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Analysis of carbide tool wear during turning of aisi 4340 with variations in cutting speed

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ABSTRACT

This research aims to analyze the wear value of carbide cutting edges when used in the process of cutting AISI 4340 workpieces using a lathe. AISI 4340 is an alloy steel that is often used in the manufacturing industry because of its high strength and wear resistance. However, cutting in these materials can cause significant wear on the tool blade, which can affect the performance and service life of the cutting tool. The experimental method was carried out using a conventional lathe and a carbide cutting tool suitable for cutting alloy steel. A series of cutting tests were conducted with varying cutting speeds, while keeping the depth of cut and feed rate constant. The cutting parameters are as follows: varying cutting speeds of 141 m/min, 220 m/min, and 351 m/min, with a constant feed rate of 0.16 mm/rev and a fixed depth of cut of 0.5 mm for all cutting speed variations. It is shown that the carbide tool wear of 0.3 mm is reached at different times of each cutting speed. Data obtained from cutting tests are used to analyze the level of wear on carbide cutting edges and the factors that influence it. It is hoped that the results of this research will provide a better understanding of the interaction between the carbide cutting edge and the AISI 4340 workpiece during the cutting process.

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1. INTRODUCTION

The turning process is a crucial stage in the manufacturing industry for producing components with tight tolerances and high-quality surfaces. One of the main challenges in this process is the wear on the cutting tool used to machine the workpiece. AISI 4340 alloy steel is a material commonly used in the manufacturing industry due to its strength, wear resistance, and good mechanical properties. However, cutting this material can cause significant wear on the cutting tool, affecting the final product quality, cutting efficiency, and overall production costs (Junaidi and Yulfitra, 2021; Purnawarman et al., 2024).

Carbide cutting tools are frequently used for machining hard materials like AISI 4340 alloy steel. However, the interaction between the carbide cutting tool and AISI 4340 workpiece during the cutting process can result in complex and difficult-to-predict wear patterns (Aminy et al., 2024; Jena et al., 2019). Therefore, analyzing wear on carbide cutting tools when machining AISI 4340 workpieces becomes very important.

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In the manufacturing industry, AISI 4340 alloy steel has a wide and crucial range of applications, especially for machine elements that require optimal performance under harsh environmental conditions. This material is used to manufacture components such as shafts, gears, and machine elements in various industries like automotive, aviation, and oil and gas (Devillez et al., 2019; Fahrizal et al., 2022). The superior mechanical quality of this alloy steel makes it the primary choice to meet heavy-duty demands and critical application requirements.

According to Rochim (1998), wear on the cutting tool continues to increase with cutting time until the tool is deemed no longer usable. The critical wear for carbide cutting tools and steel workpiece materials ranges between 0.2 to 0.6 mm (Saputro et al., 2024). In this research context, the wear value used is 0.3 mm, indicating that the cutting tool has reached a wear level where its performance is affected and it can no longer be used.

Previous studies have focused on analyzing carbide cutting tool wear when machining AISI 4340 steels, but there remains a need for a deeper understanding of the wear phenomena and the factors influencing it (Ghani et al., 2021; Lubis et al., 2021). Therefore, this study aims to investigate the wear phenomena of carbide cutting tools coded TNMG160404-MA when machining AISI 4340 steels using the roughing process with three variations of cutting speeds. Wear measurements will be conducted using a digital microscope to obtain wear values after the cutting process.

2. RESEARCH METHODS

This research begins by gathering information about carbide tool wear from various literature and research references related to the topic. The main objective of this study is to analyze the wear that occurs on carbide tools during the turning process of AISI 4340 steel. The research is conducted using an experimental method with a conventional lathe machine, varying three different cutting speed levels. Variations in cutting speed are employed to examine their effect on the wear characteristics of carbide tools, as cutting speed significantly influences heat generation and the interaction between the tool and the material during the turning process. Spindle speed is also evaluated to determine its role in achieving specific cutting speeds, which affect the thermal and mechanical environment in the cutting zone. Observations and measurements of tool wear are carried out every 5 minutes with a flank wear limit (Vb) of 0.3 mm. The machining process is conducted without the use of cooling or lubricating media, i.e., dry cutting. The cutting specifications are shown in Table 1.

Table 1 Cutting specifications

Cutting Parameters	Value
Spindle speed (r/min)	450, 710, 1120
Cutting speed (m/min)	141, 220, 351
Feed rate (mm/rev)	0,16
Depth of cut (mm)	0,5

The following are some of the equipment and materials used in this research, as shown in Figures 1, 2, 3, and 4. The equipment and materials include: (1) Microtara Turnmaster 35 conventional lathe machine, (2) AISI 4340 steel, (3) The cutting tool used is a carbide insert in a triangular shape with the code TNMG160404-MA, (4) Digital microscope used to observe and measure wear for this research, (5) Tool holder MTJNR 2020 K16 TNMG1604. The workpiece used in this study is AISI 4340 steel with a diameter of 100 mm and a length of 200 mm, which will be turned to a length of 130 mm. The image of the steel workpiece can be seen in Figure 2.

