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Evaluation of Surface Roughness of ST-60 Steel Material After Turning Process With Variation of Rotation

Bambang Herlambang

Mechanical Engineering, Universitas Pamulang, South Tangerang, 15417, Indonesia

E-mail: dosen00702@unpam.ac.id

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Abstract: It is necessary to select the right material, set the right machine, and determine the optimal machining parameters to obtain the best quality product. In the lathe process, surface roughness is a very important factor and is the main indicator in assessing the quality of the workpiece. Surface roughness can be used to evaluate whether the workpiece meets quality standards or not. The lower the surface roughness value on the workpiece, the better the quality. Conversely, a high surface roughness value can have a negative impact on the performance of the workpiece mating components, because it increases friction on the machine elements that are in contact with each other. This study aims to determine the effect of variations in spindle rotation, feed speed, and feed depth on the level of surface roughness resulting from the lathe machining process. In addition, this study also aims to identify which factors contribute the most to achieving optimal surface roughness in the lathe machining process. The samples to be used is steel ST-60 with a diameter of 22 mm and a length of 120 mm in the form of a solid cylinder. The lathe machine to be used is Conventional Milling Machine equipped with Rotary Table, Dividing Head and Machine Clamp. The samples was turned at cutting depth 0,5 mm with rotation 140, 280, 560, 1.120 Rpm and feeding length 5 cm. The experiment was conducted with three repetitions on each combination of variables to ensure the accuracy of the data obtained. Surface roughness measurements were carried out horizontally on the surface of the workpiece by taking three times the data on each workpiece. The results show that the smoothest surface is achieved at low rotation speed 140 Rpm with Ra value 1.140 µm and the highest value of Ra is 2.690 µm at 560 Rpm. This is due to at low speeds in the turning process helps reduce excess cutting forces, heat, tool wear, and vibration, resulting in smoother surfaces.

Keywords: Surface Roughness, Spindle, Lathe Machine, Steel ST-60.

Abstrak: *Pemilihan material yang tepat, pengaturan mesin yang sesuai, serta penentuan parameter pemesinan yang optimal sangat diperlukan untuk memperoleh kualitas produk yang terbaik. Dalam proses pembubutan, kekasaran permukaan merupakan faktor yang sangat penting dan menjadi indikator utama dalam menilai kualitas benda kerja. Kekasaran permukaan dapat digunakan untuk mengevaluasi apakah benda kerja memenuhi standar kualitas atau tidak. Semakin rendah nilai kekasaran permukaan pada benda kerja, maka semakin baik kualitasnya. Sebaliknya, nilai kekasaran permukaan yang tinggi dapat berdampak negatif terhadap kinerja komponen pasangan benda kerja, karena meningkatkan gesekan pada elemen mesin yang saling bersentuhan. Penelitian ini bertujuan untuk mengetahui pengaruh variasi putaran spindle, kecepatan pemakanan, dan kedalaman pemakanan terhadap tingkat kekasaran permukaan yang dihasilkan dari proses pembubutan. Selain itu, penelitian ini juga bertujuan untuk mengidentifikasi faktor mana yang paling berkontribusi dalam mencapai kekasaran permukaan optimal pada proses pembubutan. Sampel yang digunakan adalah baja ST-60 dengan diameter 22 mm dan panjang 120 mm dalam bentuk silinder pejal. Mesin bubut yang digunakan adalah mesin bubut konvensional yang dilengkapi dengan Rotary Table, Dividing Head, dan Clamp Mesin. Proses pembubutan dilakukan dengan kedalaman pemotongan 0,5 mm pada putaran 140, 280, 560, dan 1.120 Rpm serta panjang pemakanan 5 cm. Pengujian dilakukan sebanyak tiga kali pengulangan pada setiap kombinasi variabel untuk memastikan keakuratan data yang diperoleh. Pengukuran kekasaran permukaan dilakukan secara horizontal pada permukaan benda kerja dengan mengambil data sebanyak tiga kali pada setiap benda kerja. Hasil penelitian menunjukkan bahwa permukaan paling halus diperoleh pada kecepatan putar rendah yaitu 140 Rpm dengan nilai Ra sebesar 1,140 µm, sedangkan nilai Ra tertinggi sebesar 2,690 µm terjadi pada 560 Rpm. Hal ini disebabkan karena pada kecepatan rendah dalam proses pembubutan membantu mengurangi gaya potong berlebih, panas, keausan alat potong, dan getaran, sehingga menghasilkan permukaan yang lebih halus.*

