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The Effect of Variations in Cutting Tool Material Type and Spindle Rotation Speed (RPM) on Surface Roughness Level of Turned Work

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Abstract

The machining process, especially on a lathe, is greatly influenced by various factors that determine the final surface quality of the workpiece. One of the main factors that influences this quality is the type of cutting tool material and the spindle rotation speed (RPM). This study aims to analyze the effect of variations in the type of cutting tool material and spindle rotation speed on the surface roughness level of the turning results on low-carbon steel materials. The experimental method used is the Taguchi experimental design with an orthogonal approach. L9 array to identify factors that affect the surface quality of machining results efficiently. The independent variables tested were spindle rotation speed at three levels (260, 290, and 450 RPM) and the type of cutting tool material, consisting of three types, namely HSS, Carbide, and Diamond. The results showed that the type of cutting tool material had a more significant effect on surface roughness than the spindle rotation speed. Carbide cutting tools produced the lowest surface roughness, followed by HSS and Diamond. The optimal combination to minimize surface roughness was the use of Carbide cutting tools at a spindle rotation speed of 450 RPM, which produced a surface roughness of about 5.612 µm. Although the linear regression analysis did not show high statistical significance, the model remained diagnostically valid based on the residual test. This study provides an important contribution to the selection of optimal machining parameters to improve the surface quality of turning results in the manufacturing industry.

1.Introduction

In the manufacturing world, the turning process on a lathe or CNC lathe is a fundamental element in producing components with high dimensional precision and surface quality. One indicator of the quality of a lathe's surface is surface roughness. roughness), which affects the functional performance, aesthetics, and service life of components. Therefore, it is important to understand the factors that influence surface roughness [1]. Among the many machining parameters, two variables are often considered critical in determining the surface finish of turning products, namely the cutting tool material and the spindle rotation speed. The cutting tool material influences hardness, wear resistance, cutting stability, and the interaction between the tool and the workpiece. At the same time, spindle rotation speed determines cutting conditions such as cutting force, heat generation, and process stability, all of which contribute to the final surface roughness of the machined part.

Several recent studies support the importance of these variables. The machining process using a lathe to produce components with good surface quality is greatly influenced by several factors, including the type of cutting tool material and spindle rotation speed. Surface roughness is an important parameter in determining the quality of machining results, which in turn affects the performance and durability of the final product [2]. In turning operations, surface roughness is influenced by the interaction between the cutting tool, the workpiece material, and the machining conditions applied during the process.

Previous studies have also shown that cutting tool material has a major effect on surface roughness. Ginting et al. reported that, in turning AISI 4140 steel, carbide tools produced lower surface roughness than HSS tools under similar cutting conditions [3]. This result indicates that carbide tools tend to provide better surface finish because of their higher wear resistance and more stable cutting performance. In contrast, Prasad et al. 2024 also showed that tool wear in high-speed machining turning) can cause increased surface roughness, due to the influence of greater friction during the cutting process [4]. These findings highlight that the selection of cutting tool material is closely related to the ability to maintain surface quality during machining.

In addition to tool material, tool geometry also contributes to the resulting surface finish. Gimastian et al. [5] emphasized the role of tool nose radius in reducing the surface roughness of turned AISI 4140 steel. Their study showed that an appropriate tool tip radius can improve surface quality when combined with proper cutting conditions. This means that surface roughness is not controlled by a single factor, but by the combined effect of tool characteristics and machining parameters.

Spindle rotation speed is another important factor in determining the surface quality of turning results. According to a study by Sumawijaya et al. [6] found that coated carbide tools operated at high rotational speed produced lower surface roughness because they were more resistant to heat and wear under demanding machining conditions. Likewise, Lai et al. [7] reported that higher spindle speed can improve surface finish by reducing contact time between the tool and the workpiece and by supporting a more effective cutting process. However, the influence of spindle speed cannot be separated from the type of cutting tool used. Research by Ginting et al. [3] also showed that increasing spindle speed can reduce surface roughness when carbide tools are used, while the same increase may not provide similar benefits when HSS tools are applied.

