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The Effect of Tool Type and Vertical Milling Machine Feeding Depth on ST 42 Steel Surface Roughness

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Abstract

The quality of surface finish is a critical parameter that determines the performance and wear resistance of machined components. This study investigates the effects of cutting tool material (High-Speed Steel [HSS] and Carbide) and depth of cut (0.2–0.5 mm) on the surface roughness of ST 42 steel during vertical milling. An experimental approach was conducted with real-time vibration monitoring using a LUTRON VB-8201HA Vibration Meter, while surface roughness was evaluated using a Mitutoyo SJ-301 based on Ra, Rz, and Rq parameters and correlated with ISO 1302 standards. The results show that Carbide tools consistently produced smoother surfaces than HSS tools, achieving an average Ra of 0.77 µm (N6 finishing grade), whereas HSS produced an average Ra of 2.65 µm (N8 roughing grade). Increasing the depth of cut increased roughness for HSS but improved the Carbide surface finish due to thermal softening effects. Therefore, Carbide tools with deeper cutting depths provide the optimum machining performance for ST 42 steel.

Keywords : *ST 42 Steel, Vertical Milling Machine, Carbide Tool, HSS Tool, Surface Roughness .*

Abstract

Kualitas kekasaran permukaan merupakan parameter penting yang menentukan performa dan ketahanan aus komponen hasil proses pemesinan. Penelitian ini bertujuan menganalisis pengaruh jenis pahat (High-Speed Steel/HSS dan Carbide) serta variasi kedalaman pemotongan (0,2–0,5 mm) terhadap kekasaran permukaan baja ST 42 pada proses frais vertikal. Metode eksperimen dilakukan dengan pemantauan getaran mesin secara real-time menggunakan LUTRON VB-8201HA Vibration Meter, sedangkan pengukuran kekasaran permukaan menggunakan Mitutoyo SJ-301 berdasarkan parameter Ra, Rz, dan Rq yang dikorelasikan dengan standar ISO 1302. Hasil penelitian menunjukkan bahwa pahat Carbide menghasilkan kualitas permukaan yang lebih baik dibandingkan HSS, dengan nilai rata-rata Ra sebesar 0,77 µm (kelas N6), sedangkan HSS menghasilkan Ra sebesar 2,65 µm (kelas N8). Peningkatan kedalaman pemotongan meningkatkan kekasaran pada HSS, tetapi menurunkan kekasaran pada Carbide akibat efek pelunakan termal lokal. Dengan demikian, penggunaan pahat Carbide pada kedalaman pemotongan yang lebih besar merupakan kombinasi optimal untuk menghasilkan permukaan baja ST 42 berkualitas tinggi.

Key words : *ST42 Steel, Vertical Milling Machine, Carbide Chisel, HSS Chisel, Surface Roughness.*

1. Introduction

The increasingly growing manufacturing industry demands a production process capable of producing components with a high level of precision and surface quality. One of the machining processes widely used in the manufacturing industry is the milling process. The milling process is used to shape the surface of a workpiece through a cutting process using a rotating chisel so that it can produce various surface shapes according to the needs of mechanical components [1]. The quality of the machining surface is an important factor because it affects the level of friction, wear, component durability, and product performance when used. In addition, good surface quality can also reduce further finishing processes, thereby increasing production efficiency in the manufacturing industry [2].

The surface quality of machining results is generally expressed in surface roughness values [3]. Surface roughness is one of the parameters used to evaluate the quality of cutting process results [4]. Surface roughness values are influenced by various factors such as cutting speed, feed rate, feed depth, workpiece material, and the type of tool used during the machining process [5]. The smaller the surface roughness value produced, the better the surface quality of the workpiece will be [6]. Therefore, proper cutting parameter settings are very necessary to obtain optimal machining results [7].