Kata kunci: *Kekasaran Permukaan, Spindle, Mesin Bubut, Baja ST-60.*

INTRODUCTION

Carbon steel is one of the materials often used in the construction industry because it has good mechanical properties, high strength, and a relatively affordable price compared to other metal materials [1]–[5]. Carbon steel itself, based on its chemical composition, is classified into three types, namely low carbon steel, medium carbon steel, and high carbon steel. This classification is based on the carbon content contained in it, which affects its physical and mechanical properties. Low carbon steel contains around 0.05% to 0.25% carbon and has the properties of being easy to form and resistant to corrosion, so it is widely used in the manufacture of light construction and vehicle components. Meanwhile, medium carbon steel contains between 0.25% and 0.60% carbon and has a balance between strength and ductility. ST 60 steel is included in the medium carbon steel category because it has a carbon content of around 0.09% to 0.23%. This type of steel is often used in industrial machine components, such as bolts, shafts, hinges, and other components that require moderate strength but are still easy to form. On the other hand, high carbon steel has a carbon content between 0.60% to 1.70% and is usually used in components that require high strength and wear resistance, such as agricultural equipment, blades, and springs. Carbon steel, especially medium carbon steel such as ST-60, plays an important role in the industrial world because of its versatile nature and ability to withstand mechanical loads without excessive deformation.

One of the ideal geometric characteristics of a component is a smooth surface [6]–[20]. A smooth surface on a component is very important because it can reduce friction, increase wear resistance, and improve performance in mechanical and structural applications. A smooth surface also contributes to improving the aesthetic quality and dimensional precision of the component. However, in practice, obtaining components with a completely smooth surface is almost impossible. This is due to various factors that can affect the final surface results. One of the main factors is the human factor, namely the skills and experience of the operator in carrying out the machining or surface finishing process. Human error, such as errors in machine settings or the use of inappropriate techniques, can cause irregularities on the surface of the component. In addition, factors from the machine used also play an important role. Machines that have experienced wear, damage, or improper calibration can produce surfaces with undesirable roughness. Even on machines with optimal conditions, vibrations during the machining process or variations in cutting speed and feed can produce micro defects on the surface of the component. Therefore, to obtain a surface that is close to smooth, strict process control, routine machine maintenance, and operator skill improvement are required. In addition, the use of advanced technology, such as high-precision machines and modern finishing techniques such as fine grinding or special coatings, can minimize imperfections on the component surface.

A good machining process will produce good workpiece results [6], [7], [13]–[15]. This statement applies when we do work using a lathe, especially a conventional lathe. The lathe machining process includes a series of activities from the beginning of operating the lathe to the end of operating the lathe, starting from the initial process, the machining process, and the final process.

Good turning workpieces are usually seen in terms of shape, size precision, and surface characteristics in the form of roughness of the workpiece surface [13], [14]. The shape aspect in the turning process results to check it is usually adjusted to the working drawing or the desired object image previously. Similarly, the precision of the size of the workpiece resulting from the turning process can be checked using a measuring instrument and adjusted to the size of the working drawing. The precision of the size of the object with a high level of size accuracy is usually given a tolerance limit as a sign of its workmanship.

Surface roughness on the results of the lathe machining process is the result of friction between the cutting tool (chisel) and the rotation of the workpiece on the spindle [8]–[12], [15]–[21]. The greater the friction force generated, the rougher the level of roughness produced in the turning process. Likewise, the smaller the friction force generated between the cutting tool and the workpiece will produce a good level of surface roughness. This is also influenced by the depth of the cutting tool feed (feeding) and the spindle speed / constant vise in rotating the workpiece. This often occurs in the turning process using a conventional lathe. This phenomenon is indeed common during the turning process. It can be seen from the friction force between the machine and the cutting tool that produces burrs.