Based on these studies, the current state of the art shows that surface roughness in turning is strongly influenced by the interaction between cutting tool material, spindle speed, tool wear, and tool geometry. Previous research has consistently shown the advantages of carbide tools in producing smoother surfaces and has highlighted the importance of selecting suitable cutting conditions to improve machining quality [3], [4], [5], [6], [7]. However, studies that specifically compare three cutting tool materials, namely HSS, Carbide, and Diamond, under several spindle rotation speed levels in the turning of low-carbon steel using a Taguchi L9 design are still limited.

Therefore, the novelty of this study lies in the integrated evaluation of the effect of three cutting tool materials and three spindle rotation speeds on the surface roughness of low-carbon steel in a turning process. By applying the Taguchi experimental design, this study aims to determine the optimum combination of cutting tool material and spindle rotation speed for minimizing surface roughness. The findings of this research are expected to provide a clearer contribution to the selection of machining parameters for improving the surface quality of turned low-carbon steel components.

2.Research Methodology

2. 1. Method

This research begins with Stage 1: Process Selection and Preparation. The first step is selecting suitable cutting tool materials—HSS, Carbide, and Diamond. Next, several input parameters are determined. The spindle rotation speed is tested at 260, 290, and 450 rpm. The cutting rate and depth are kept constant at 25 m/min and 1 mm. The work material is low-carbon steel with set dimensions for each experiment.