Ingestion depth is one of the cutting parameters that has a major influence on the surface quality of the milling process [8]. Increasing the depth of feed will increase the cutting force during the machining process. These conditions can cause vibration and deformation during the cutting process, thereby affecting the surface quality of the workpiece [9]. The greater the depth of ingestion, the clearer the cut marks on the workpiece surface will be, so the surface roughness value tends to increase. Therefore, selecting an appropriate infeed depth is an important factor in obtaining good machined surface quality [10] .

In addition to the depth of cut, the type of tool also affects the surface quality of the milling process. High Speed Steel (HSS) and carbide tools are the types of tools commonly used in the milling process. Carbide tools have better hardness, wear resistance, and thermal stability than HSS tools, thus producing a more stable cutting process. The differences in the characteristics of the two types of tools cause the surface quality of the resulting machining results to also differ. Using the right type of tool can help produce a smoother workpiece surface and increase the efficiency of the machining process [11].

Aluminum is a material that is widely used in the manufacturing industry because it has a light density, good corrosion resistance, and is easy to machining. However, aluminum material has relatively soft properties so that the surface quality of the machining results is greatly influenced by the cutting parameters and type of tool used **[12]**. Several previous studies generally only focused on the influence of cutting parameters on surface roughness values using one roughness parameter such as Ra. Meanwhile, analysis using the parameters Rz and Rq is still relatively limited, especially in the aluminum milling process using a comparison of HSS and carbide tools. Therefore, this research was conducted to analyze the effect of variations in feed depth on surface roughness values based on the parameters Ra, Rz, and Rq using HSS and carbide chisels in the aluminum milling process.

Previous research on the analysis of tool types and depth of cut in the vertical milling process was carried out using aluminum and ST 37 steel materials with variations of HSS Sutton, HSS JCK, and HSS Japan tool types and variations of depth of cut of 0.2 mm, 0.4 mm, and 0.6 mm. The testing process was carried out using a vertical milling machine and surface roughness measurements using a Mitutoyo SJ-301 surface roughness tester. The results of the study showed that the type of tool and depth of cut affected the surface roughness value of the workpiece. In aluminum material, the lowest surface roughness value was obtained when using a HSS Japan tool with a depth of cut of 0.2 mm, which was 0.557 μm. Meanwhile, in ST 37 steel material, the lowest surface roughness value was obtained at 0.653 μm when using the same tool. The results of this study indicate that tools with a higher level of hardness are able to produce better surface quality because the cutting process is more stable and friction between the tool and the workpiece is smaller.

Previous research also shows that increasing the depth of cut causes the surface roughness value of the workpiece to tend to increase. In the study, it was explained that the greater the depth of cut, the greater the cutting force and cutting load received by the tool, causing vibration and increasing friction during the machining process. This condition causes the surface of the workpiece to become rougher due to the less stable cutting process. In addition, increasing the depth of cut also causes the tool temperature to increase, thus accelerating tool wear. Based on previous research, this study was conducted to analyze the effect of variations in the depth of cut on the surface roughness value based on the parameters Ra, Rz, and Rq using HSS and carbide tools in the aluminum milling process so that a more comprehensive surface quality analysis is obtained **[13]**.

2. Method

The experimental procedure begins with a vertical milling machining process integrated with machine vibration testing. The first step is carried out by setting the automatic longitudinal slide system on the X-axis to move the milling machine table in the opposite direction to the spindle rotation using the *up milling method* . After the table setting is complete, the milling machine is activated via the main power button. When the milling tool begins to touch the workpiece surface to carry out the feed process, the *Record button* on the LUTRON VB-8201HA *Vibration Meter device* is pressed to start recording mechanical vibration data generated by the machining activity.