Burrs from the turning process that have a good level of roughness are usually in the form of a winding cut from the workpiece with a cutting tool that is not broken (forming a thread) [22]. The results of this unbroken cut are what greatly affect the results of the turning process, especially in terms of the roughness of the object. Another phenomenon of the emergence of causes that can cause the value of the level of roughness of the turning process results is usually the characteristics of the roughness of the workpiece. Objects that have good roughness can be seen from the turned object which shows no bumps on the object. The absence of these bumps indicates a flat object. Flat objects usually have a high level of surface roughness.

Bumps on the surface of the object in the turning process are usually factors caused by tool wear [23]. Tool wear is evidence of a blunt (not sharp) chisel condition. This condition is a common phenomenon in the turning process, a blunt chisel tends to have a large friction force with the workpiece when the machining process takes place. This excessive friction force causes the cutting results to be less than optimal in cutting the workpiece, resulting in the workpiece having bumps on its surface.

The tool wear that occurs in the turning process with surface roughness on the workpiece is due to the largest factor being the error in setting the feed motion and the smallest factor being the cutting speed [24]. The feed motion in question is the feed motion speed. The greater the feed speed used in the turning process, the poorer the surface roughness will be and the faster the chisel will become blunt. While the cutting speed in question is the spindle rotation speed of the machine, which has a small effect on producing the roughness of the object and the chisel becomes blunt quickly.

Referring to the explanations in the description of the background of the problem, it was found that the phenomena of surface roughness in the turning process where to find out the parameters of surface roughness on a material requires a perfect explanation to find out the condition of the surface of a material before and after undergoing a machining process. In its testing, a Roughness Tester test tool was used to determine the level of roughness or smoothness of the material surface.

METHODS

Materials and Samples

The materials to be used in this research is ST-60 steel material with a diameter of 22 mm and a length of 120 mm. The need for ST-60 steel material is 3 bars with the shape as shown in fig 2 and the composition as shown in Table 1.

Table 1. Percentage of Chemical Composition of ST-60 Steel Material Ø 22 mm [1]–[5]

No	Elements (symbol)	Percentage (%)
1	Mangan (Mn)	0,33
2	Carbon (C)	0,04
3	Silicon (Si)	0,05
4	Phosfor (P)	0,013
5	Sulphure (S)	0,004

Figure 1. ST-60 Steel Material

Methods

This research was conducted by following the flow chart as shown in Fig 1. The first step is the preparation of the tools and materials used in this study. The sample used is ST-60 steel material with a diameter of 22 mm and a length of 120 mm in the form of a solid cylinder. The number of samples needed is 12 bars for testing with 4 parameters and 3 trials for each parameter.

The lathe used is a Conventional Milling Machine, Chung Shin 5H brand with a Spindle Speed Max 1020 Rpm [25]. The cutting tool used is a Cutter HSS-Co End Mill, SHERPA. High-speed Steel is a high alloy tool steel that is able to maintain its hardness properties at high temperatures [26]. To measure the surface roughness of the workpiece, a Surface Roughness Tester type KR220 is used with a Measurement Range (µm): Ra: 0.005 - 16000 Rz: 0.02 -160.00 [27].

Figure 2. Research flowchart

The turning process is carried out with the following procedures:

1. Install the workpiece in a vice/clamp.
2. Install the milling cutter on the arbor.
3. Adjust the tool feed depth to 0.5 mm and tool feed length (feeding) to 5 cm with a spindle rotational speed (Rpm) of 1120, 560, 280 and 140 Rpm following parameter as shown in Table 2.
4. Turn on the milling machine, including rotating the milling knife.
5. Find the zero point on the material to be tested.
6. Take measurements of the workpiece, first move the workpiece away from the milling knife or turn off the rotation of the milling knife first.
7. Continue the milling process until it matches the size of the workpiece.