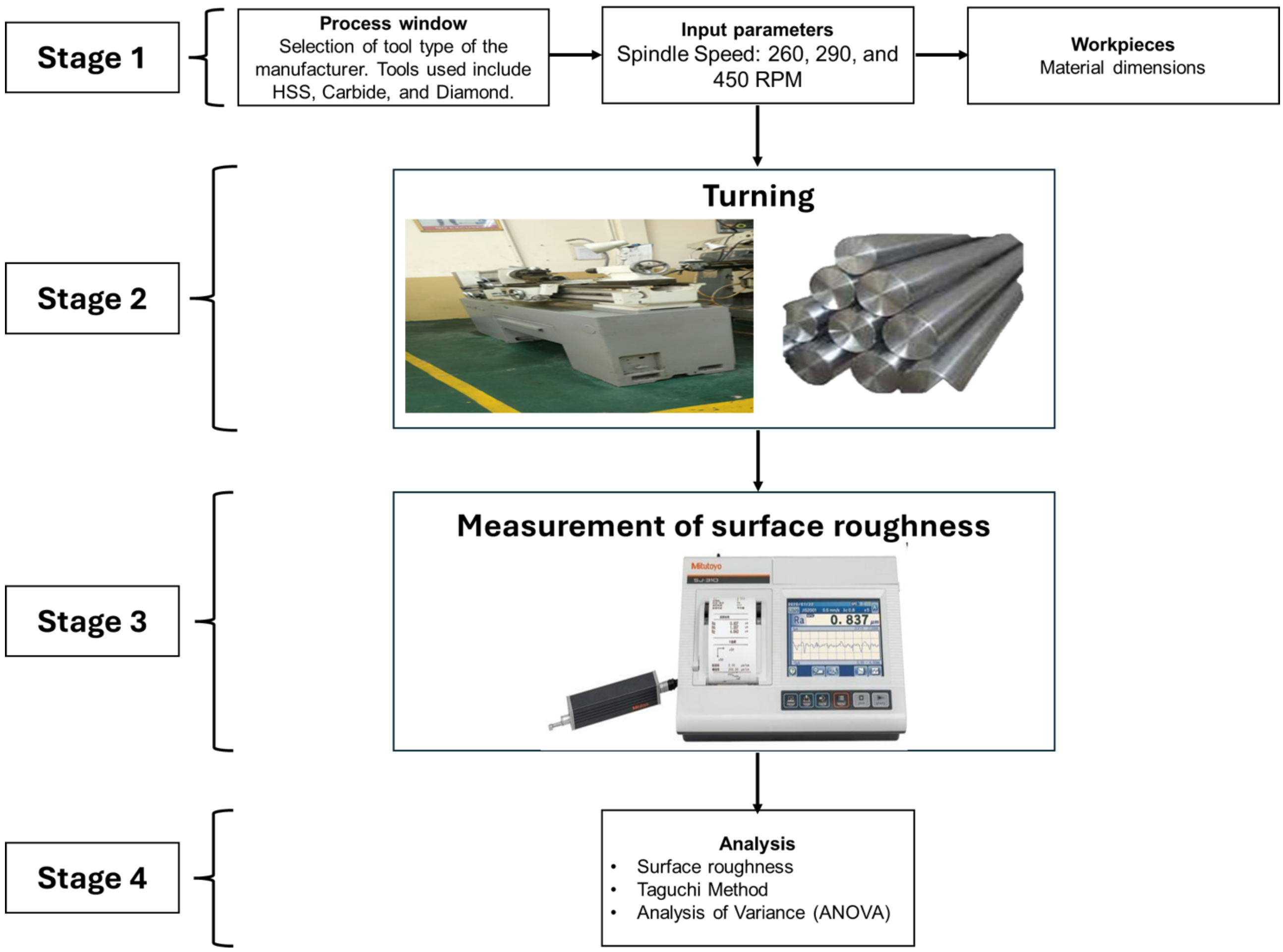

FIGURE 1. Flowchart research

After the preparation phase, the research continued with the machining process (turning) in Stage 2, using a lathe. In this stage, low-carbon steel material was cut using a selected cutting tool, according to the specified rotational speed level. Cutting was carried out by paying attention to the parameters of spindle rotational speed and the type of tool material, which will affect the machining results.

In Stage 3, measurements are taken for two important parameters: tool wear and surface roughness. Tool wear is measured using a microscope to determine the extent of tool material damage after a certain amount of cutting time. Meanwhile, the surface roughness of the turning result is measured using a Surface Roughness Tester Mitutoyo SJ-310, where measurements are taken at three points along the surface of the workpiece to ensure representative results.

After the measurements are carried out, the final stage is data analysis (Stage 4), where the data obtained from the tool wear and surface roughness measurements are analyzed using Analysis of Variance (ANOVA) to determine the significant influence of the tested factors, namely the type of cutting tool material and spindle rotation speed, on surface roughness (Ra). If a significant difference is found, further analysis is carried out using the Taguchi Test to determine the combination of factors and levels that produce the lowest surface roughness.

By following this flow, the research aims to identify the optimal combination of machining parameters in producing smooth surfaces in machining with low-carbon steel materials, as well as providing a deeper understanding of the influence of tool material type and spindle rotation speed on surface quality.

2. 2. Table Parameters

TABLE 1. The parameters used in the research design

Factors	Research Parameters	Value	Units
A	Spindle rotation	260; 290; 450	mm/min
B	Cutting tools	x	-

3.Results and Discussion

In this section, the results of the research are presented based on the data obtained from the conducted experiments. The data shown in Table 2 illustrates the surface roughness (Ra) levels produced by varying spindle speeds and cutting tool materials used in the study. These results highlight a significant relationship between both factors and the quality of the surface finish. The subsequent analysis of this data will provide insights into the impact of each factor and their interaction on the surface roughness of low-carbon steel material tested in the experiment.

TABLE 2. Roughness level of turned work with Spindle Rotation and Cuttingl Tool Type

Speed Spindle Rotation	Cutting Materials		
(rpm)	HSS	Carbide	Diamond
260	5.273	6.241	8.198
260	9.501	6.482	10.868
260	9.906	7.477	9.247
Average	8.227	6.733	9.438
290	8.882	7.390	10.614
290	11.467	7.145	8.221
290	8.950	4.414	9.745
Average	9.766	6.317	9.527
450	8.399	4.968	10.910
450	5.992	6.385	11.284
450	4.709	5.482	9.935
Average	6.367	5.612	10.170

Table 2 presents the surface roughness level (Ra) of turning results with variations in spindle rotation speed and cutting tool material types at three different experimental levels. Based on the data, it can be seen that Carbide cutting tools produce the lowest surface roughness at each spindle rotation speed level, followed by HSS and Diamond. In general, increasing spindle rotation speed contributes to a decrease in surface roughness, although the effect is smaller compared to the type of cutting tool used.

