated using the following equation [3,20]:

$$Ra = 1{,}22 \times 10^5 . \mu . f^{1{,}004} . Vc^{-1{,}252} \tag{1}$$

$$\mu = r^{-0{,}714} . (BHN)^{-0{,}323} \tag{2}$$

where the radius angle of cutting tool, r, Brinell hardness value for workpieces, BHN, cutting feed, f and cutting speed, Vc.

The cutting parameters studied include cutting speed, cutting feed rate, and cutting depth [4]. Cutting force in the machining process, affects the hardness of the workpiece used, Cutting force increases along with the increasing hardness of the workpiece. The effect of cutting speed will affect the wear on cutting tools, and this affects the roughness of the surface of the workpiece produced [5].

Research related to the effect of cutting speed and feeding rate towards the surface integrity of AISI 1045 steel in the turning process has been carried out by Jacas *et al.*, [23] and Lubis *et al.,* [6]. The research was done to understand how the cutting parameters affect the surface quality of the workpiece material. Cutting tools that wear out more quickly tend to produce surfaces with higher roughness. Coated carbide cutters, due to their high wear resistance, could produce a much lower surface roughness on the workpiece compared to uncoated cutters [6,23].

The main factors determining the surface quality of machine components and the technological efficiency of the cutting process are cutting tools, more specifically, their design features and the material of the cutting tool [7]. Several factors causing measurement uncertainty that has been identified include the condition of the measuring instrument, measurement technique, environmental conditions, and variations in the surface of the measured material [8].

According to Parkas *et al.,* (2018), research on the surface roughness of workpiece is very important for the manufacturing industry, where surface roughness is a critical parameter for the quality of a product. Understanding and managing uncertain measurement can help in better quality control [8]. The results of the research conducted by Qehaja *et al.,* (2015) indicate that machining parameters have a significant impact on the final surface quality. Higher cutting speeds and lower feeding rates tend to produce smaller surface roughness values. Additionally, extended machining time could increase the surface roughness of the cutting tool, leading to wear [9].

Akgün *et al.,* (2021) conducted research on the optimization of cutting parameters concerning the surface roughness values produced in the machining of Inconel 625. The research results show that cryogenic treatment on tungsten carbide insert cutting tools significantly reduces surface roughness. Higher cutting speeds and lower feed rates result in smaller surface roughness values. This study makes an important contribution to the machining industry in determining optimal cutting parameters to achieve the desired surface quality on difficult-to-machine materials such as Inconel 625 [10]. The results of the research conducted by Asiltürk *et al.,* (2011) show that the cutting feed rate is the most significant factor that affects the surface roughness, followed by cutting speed and cutting depth. The use of the Taguchi method allows researchers to identify combinations of cutting parameters that can produce lower surface roughness values with higher efficiency [11].

The study conducted by El-Kady *et al.,* (2015) involved a series of experiments in which machining parameters such as cutting speed, feeding rate, and cutting depth were varied. The research results show that cutting depth has the greatest influence on cutting force, followed by feeding rate and cutting speed. The wear of the cutting tool is also significantly influenced by these parameters, which in turn affect the surface roughness of the machining results [12,23]. Based on the research that has been done, cutting parameters such as cutting speed, cutting depth, and cutting flow have an effect on the workpiece. However, a cutting study on AISI D3 steel which has high hardness needs to be done because the minimum surface roughness value is very much needed in the application of the resulting part/component.

Increasing cutting speed generally reduces surface roughness, but it can increase temperature and the potential for thermal damage. A higher cutting feed rate tends to increase surface roughness. Too high can cause deformation and more severe damage [13,19]. This research was conducted to identify the influence of cutting parameters on the turning process of AISI D3 steel workpieces to produce a smoother product surface.

2. Methodology

2.1 Equipment

The research was conducted using an experimental method. Materials and equipment used are as follows:

2.1.1 CNC Mazak Type Quick Turn 8N Lathe

The CNC Mazak Type Quick Turn 8N Lathe, as seen in Figure 1 below, uses three main cutting parameters, such as cutting speed, cutting feed and cutting depth. All of which are shown in Table 1.