Figure 3. Conventional Milling Machine Chung Shin 5H

Table 2. Parameters to be used in research

Cutting depth (mm)	Rotation speed (Rpm)	Feeding Length (cm)
0,5	140	5
0,5	280	5
0,5	560	5
0,5	1.120	5

This research used following equation to calculate cutting speed and feeding speed [28], [29]:

1. Cutting Speed

$$V_c = \frac{\pi \times d \times n}{1000} \quad (1)$$

Where:
d : average diameter (mm)
n : rotation speed (rpm)

2. Feeding Speed

$$F = f \times n \quad (2)$$

Where:
f : feeding length (mm)
n : rotation speed (rpm)

RESULT AND DISCUSSION

First Test Results of ST-60 Steel Material

Dimensions Ø 22 mm x P 120 mm, with a chisel depth of 0.5 mm, a chisel feed length (feeding) of 5 cm and a rotation speed (Rpm) in the turning process of 140 Rpm. The roughness measurement results can be seen on Table 3.

Table 3. Results of First Sample Roughness Measurement

No.	Speed Rotation (RPM) (m/menit)	Speed Feeding (Feed-F) (mm/menit)	Roughness Value (µm)				Results Average (µm)
			Parameter	Test 1	Test 2	Test 3	
1	9.67	7000	R_a	1.011	1.079	1.034	1.143
2			R_z	6.834	7.011	8.447	7.431
3			R_t	9.334	9.152	10.760	9.749
4			R_q	1.288	1.37	1.666	1.441
5			R_{max}	9.334	9.152	10.760	9.749

In addition to the table above, the test tool can also read or attach the roughness curve obtained from the test as shown in Fig. 4 and Fig. 5.

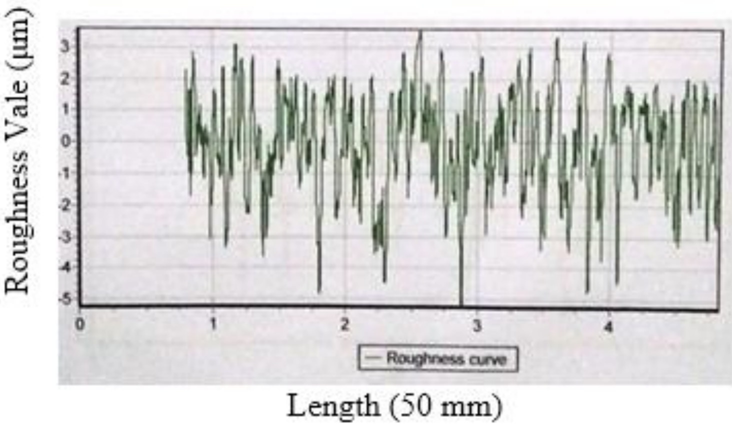

Figure 4. Roughness Curve of First Sample Roughness Reading

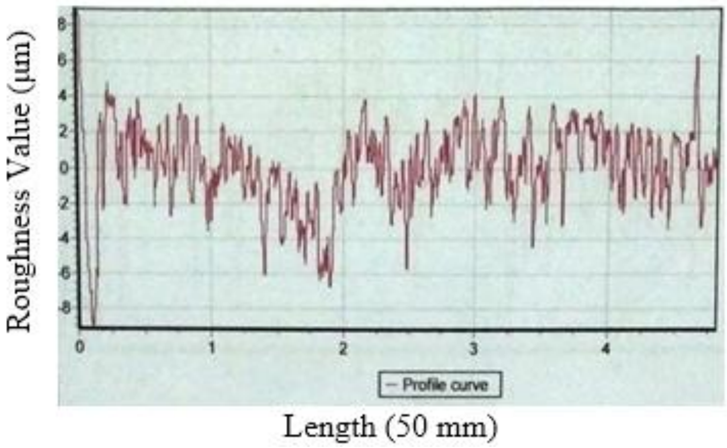

Figure 5. Profile Curve of the First Sample Read by the Test Equipment

Results of the Second Test of ST-60 Steel Material

Dimensions Ø 22 mm x P 120 mm, with a chisel depth of 0.5 mm, a chisel feed length (feeding) of 5 cm and a rotation speed (Rpm) in the following turning process of 280 Rpm. The following results are obtained as shown on Table 4.