At a speed of 260 RPM, the Carbide chisel produced an average surface roughness value of 6.733 µm, lower than that of HSS (8.227 µm) and Diamond (9.438 µm). This indicates that at lower rotational speeds, the Carbide chisel is more efficient in producing smoother surfaces. In line with the findings of Ginting et al., who showed that carbide tools produce smoother surfaces due to their better wear resistance compared to HSS.

At a speed of 290 RPM, the Carbide tool still showed the lowest surface roughness (6.317 µm), while HSS and Diamond produced higher roughness. This finding supports the research of Lai et al. [7], who also found that carbide tools were more effective in reducing surface roughness at high cutting speeds.

At a speed of 450 RPM, the Carbide chisel still produces a lower surface roughness (5.612 µm) compared to HSS (6.367 µm) and Diamond (10.170 µm). This decrease in surface roughness is in line with research by Lai et al. [6] and Kang et al. [8] who revealed that coated carbide chisels in fast machining tend to produce better surface quality.

TABLE 3. Orthogonal array L9 (factor, level and response)

Run	A	B	Response Ra (µm)
1	1	1	8.227
2	1	2	6.733
3	1	3	9.438
4	2	1	9.766
5	2	2	6.317
6	2	3	9.527
7	3	1	6.367
8	3	2	5.612
9	3	3	10.17

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Carbide chisels are more effective in producing smooth surfaces at various spindle rotation speeds. This is in line with the findings in Ginting et al. [3], which shows that carbide tools can reduce surface roughness better than HSS and Diamond, especially under fast machining conditions. However, the spindle rotation speed has an effect on reducing surface roughness; the effect is smaller compared to the type of cutting tool. This finding is relevant to previous research, which shows that increasing spindle rotation speed can improve machining quality only when combined with the right tool, such as a Carbide tool at high speed.

This analysis aims to evaluate the combination of factors and levels that produce the lowest surface roughness (Ra) value, according to the optimization principles in the Taguchi method.

1. Taguchi Design Analysis

TABLE 4. Response for Signal to Noise Ratios (Smaller is better)

Level	A	B
1	-18.12	-18.06
2	-18.46	-15.85
3	-17.07	-19.74
Delta	1.39	3.89
Rank	2	1

TABLE 5. Response for Means

Level	A	B
1	8.133	8.120
2	8.537	6.221
3	7.383	9.712
Delta	1.154	3.491
Rank	2	1

Based on the results of the Taguchi Test and Signal-to-Noise Analysis Ratio (SNR), the cutting tool material type factor (B) has a greater influence on surface roughness compared to the spindle rotation speed factor (A). The SNR analysis presented in Table 3 shows that cutting Tool (B) has the largest contribution to the variation in surface roughness with a delta value of 3.89, while the spindle rotation speed (A) has a smaller delta of 1.39. This shows that the selection of the cutting tool type is more dominant in reducing surface roughness compared to the spindle speed setting.

These results are consistent with the findings in Sukkam et al. [9] , who stated that carbide tools are more effective at high speeds in producing smooth surfaces compared to HSS. Their research revealed that carbide tools provide better surfaces in machining AISI 4340 steels at high speeds.

FIGURE 2. Plot of Main Effects for means

Figure 2. shows the Main Effects Plot for the average surface roughness (Ra) values at each level of factors A and B. From this graph, it can be seen that the type of cutting tool (B) has a greater impact on surface roughness compared to the spindle rotation speed (A). In factor B, level 2 (Carbide) produces the lowest Ra value, while in factor A, level 3 (450 RPM) provides the lowest surface roughness, although the difference is smaller. This indicates that Carbide is more sensitive to variations in spindle rotation speed compared to other tools.