Fig. 1. CNC Mazak Type Quick Turn 8N Lathe

Table 1
Cutting parameters

Cutting Speed ($^{m}/_{min}$)	120-200
Cutting Feed ($^{mm}/_{rev}$)	0.1, 0.15, 2.00
Cutting Depth (mm)	0.5

2.1.2 Surface roughness measuring tool

The surface roughness value of a workpiece is measured by using measuring tools, as shown in Figure 2. The measurements of surface roughness values can be referred to a standard average of tolerance by using Table 2.

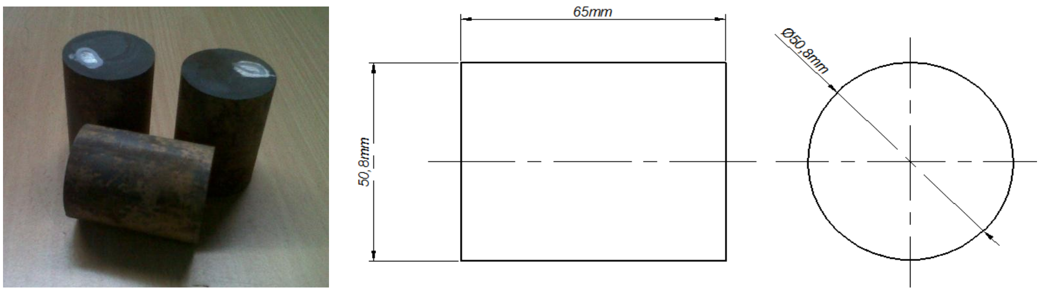
Fig. 2. Surface tester Mitutoyo

Table 2
Average surface roughness value tolerance (*Ra*) (ISO – 1302, 2001) [4,17,18,21]

Roughness Level	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

2.1.3 AISI D3 steel workpiece

This experiment will be conducted using an AISI D3 Steel workpiece, as shown in Figure 3(a), where the dimensions of the workpiece are shown in Figure 3(b). The chemical compositions and mechanical properties of AISI D3 Steel are shown respectively in Table 3 and Table 4.



(a) (b)

Fig. 3. (a) AISI D3 Steel workpiece (b) Workpiece specification

Table 3
Chemical Compositions of AISI D3 Steel [15,20,22]

Chemical Elements	Composition (%)
C	2.00-2.35
Mn	0.60
Si	0.60
Cr	11.00-13.00
Ni	0.30
W	1.00
V	1.00
P	1.00
S	0.03
Cu	0.26

Table 4
Mechanical Properties [15,20,22]

Impact load	28. J
Poisson ratio	0.27-0.30
Elastic modulus	190-210 GPa
Density	7.7 x 100 kg/m^3
Melting point	1421 ^{o}C
Thermal Expansion	12 x 10-6/^{o}C

2.1.4 Ceramic Cutting Tool

In the turning process, the ceramic cutting tool (Figure 4) will be used to cut the workpiece with the determined cutting parameters.

Fig. 4. Ceramic cutting tool [24]

2.2 Experiment Procedure

To conduct this experiment, a planned procedure will be drawn to make sure the process goes smooth and efficient. The planned procedure is shown as a flowchart diagram in Figure 5.

As a first step, the preparation of the workpiece, cutting tool, and machine tool used is carried out. Then the plan proceeds to cut the workpiece. Next step is to determine the combination of cutting parameters consisting of cutting speed, feeding rate, and cutting depth. The turning process begins, during which the condition of the machined workpiece surface is observed. Then, the machining process is halted, and surface roughness measurements are taken using a surface test tool on the workpiece surface. Measurements are conducted at five points on the machined workpiece surface. Subsequently, cutting parameters are altered by varying the cutting feed, and the turning process is carried out. After every turning process is finished, the surface roughness of the workpiece is measured again. The surface roughness values will be inputted into a data table to create graphs and conduct an analysis. The flowchart diagram of this process can be seen in Figure 5.