Table 4. Results of Second Sample Roughness Measurement

No.	Speed Rotation (RPM) (m/menit)	Speed Feeding (Feed-F) (mm/menit)	Roughness Value (µm)				Results Average (µm)
			Parameter	Test 1	Test 2	Test 3	
1	19.34	14000	R_a	1.242	1.319	1.156	1.239
2			R_z	7.929	7.783	6.881	7.531
3			R_t	10.371	9.645	7.856	9.291
4			R_q	1.544	1.614	1.428	1.529
5			R_{max}	10.371	9.645	7.856	9.291

In addition to the table above, the test can also include a roughness curve obtained from the test as shown in Fig. 6 and Fig. 7.

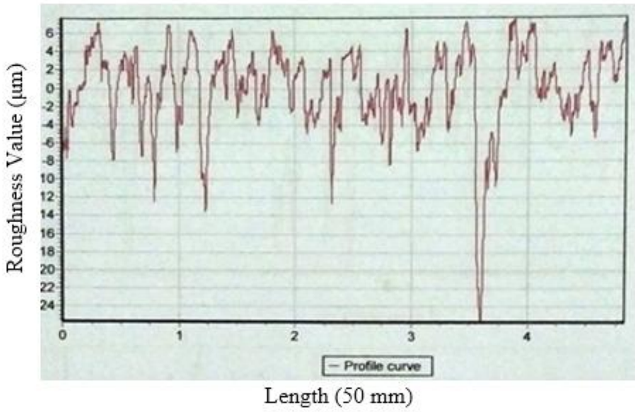

Figure 6. Profile Curve of Roughness Reading of Second Sample

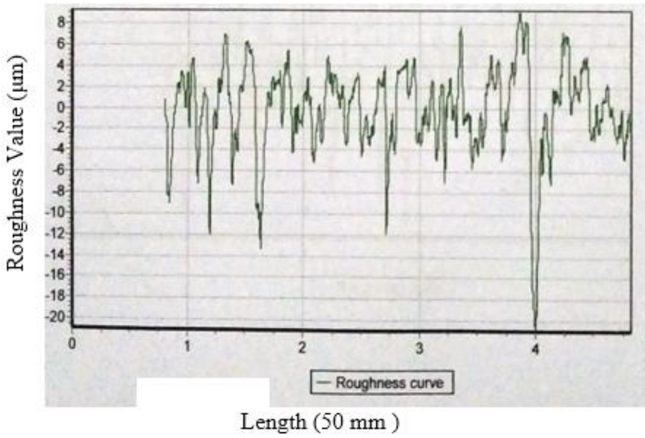

Figure 7. Roughness Curve of the Second Sample Read by the Test Equipment

Results of the Third Test of ST-60 Steel Material

Dimensions Ø 22 mm x P 120 mm , with a chisel depth of 0.5 mm, a chisel feeding length of 5 cm and a rotation speed (Rpm) in the turning process of 560 Rpm, the results of the roughness is shown on Table 5.

Table 5. Results of Third Sample Roughness Measurement

No.	Speed Rotation (RPM) (m/menit)	Speed Feeding (Feed-F) (mm/menit)	Roughness Value (µm)				Results Average (µm)
			Parameter	Test 1	Test 2	Test 3	
1			R_a	3.085	2.585	2.401	2.690
2			R_z	22.458	14.514	14.550	17.174
3	38.68	28000	R_t	30.257	18.279	19.679	22.738
4			R_q	4.099	3.254	3.024	3.459
5			R_{max}	30.257	18.279	19.679	22.738

In addition to the table above, the test can also include a roughness curve obtained from the test as shown in Fig. 8 and Fig. 9.