During the machining process, vibration visualization was continuously observed along with the periodic administration of coolant to maintain the stability of the cutting tool temperature. These machining and monitoring operations were carried out collaboratively by two operators, where one operator focused on controlling the milling machine, while the other operator was tasked with observing fluctuations in vibration measurements displayed on the Vibration Meter screen . *After* the milling process was completed, the milling machine was turned off. Vibration data collection was carried out by pressing the *Recall button* to identify and record the minimum and maximum values of the recorded measurement results. All stages of machining and data collection were repeated for the next specimen by varying the spindle rotation speed parameters.

Evaluation of the quality of the machining results is continued with testing the surface roughness of the specimen using the Mitutoyo SJ-301 *Surface Roughness Tester . The working characteristics of this tool rely on a sensor in the form of a needle (stylus*) which is placed and aligned precisely with the surface plane of the material being tested. During the data scanning process, the measuring device must be conditioned in a static state and free from shifts so as not to interfere with the accuracy of the sensor in reading the surface roughness level. The roughness testing procedure is carried out by locking the milled workpiece in a vise or support stand. The position of the specimen is arranged horizontally in the direction of the movement of the sensor needle. To ensure the validity of the data, each specimen is tested four times at different sampling points consistently.

3. Results and Discussion

3.1. Analysis of the Influence of Machining Parameters on Average Roughness (Ra)

The following roughness level values Ra for each depth variation and type of chisel used can be seen in table 4.1 below.

Table 1. Data on Ra Values for Varying Depth of Digging and Type of Tool

No.	*a* (mm)	Type Chisel	Roughness Level (μm)				Average
			Specimen				
			A	B	C	D	
1	0.2	HSS	2.35	2.54	2.57	2.71	2.54
		CARBIDE	0.69	0.83	0.92	0.93	0.84
2	0.3	HSS	2.57	2.59	2.64	2.75	2.63
		CARBIDE	0.63	0.79	0.80	0.92	0.78
3	0.4	HSS	2.49	2.68	2.69	2.80	2.66
		CARBIDE	0.66	0.73	0.73	0.82	0.73
4	0.5	HSS	2.41	2.84	2.88	2.97	2.77
		CARBIDE	0.56	0.74	0.74	0.88	0.73

Based on the table data above, it shows the average roughness characteristics (Ra) of ST 42 steel material after the vertical milling process using various types of chisels and feed depths. The graphic results based on the average values are shown in the following figure.