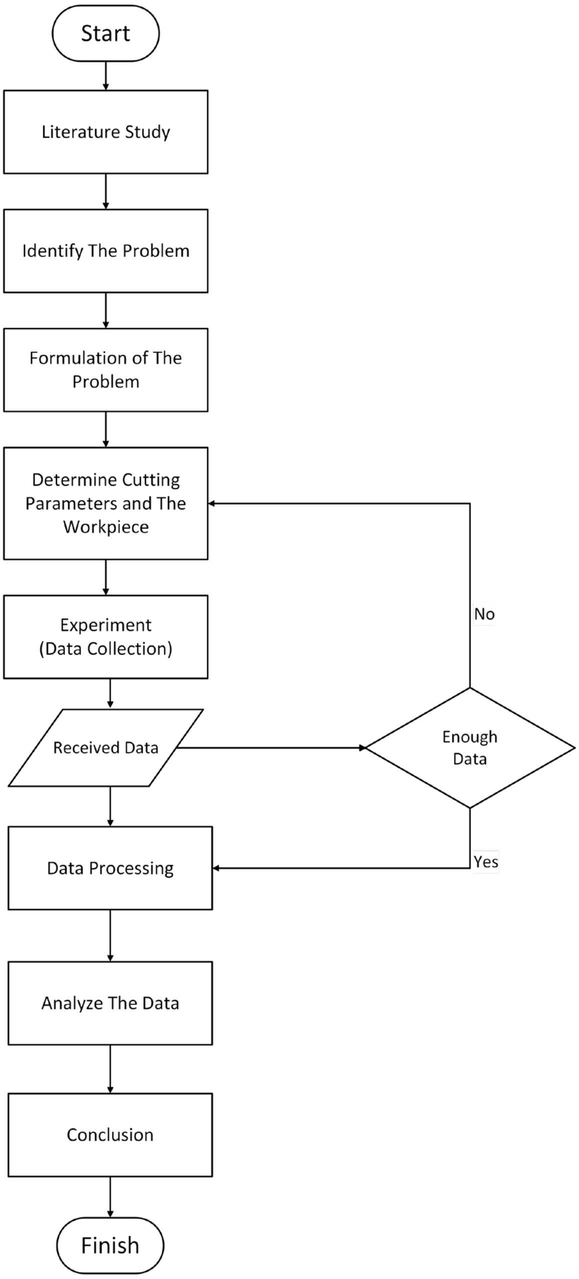


Fig. 5. Flowchart diagram

3. Results

The results of the surface roughness measurements with variations in cutting speed and feeding rates are presented in Table 5 and Table 6.

Table 5
Results data of measured surface roughness of the workpiece

Tool Nose Radius: 0.8
Depth of cut: 0.25 mm

No	Vc (m/min)	F (mm/rev)	n (rmin)	Surface Roughness Ra (µm)					Ra_{av} (µm)
				Ra_1	Ra_2	Ra_3	Ra_4	Ra_5	
1	120	0.10	780	1.42	0.9	0.81	0.69	1.12	0.99
2	120	0.15	790	1.22	1.03	1.18	1.27	1.57	1.25
3	120	0.20	800	3.12	1.96	2.16	2.29	2.57	2.42
4	140	0.10	930	1.86	1.33	1.15	1.78	1.57	1.54
5	140	0.15	940	2.14	1.77	2.27	1.23	1.52	1.79
6	140	0.20	950	2.57	2.31	2.76	2.53	1.89	2.41
7	160	0.10	1090	1.37	1.74	1.17	0.88	1.85	1.40
8	160	0.15	1110	2.74	1.42	1.21	1.91	1.75	1.80
9	160	0.20	1120	2.23	2.09	2.93	1.73	1.72	2.14
10	180	0.10	1280	0.93	0.92	0.83	0.83	0.58	0.82
11	180	0.15	1290	1.63	1.72	1.74	1.72	1.55	1.67
12	180	0.20	1300	1.68	1.55	1.26	1.38	1.44	1.46
13	200	0.10	1460	1.20	1.22	0.91	0.87	0.83	1.01
14	200	0.15	1480	1.30	1.54	1.48	0.99	1.26	1.31
15	200	0.20	1500	2.13	2.74	3.25	3.11	3.15	2.88

Table 6
Surface roughness value results

Machine Data: Turning CNC Tool: Ceramics Insert "TNGA 160408 AB30" Machining Parameters: Cutting Depth (a): 0.25 mm	Material Data: Grade: Hardened AISI D3 Dimension: Diameter: 50.8 mm Length: 65 mm