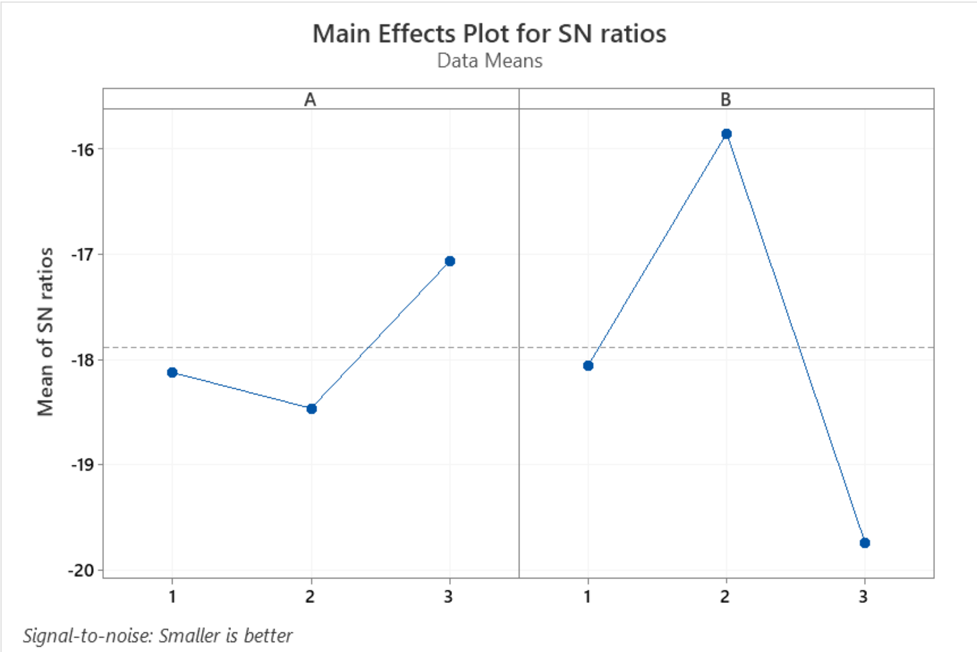

FIGURE 3. Plot of Main effects for SN ratios

Figure 3, which shows the Main Effects Plot for SN Ratios, also shows a similar pattern, where factor B (cutting tool) has the greatest influence on surface roughness. Level 2 (Carbide) provides the highest SN ratio, meaning the lowest surface roughness, while level 3 (Diamond) produces the lowest SN ratio, indicating higher roughness.

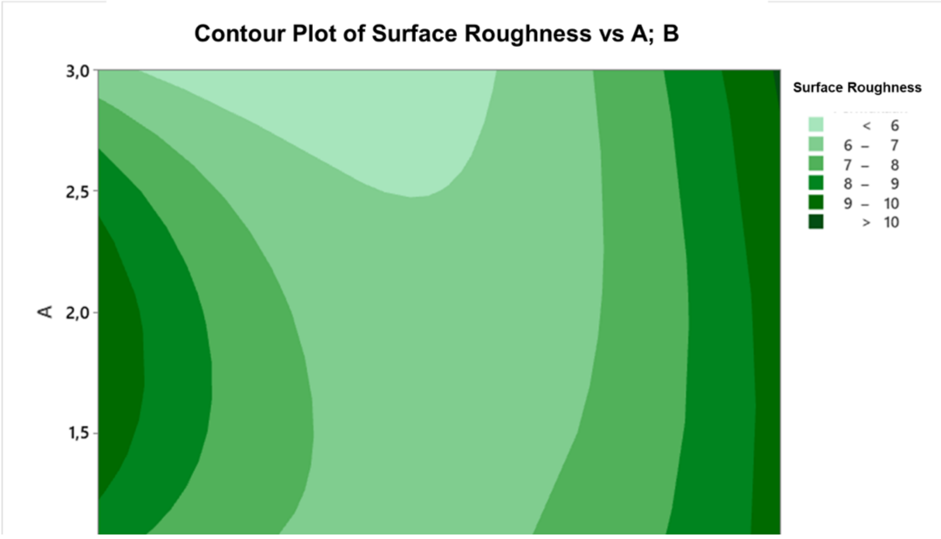

FIGURE 4. Contour plot of the interaction effect of factors A and B on surface roughness

Figure 4 shows a contour plot depicting the interaction between factors A and B on surface roughness. This plot confirms that the combination of high speed (A3) with a carbide tool (B2) produces the lowest surface roughness, with lighter colors on the plot indicating roughness below 6 µm. This is in accordance with the findings of Muhammed et al. [10] who suggested that to achieve optimal surface quality, carbide chisels should be used at high speeds.