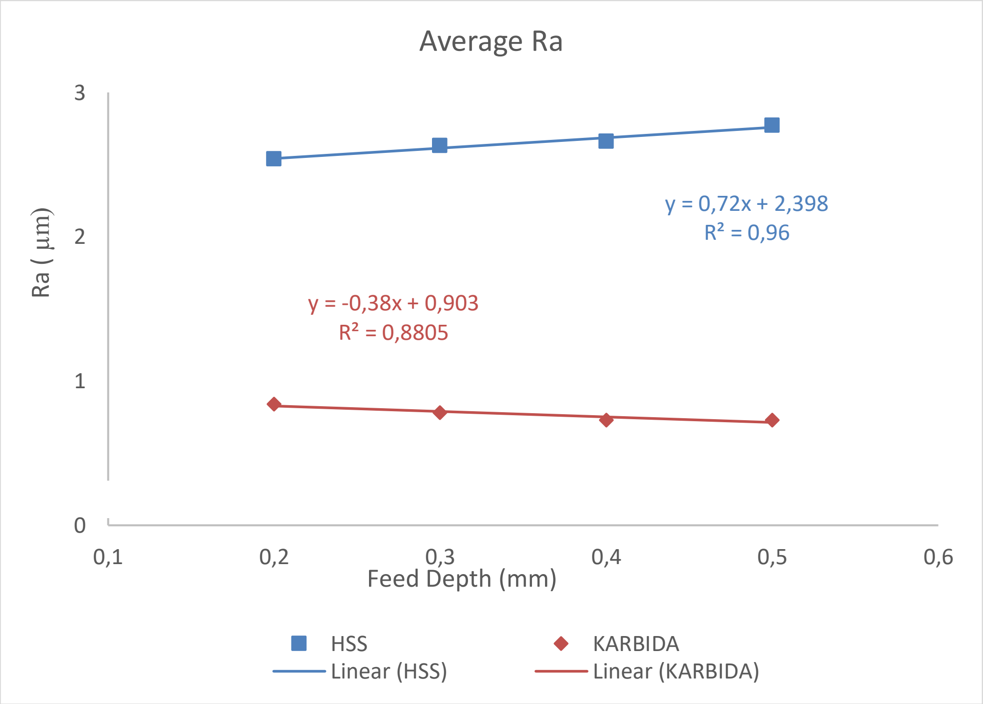

Figure 1. Effect of Burial Depth on the Ra Value

Based on the data shown in the image above, there is a contrasting difference in the trend of Ra values between the use of HSS tools and Carbide tools. In HSS tools, increasing the depth of cut from 0.2 mm to 0.5 mm triggers a linear increase in the Ra roughness value from the range of 2.55 µm to reach the highest value of 2.78 µm. This increasing trend is represented by the regression equation $y = 0.72x + 2.398$ with a high level of model accuracy of $R^2 = 0.96$. This increase in the Ra value occurs due to the increase in the depth of cut which enlarges the chip cross-section, so that the cutting load on the HSS tool increases and triggers micro-deflection.

On the other hand, when using Carbide tools, increasing the depth of cut actually has the opposite effect, where the Ra value experiences a linear decrease from 0.84 µm to 0.71 µm. This decreasing trend is represented by the regression equation $y = -0.38x + 0.902$ with $R^2 = 0.8805$. This proves that Carbide tools have better thermal and mechanical stability; increasing the depth of cut triggers an increase in temperature in the cutting area which softens the workpiece material locally, making it easier for Carbide tools to produce smoother and cleaner cuts in ST 42 steel.

3.2. Analysis of the Effect of Machining Parameters on Ten-Point Roughness (Rz)

The following table data from the results of measuring the Rz roughness level can be seen in the following table.

Table 2. Data on Rz values for varying Depth of Feed and Type of Tool

No.	*a* (mm)	Type Chisel	Roughness Level (µm) Specimen A	B	C	D	Average
1	0.2	HSS	15.32	14.70	19.34	18.34	16.92
		CARBIDE	3.45	5.07	6.41	6.48	5.35
2	0.3	HSS	15.07	15.46	15.04	14.72	15.07
		CARBIDE	4.27	4.60	3.56	4.25	7.27
3	0.4	HSS	15.28	14.65	14.82	14.81	14.89
		CARBIDE	4.59	3.75	4.57	4.28	4.29
4	0.5	HSS	14.49	17.05	17.68	13.69	15.72
		CARBIDE	4.16	5.17	3.95	0.93	3.55

From the table data above, the characteristics of the average ten-point roughness height (Rz) which represents the distance between the highest peak and the lowest valley of the surface profile are shown in the following graphic image.