No	Cutting Speed Vc (m/min)	Average Surface Roughness Ra_{av} (µm) Feed Rate (mm/rev)		
		0.1	0.15	0.2
1	120	0.99	1.25	2.42
2	140	1.54	1.79	2.41
3	160	1.40	1.80	2.14
4	180	0.82	1.67	1.46
5	200	1.01	1.31	2.88

3.1 The Effects of Cutting Speed on Surface Roughness Value

Based on the data from Table 6, a graphic on the effects of cutting speed towards roughness value are as follows (Figure 6-8):

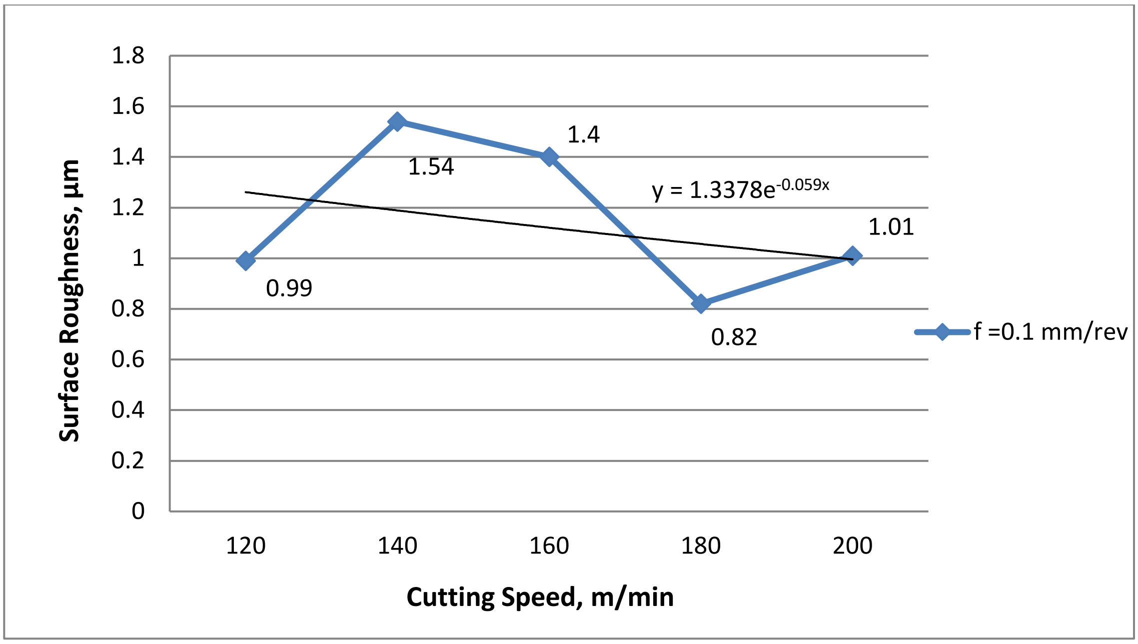


Fig. 6. Graphic of cutting speed vs surface roughness of the workpiece where cutting feed, f is 0.1 mm/rev