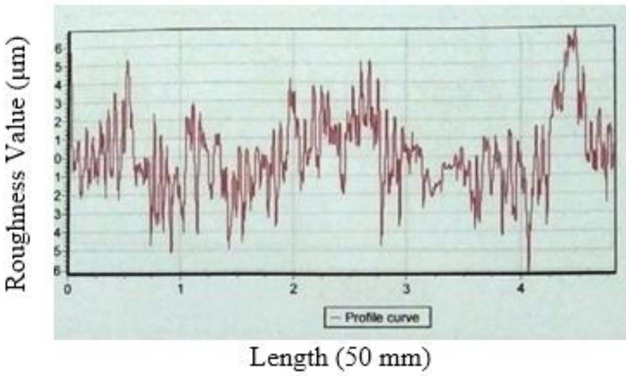

Figure 8. Profile Curve of Roughness Reading of Third Sample

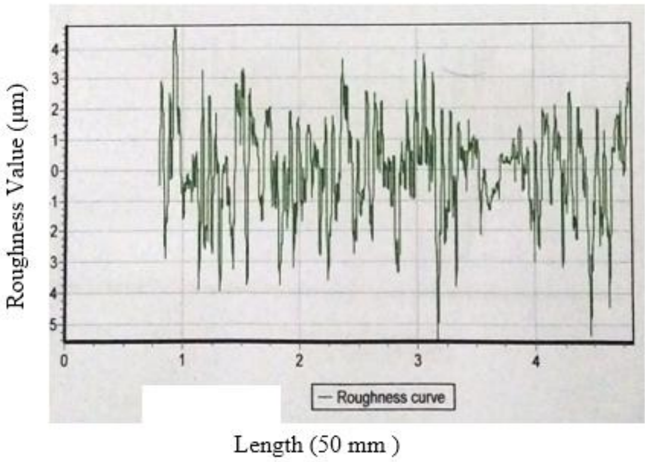

Figure 9. Curve of Roughness of the Third Sample Read by the Test Equipment

Results of the Fourth Test of ST-60 Steel Material

Dimensions Ø 22 mm x P 120 mm, with a chisel depth of 0.5mm, a chisel feed length (feeding) of 5 cm and a rotation speed (Rpm) in the turning process of 1.120 Rpm. The results of the roughness measurement can be seen on Table 6.

Table 6. Results of Roughness Measurement of the Fourth Sample

No.	Speed Rotation (RPM) (m/menit)	Speed Feeding (Feed-F) (mm/menit)	Roughness Value (µm)				Results Average (µm)
			Parameter	Test 1	Test 2	Test 3	
1			R_a	1.321	1.697	1.649	1.556
2			R_z	7.478	10.739	10.905	9.707
3	77.37	56000	R_t	8.855	14.908	15.660	13.141
4			R_q	1.617	2.141	2.126	1.961
5			R_{max}	8.855	14.908	15.660	13..141

In addition to the table above, the test can also include a roughness curve obtained from the test as shown in Fig. 10 and Fig. 11.

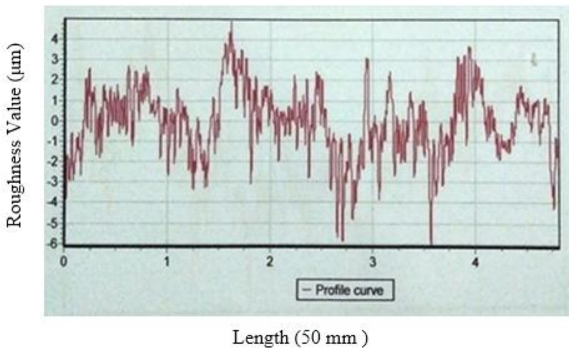

Figure 10. Profile Curve of Roughness Reading of Fourth Sample

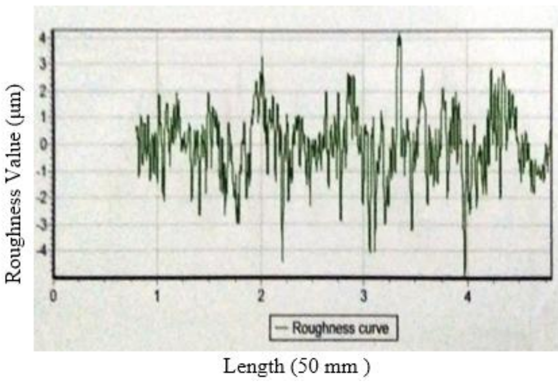

Figure 11. Roughness Curve of the Fourth Sample

Discussion

From the results above, it can be seen that there are different values from each tested Rotation Variation where the material has the following roughness values as shown in Table 7.