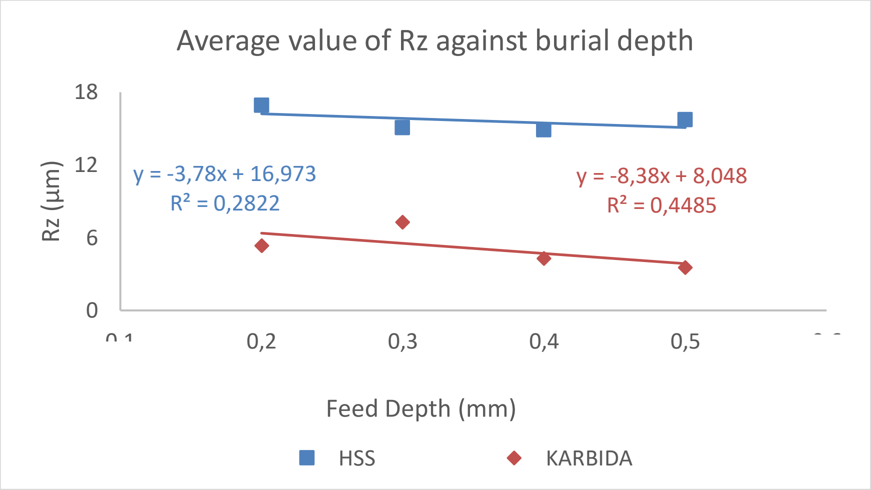

Figure 2. Effect of Burial Depth on the Rz value

Based on the data shown in the image above, the use of HSS tools produces fluctuating Rz values but has a tendency to decrease as the depth of cut increases. The highest Rz value was recorded at 0.2 mm of 16.92 µm and decreased to 15.82 µm at 0.5 mm of cut, with a regression model of y = -3.78x + 16.573 (R2 = 0.2822). The very high Rz value on this HSS tool indicates the presence of extreme surface profile irregularities, which are generally triggered by the *Built-Up Edge* (BUE) phenomenon. The attachment of residual material to the tip of the HSS tool damages the cutting geometry and scratches the workpiece surface randomly, creating deep micro valleys and peaks.

Meanwhile, testing using Carbide chisel consistently produces a much lower Rz value and decreases linearly from 5.28 µm at a depth of 0.2 mm to reach a lowest point of 3.54 µm at a depth of 0.5 mm. This pattern is reinforced by the regression equation y = -8.38x + 8.048 with a coefficient of determination value of R^2 = 0.6485. This low Rz roughness level indicates that the Carbide chisel is able to maintain the sharpness of its cutting edge without deformation, thus minimizing the formation of extreme peaks and valleys on the surface topography of ST 42 steel.

3.3 Analysis of the Influence of Machining Parameters on Mean Square Roughness (Rq)

The data from the Rq roughness level measurements can be seen in the following table.

Table 3. Rq Value Data for Variations in Feed Depth and Tool Type

No.	***a*** (mm)	Type Chisel	Roughness Level (μm)				Average
			Specimen				
			A	B	C	D	
1	0.2	HSS	3.11	3.53	4.03	3.89	3.63
		CARBIDE	0.84	1.02	1.21	1.22	1.07
2	0.3	HSS	3.29	3.28	3.03	3.59	3.29
		CARBIDE	0.99	1.13	0.79	0.98	0.97
3	0.4	HSS	3.33	3.35	3.33	3.40	3.35
		CARBIDE	1.01	0.80	0.92	0.91	0.91
4	0.5	HSS	3.33	3.49	3.62	3.08	3.38
		CARBIDE	0.91	1.15	0.73	0.93	0.93

Evaluation of the mean square roughness (Rq) value, which provides the statistical deviation of the material surface profile is presented in the graphic image below.