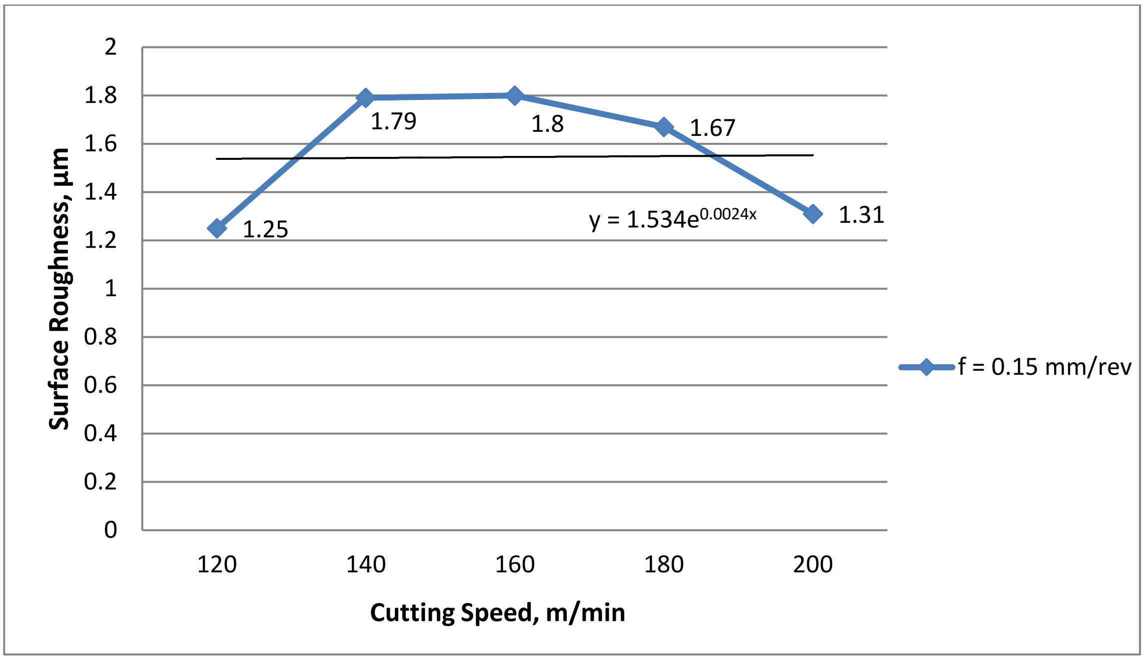


Fig. 7. Graphic of cutting speed vs surface roughness of the workpiece where cutting feed, f is 0.15 mm/rev

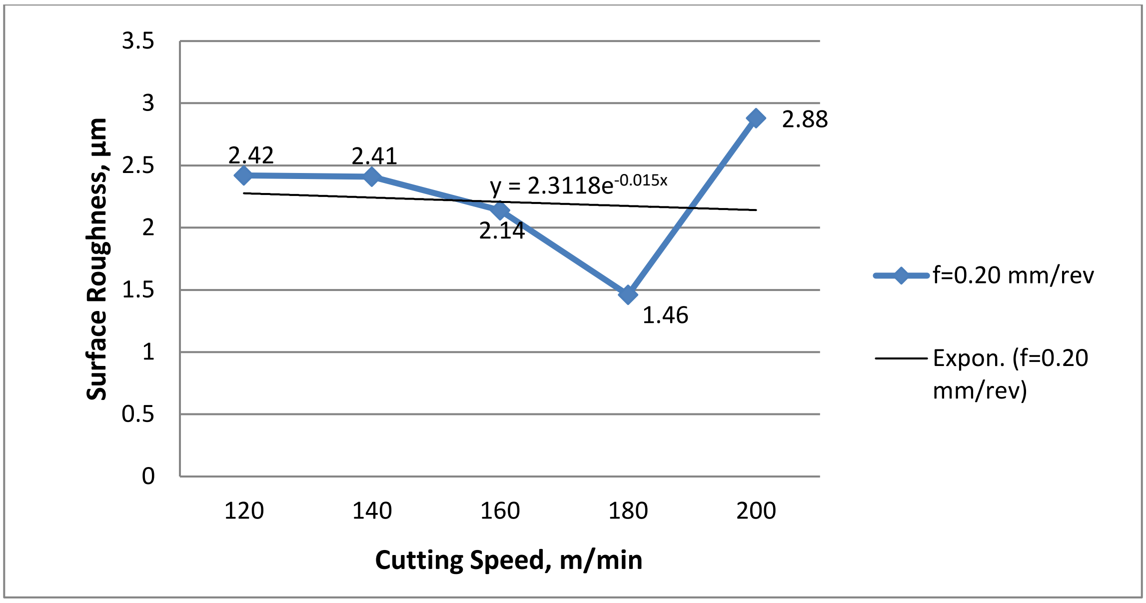


Fig. 8. Graphic of cutting speed vs surface roughness of the workpiece where cutting feed, f is 0.20 mm/rev

Based on Figures 6, 7 and 8, it can be observed that the increase in cutting speed initially produced higher roughness value, but as the cutting speed is increased, the surface roughness values on the workpiece begin to decrease, indicating that the surface condition of the workpiece is becoming smoother. At higher cutting speeds, the temperature in the cutting zone increases, which can reduce cutting forces and decrease surface roughness. However, excessive high speeds can lead to excessive temperature increases and accelerate tool wear, ultimately increasing surface roughness. While lower cutting speeds tend to produce higher surface roughness due to greater cutting forces and an increased likelihood of vibration and abrasion on the workpiece surface.