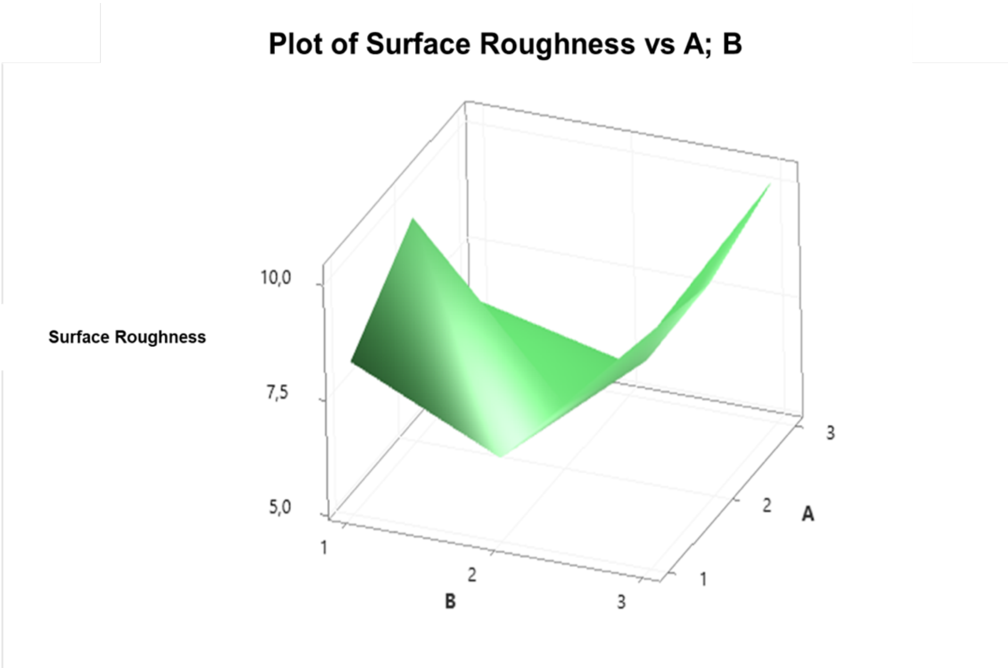

FIGURE 5. Plot of surface effects interaction factors A and B against the surface roughness

Based on Figure 5, which shows the surface plot, also illustrates that the combination A3B2 (450 RPM spindle speed and Carbide tool) produces the lowest surface roughness, reinforcing the results of the previous analysis and indicating that the interaction between factors A and B greatly affects the surface quality. This combination forms the lowest curve on the graph, indicating the most optimal conditions for minimizing surface roughness.

The interaction analysis between the spindle speed (A) and cutting tool type (B) factors revealed that the Carbide tool at a speed of 450 RPM produced a smooth surface with the lowest roughness value, which is consistent with the results of research by Lai et al. [7] who stated that the combination of high speed and the right tool is the key to achieving optimal surface quality.

2. Analysis of Variance (ANOVA)

TABLE 6. Result of ANOVA

Source	DF	Seq SS	Contribution	Adj SS	Seq MS	F-Value	P-Value
Regression	2	4.6431	18.51%	4.6431	2.3216	0.68	0.541
A	1	0.8430	3.36%	0.8430	0.8430	0.25	0.637
B	1	3.8001	15.15%	3.8001	3.8001	1.12	0.332
Error	6	20.4399	81.49%	20.4399	3.4067		
Total	8	25.0830	100.00%				

Tests use the sequential sums of squares

Table 6 shows the results of the Analysis of Variance (ANOVA) to evaluate the influence of factor A (spindle speed) and factor B (cutting tool) on surface roughness. The ANOVA results show that although factor B has a greater contribution to the variation in surface roughness, these two factors do not have a statistically significant effect, with a P-value greater than 0.05. However, factor B (cutting tool) has the largest contribution, namely 15.15%, compared to factor A (spindle speed), which only contributes 3.36%. This indicates that although both factors are not statistically significant, the type of cutting tool remains a more dominant factor in influencing surface roughness in this experiment.