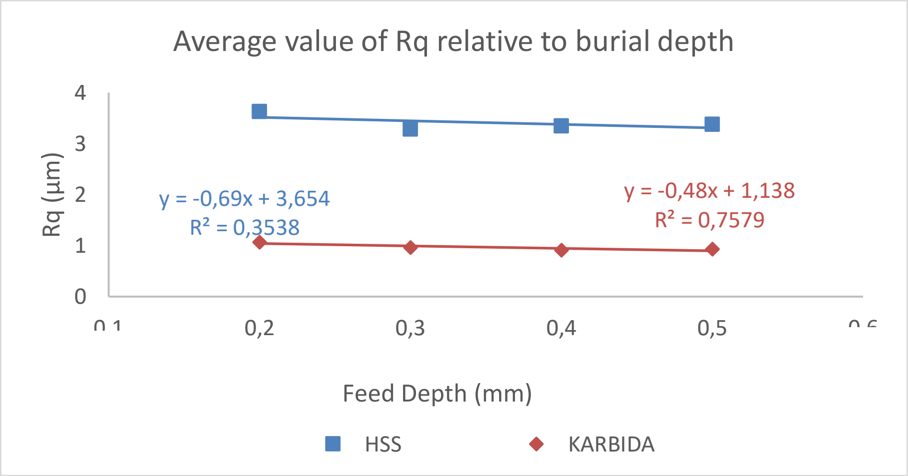

Figure 3. Effect of burial depth on the Rq value

Based on the graphic data in the image above, the trend of the Rq roughness parameter shows a deviation pattern that is in line with the previous roughness parameters. In the HSS tool curve, the Rq value experienced a minor decrease from 3.64 μm at a feed depth of 0.2 mm to 3.38 μm at a feed depth of 0.5 mm. This relationship is defined by the linear equation $y = -0.69x + 3.654$ with a correlation level of $R^2 = 0.3938$. Although the Rq value decreased slightly, the roughness figure is still categorized as high, which reflects variations in the distribution of non-uniform surface profiles due to mechanical vibrations (*chatter*) during machining with the HSS tool.

On the other hand, the Carbide tool test curve produces a very stable Rq value and is at a very low level, which ranges from 1.06 μm to 0.93 μm. The regression function equation for the

Carbide tool is y = -0.45x + 1.138 with a strong coefficient of determination of $R^2 = 0.7579$. The consistent Rq value around 1.0 μm proves statistically that the deviation of the specimen surface is very minimal. The use of Carbide tools on a vertical milling machine is proven to be able to guarantee the homogeneity and regularity of the surface microstructure of ST 42 steel across all variations in the tested feed depths.

3.4 Comparative Analysis of Surface Roughness Values Based on Tool Type

To comprehensively evaluate the overall performance of both types of cutting tools, we compiled the average values of the surface roughness parameters Ra, Rz, and Rq based on each tool type used. The results of this comprehensive comparison are presented in the table and graph below.

Table 4. Average Surface Roughness Values Based on Tool Type

Roughness parameters	Types of Chisels	Overall average value of depth of ingestion (μm)
Ra	HSS	2.65
	Carbide	0.77
Rz	Hss	15.56
	Carbide	5.12
Rq	HSS	3.41
	Carbide	0.97

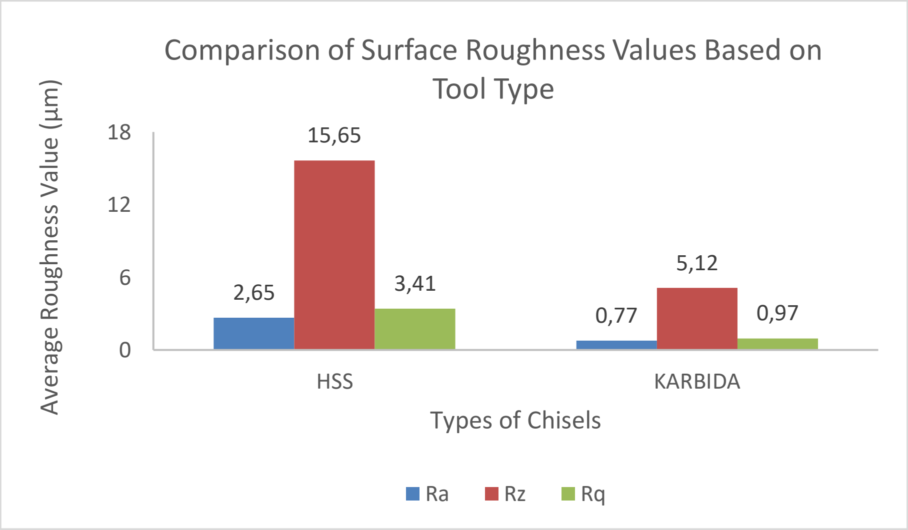

Figure 4. Comparison of Roughness Values Between Tools

Based on the accumulated data in the image above, the Carbide chisel shows a far superior performance dominance in producing smooth surface quality of ST 42 steel specimens compared to the HSS chisel. In the average roughness parameter (Ra), the use of the Carbide chisel is able to suppress the roughness level to reach an average value of 0.77 μm, while the HSS chisel produces a much higher roughness value of 2.65 μm. This indicates that the characteristics of the Carbide material which has a high level of mechanical hardness are able to cut the material more stably, minimize excessive friction, and prevent plastic deformation at the tip of the chisel during the vertical milling process.