The comparison of surface roughness values influenced by cutting speed with the three cutting feeds used is presented in Figure 9.

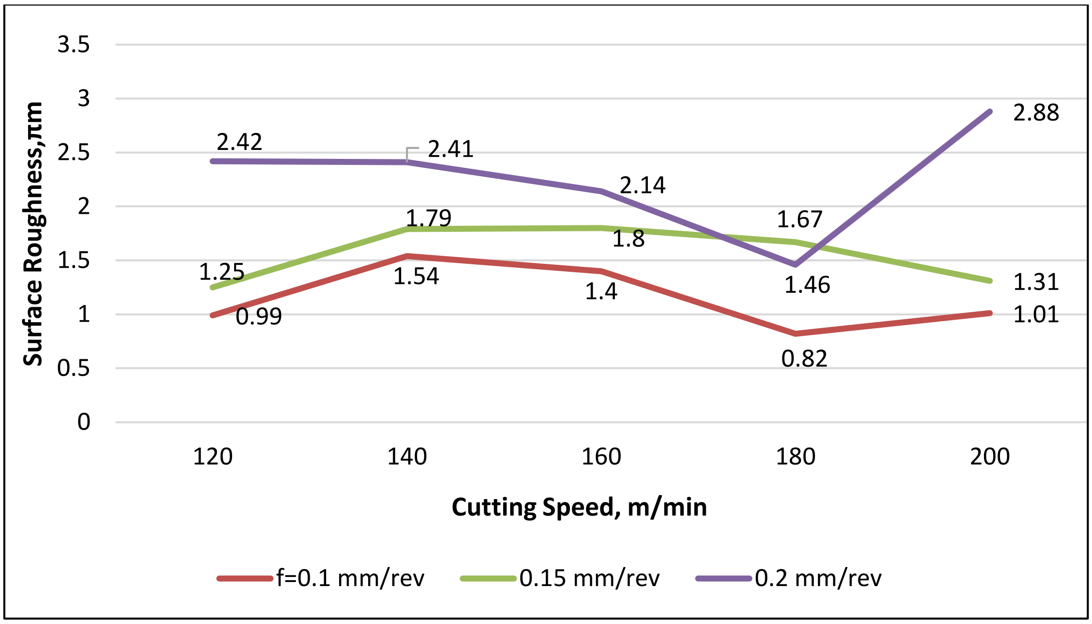


Fig. 9. Graphic of cutting speed vs surface roughness of the workpiece in different cutting feed

Based on Figure 9, it can be seen that the comparison of cutting feed to surface roughness shows that the lowest surface roughness value of 0.82µm is obtained at a cutting speed of 120 m/min with a cutting feed of 0.10 mm/rev. The comparison of cutting feeds indicates that the use of a 0.10 mm/rev cutting feed results in a lower roughness value compared to cutting feeds of 0.15 and 0.2 mm/rev. Based on these test results, it can be concluded that the use of a smaller cutting feed produces a smoother surface condition.

Since hardened steel materials are very difficult to cut, improving machinability becomes very important, which is a challenging task due to the following critical issues: excessive tool wear, high heat generation, higher power consumption, large cutting forces, and difficulty in chip transport management, which affects the surface integrity as well as the fatigue life of the machined components [16].

3.3 The Effects of Cutting Feed on Surface Roughness Value

The effects of cutting feed in the turning process on the surface roughness value of the workpiece is presented in Figure 10.