Table 7. Results of Roughness Ra, Rz, Rq, Rt, and Rmax From Each Test

No	Roughness Value (µm)				
	Parameter	Rpm 140	Rpm 280	Rpm 560	Rpm 1.120
1	R_a	1.143	1.239	2.690	1.556
2	R_z	7.431	7.531	17.174	9.707
3	R_t	9.749	9.291	22.738	13.141
4	R_q	1.441	1.529	3.459	1.961
5	R_{max}	9.749	9.291	22.738	13.141

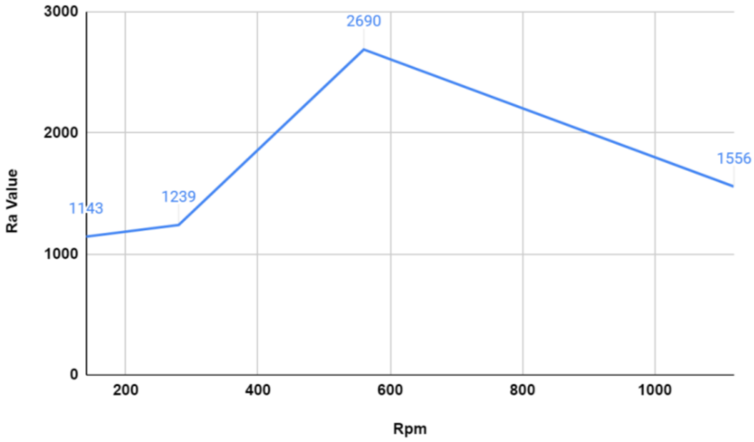

Figure 12. Ra value of each rpm

The results of surface roughness measurements indicate the level and profile of roughness of an object. The level of roughness is usually expressed in units such as Ra (average roughness) or Rz (average peak to valley height) in micrometers (µm). The roughness profile shows the pattern or shape of the peaks and valleys on the surface. Surface roughness measurements provide information about how rough or smooth a surface is. The lower the roughness value, the smoother the surface.

In this analysis, the surface roughness parameter value to be analyzed is the Ra value where the Ra value is widely used to see how rough the machining surface is. The results of measuring the Ra value of the four samples tested are shown in Fig 12. There is a trend of increasing Ra value along with increasing Rpm. This shows that the lowest surface roughness is obtained at a low speed of 140 Rpm, which is 1.143 µm and the highest is achieved at 560 rpm, which is 2.690 µm. This phenomenon shows that there is a relationship between surface roughness and rotational speed, where low rotational speeds produce a smoother surface than high speeds.

Turning at low speeds can produce smoother surfaces due to several factors [28]–[32]. The first, turning at high speeds will produce greater heat due to friction between the tool and the workpiece. Excessive heat can cause material melting or changes in the microstructure of the surface, resulting in a rough surface. Low speeds reduce heat, so that thermal deformation can be minimized. The second, at high speeds, cutting forces tend to be greater, so that the cutting tool can experience vibration or chattering. With low speeds, cutting forces are more stable and vibrations can be minimized so that the surface results are smoother. The third, lathes tend to be more stable at low speeds due to the reduction in dynamic forces. This reduces deflection on the workpiece and tool, so that the final result is flatter and smoother.

CONCLUSIONS

From the calculation results and discussions, it can be concluded that the average surface roughness of each parameter are 1.143 µm, 1.239 µm, 2.690 µm and 1.556 µm at 140 Rpm, 280 Rpm, 560 Rpm and 1.120 Rpm respectively. Of the four samples tested, the sample with the best level of smoothness is the first sample because it has the smallest roughness level of Ra 1.143 µm with a feed depth of 0.5 mm, a feed length of 5 cm and Rpm 140. It can be concluded that at low speeds in the turning process helps reduce excess cutting forces, heat, tool wear, and vibration, resulting in smoother surfaces.

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