The contrasting differences in machining quality were also identified in the ten-point average roughness (Rz) and mean square deviation (Rq) parameters. The HSS tool produced a very high average Rz value, reaching 15.65 μm, with an Rq value of 3.41 μm. The high value of this macro parameter is caused by the susceptibility of the HSS tool to high temperatures which trigger rapid wear and the formation of *Built-Up Edge* (BUE), thus leaving micro traces in the form of extreme peaks and valleys on the workpiece surface. In contrast, the Carbide tool was significantly able to reduce the Rz value to 5.12 μm and maintain the stability of the Rq deviation value at 0.97 μm. The stability of these statistical values proves that the Carbide tool provides homogeneous cutting results and excellent surface microstructural regularity on ST 42 steel material.

3.4 Surface quality standardization based on ISO 1302 Roughness Class

To provide practical validation of the test results in the manufacturing industry, the average roughness (Ra) values obtained were correlated with the surface quality grade standards based on ISO 1302. This standard classifies roughness grades into 12 classes, ranging from N1 (the smoothest) to N12 (the roughest).

Based on this classification, the use of HSS chisels that produce an average Ra value of 2.65 μm falls into the **N8 Roughness Class category** . In the industrial world, N8 surface quality is generally produced from roughing or planing processes , where cutting traces are still clearly visible visually and felt by physical touch. This N8 surface characteristic limits the functionality of ST 42 steel components, so it can only be applied to structural parts that do not receive high dynamic loads or do not require precision contact between components.

In contrast, testing using a Carbide chisel successfully suppressed the average Ra value to 0.77 μm, which officially categorizes the specimen's surface quality into **Roughness Class N6** . The N6 roughness level is a quality standard generally achieved through high-level fine machining (*finishing*) processes. Functionally, ST 42 steel components with N6 surface quality are ideal for application in moving machine components, such as gears, rotating shafts , and sliding bearings. This smooth surface is mechanically able to minimize the coefficient of friction, reduce the rate of wear, and extend the fatigue life *of* the component due to a more even distribution of micro-stresses.

4. Conclusion

The conclusion section summarizes the research results or findings, which correlate with the research objectives outlined in the introduction. Then, state the main points of the discussion. A conclusion typically concludes with a statement about how the research contributes to the field of study as a whole (showing how it advances current knowledge). Common mistakes in this section include repeating experimental results, abstracting the results, or presenting them in a list-like manner. The conclusion should provide clear scientific evidence. It can also provide suggestions for future experiments.

5. *Acknowledgement*

Based on the test results and analysis of vertical milling data on ST 42 steel, it can be concluded that the characteristics of the tool material have a very dominant influence on the quality of the surface topography compared to variations in the depth of cut. Carbide tools consistently show much superior performance with an average roughness value (Ra) of 0.77 µm, which officially categorizes the surface quality of the specimen into the class standard. **N6** roughness for fine *finishing process qualification* . Other macro parameter values are also maintained very low, namely ten-point roughness (Rz) of 5.12 µm and statistical deviation (Rq) of 0.97 µm. On the other hand, the use of HSS tools produces less than optimal surface quality due to the high tendency of cutting edge wear, resulting in a spike in the average roughness value with a Ra value of 2.65 µm which falls into the **N8 roughness class category (** *rough* machining standard), with an Rz value of 15.65 µm and an Rq of 3.41 µm.

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