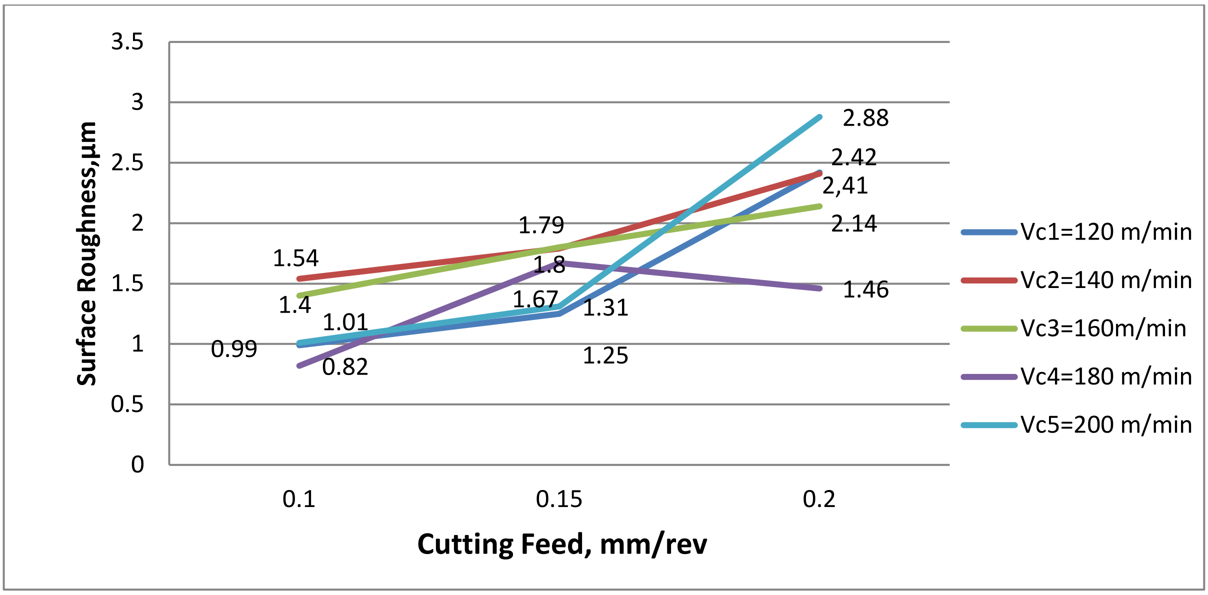


Fig. 10. Graphic of cutting feed towards surface roughness in different cutting speed

Based on the comparison presented in Figure 10, it can be observed that the increased use of cutting feeds affects the increase in the surface roughness value of the workpiece. Even though the cutting speed has increased, the effect of using the cutting feed is more dominant in influencing the increase in the surface roughness value of the workpiece.

Although the cutting speed has increased, the effect of using cutting feed is more dominant in influencing the increase in the surface roughness value of the workpiece. This has an impact on the industry, where in terms of efforts to produce a smaller surface roughness value, increasing the cutting speed can have a significant effect, in addition the process time becomes shorter so that the amount of production achieved can be met in a relatively fast time.

The cutting angle plays an important role in force distribution and chip formation. It must be carefully selected to reduce friction and improve the final result.The geometry of the cutting tool is an important factor affecting the cutting result. The cutting angle affects the force distribution and chip formation, which in turn affects the surface quality. For example, a smaller cutting angle can reduce the stress on the material, but also potentially increase friction and temperature.

The shape of the cutting tool tip and the size of the cut can affect the dimensional accuracy and surface finish. A cutting tool with a sharper and more precise shape can produce a smoother surface quality. The use of cutting tools with special protective coatings (such as TiN or TiAlN) can reduce wear and increase temperature resistance, which contributes to improved surface quality during the cutting process.

4. Conclusions

From the research conducted on the surface roughness analysis of hardened AISI D3 steel, the following conclusions can be drawn the increase in surface roughness at cutting speeds that exceeded the maximum limit is caused by the tool's inability to remove material completely. The cutting feed rate is directly proportional to the surface roughness value. Where the greater the cutting feed rate, the higher the surface roughness value will be. At higher cutting speeds, the temperature in the cutting zone increases, which can reduce cutting force and reduce surface roughness. The lowest surface roughness value was obtained at 0.82 µm at a cutting speed of 180 m/min and a cutting feed rate of 0.1 mm/rev, while the highest surface roughness value was obtained at 2.88 µm at a cutting speed of 200 m/min and a cutting feed rate of 0.2 mm/rev. To achieve the desired surface roughness value, the use of high or low cutting feeds must be balanced with the appropriate cutting speed.

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