4.Conclusion

Based on the research results, it can be concluded that the type of cutting tool material has a more significant influence on surface roughness compared to the spindle rotation speed. Carbide tools produce the lowest surface roughness at every level of spindle rotation speed tested, with the combination of Carbide tools at a speed of 450 RPM providing optimal results with a surface roughness of around 5.612 μm. Although the spindle rotation speed affects surface roughness, its influence is smaller compared to the selection of the right type of cutting tool. This study suggests the use of Carbide tools at high speeds to achieve the best surface quality in machining low-carbon steel, as well as opening room for further research on the influence of other factors, such as tool geometry and cooling techniques.

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References

[1] Y. C. Lin, Y. C. Chen, K. Da Wu, and J. P. Hung, "Prediction of Surface Roughness based on the Machining Conditions with the Effect of Machining Stability," Advances in Science and Technology Research Journal, vol. 14, no. 2, pp. 171–183, Jun. 2020, doi: 10.12913/22998624/119048.

[2] Nurhidayanti, Lukmanul Hakim Arma, and Rusdi Nur, "Analysis Of The Effect Of Layer Thickness On Surface Roughness Of PLA Printed Products Using FDM Technology For The Manufacturing Industry," Scientific Journal of Mechanical Engineering Kinematika, vol. 10, no. 1, pp. 125–135, May 2025, doi: 10.20527/sjmekinematika.v10i1.737.

[3] A. Ginting and Z. Masyithah, "Predictive mapping of surface roughness in turning of hardened AISI 4340 using carbide tools," Communications in Science and Technology, vol. 9, no. 1, pp. 179–184, 2024, doi: 10.21924/cst.9.1.2024.1417.

[4] G. Prasad, G. S. Vijay, and R. C. Kamath, "Evaluation of tool wear and surface roughness in high-speed dry turning of Incoloy 800," Cogent Eng., vol. 11, no. 1, 2024, doi: 10.1080/23311916.2024.2376913.

[5] M. I. Gimastian, M. S. Y. Lubis, and R. Rosehan, "Pengaruh Variasi Tool Nose Radius Pahat Karbida Terhadap Kekasaran Permukaan Baja AISI 4140 Pada Proses Bubut," IRA Jurnal Teknik Mesin dan Aplikasinya (IRAJTMA), vol. 4, no. 2, pp. 8–16, Aug. 2025, doi: 10.56862/irajtma.v4i2.216.

[6] S. Sumawijaya, Albert Hendi Yanto Larosa, Yakmuri Lubis, and Burhan Hafid, "Performance Analysis of TiAlN/TiN PVD Coated Carbide Tools in High-Speed and Dry Machining of AISI 1070 Alloy Steel," Journal Of Mechanical Engineering Manufactures Materials And Energy, vol. 8, no. 2, pp. 241–250, Dec. 2024, doi: 10.31289/jmemme.v8i2.12592.

[7] Y. S. Lai, W. Z. Lin, Y. C. Lin, and J. P. Hung, "Development of Surface Roughness Prediction and Monitoring System in Milling Process," Engineering, Technology and Applied Science Research, vol. 14, no. 1, pp. 12797–12805, Feb. 2024, doi: 10.48084/etasr.6664.

[8] I. S. Kang, J. S. Kim, and Y. W. Seo, "Investigation of cutting force behaviour considering the effect of cutting edge radius in the micro-scale milling of AISI 1045 steelg," Proc. Inst. Mech. Eng. B J. Eng. Manuf., vol. 225, no. 2, pp. 163–171, Feb. 2011, doi: 10.1243/09544054JEM1762.

[9] C. Sukkam and S. Chaijit, "Investigation of Influencing Factors on Surface Quality during Low-Speed Cutting of Steels with a Hardness exceeding 50 HRC for forging Dies," Engineering, Technology and Applied Science Research, vol. 14, no. 3, pp. 14056–14061, Jun. 2024, doi: 10.48084/etasr.7079.

[10] M. Muhammed, M. Javidani, M. Heidari, and M. Jahazi, "Enhancing the Tribological Performance of Tool Steels for Wood-Processing Applications: A Comprehensive Review," Aug. 01, 2023, Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/met13081460.