Figure 1. Lathe machine

Figure 2. AISI 4340 steel

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Before starting the experiment, the AISI 4340 workpieces are prepared according to the specified specifications. Next, the lathe machine is set up based on the cutting specifications listed in Table 1. After that, the workpiece is placed in the chuck, and centering is performed using the tailstock to ensure the workpiece remains stable while rotating. The insert cutting tool is then mounted on the toolholder in the tool post.
The turning process is carried out using three different cutting speed variables: 141 m/min, 220 m/min, and 310 m/min. Before observing tool wear, the digital microscope must be calibrated using a Microscope Micrometer Calibration Ruler as shown in Figure 6.

Figure 3. Carbide cutting tool with a triangular insert shape, coded TNMG160404-MA


Figure 4. Digital microscope

Figure 5. Tool holder MTJNR 2020 K16 TNMG1604

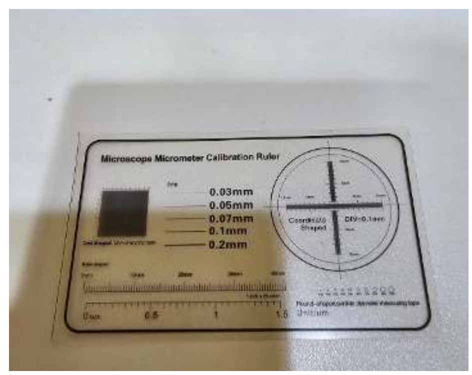

Figure 6. Microscope micrometer calibration ruler

3. RESULTS AND DISCUSSION

The study on tool wear is conducted using a digital microscope to observe the cutting edge of the tool at 5-minute intervals. Measurement data will be recorded based on the observations from the microscope. If the Vb value on the tool has not yet reached 0.3 mm, the tool will be tested again every 5 minutes until the wear reaches Vb = 0.3 mm. The data from the wear measurements during the machining process can be seen in Tables 1, 2, and 3.

Table 1 Tool wear values at a spindle speed of 450 r/min

No.	Vc(m/minute)	Time(minute)	Vb1	Vb2	Vb3	Average Vb (mm)
1	141,3	5	0.06	0.092	0.069	0.073
		10	0.088	0.106	0.094	0.096
		15	0.101	0.125	0.102	0.109
		20	0.134	0.147	0.112	0.131

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		25	0.17	0.18	0.154	0.168
		30	0.184	0.22	0.201	0.201
		35	0.207	0.254	0.227	0.229
		40	0.249	0.265	0.243	0.252
		45	0.297	0.318	0.308	0.307

Table 2 Tool wear values at a spindle speed of 710 r/min

No.	Vc(m/minute)	Time(minute)	Vb1	Vb2	Vb3	Average Vb (mm)
2	220.48	5	0.063	0.064	0.072	0.066
		10	0.126	0.17	0.118	0.138
		15	0.151	0.185	0.128	0.154
		20	0.171	0.267	0.263	0.233
		25	0.351	0.43	0.393	0.391

Table 3 Tool wear values at a spindle speed of 1120 r/min

No.	Vc(m/minute)	Time(minute)	Vb1	Vb2	Vb3	Average Vb (mm)
3	351.85	5	0.177	0.162	0.157	0.165
		10	0.355	0.315	0.31	0.326

Based on Tables 1, 2, and 3, tool wear occurs more rapidly at a cutting speed of 351.85 m/min, with VB=0.3 mm observed at the 10-minute mark. In contrast, at a cutting speed of 220.48 m/min, wear occurs at 25 minutes, and at a cutting speed of 141.3 m/min, wear is observed at 45 minutes.

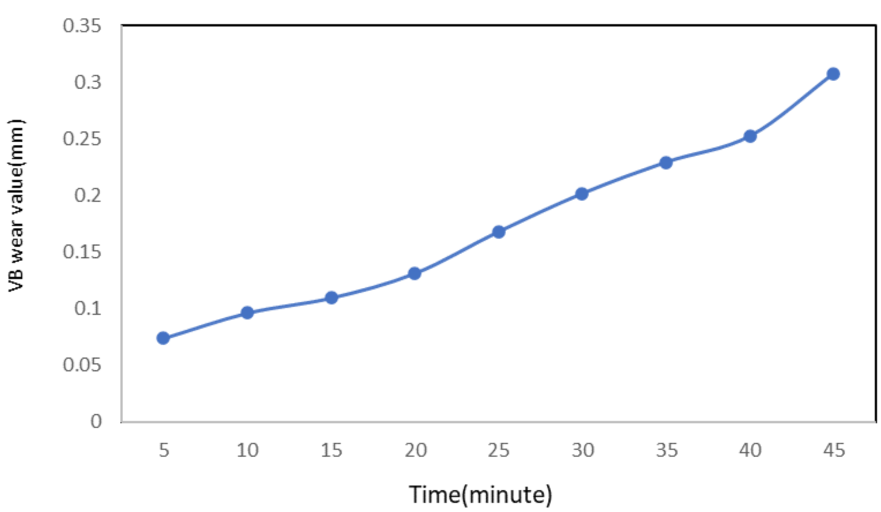

Figure 8. The value of tool wears versus cutting time at a cutting speed of 141.3 m/min.

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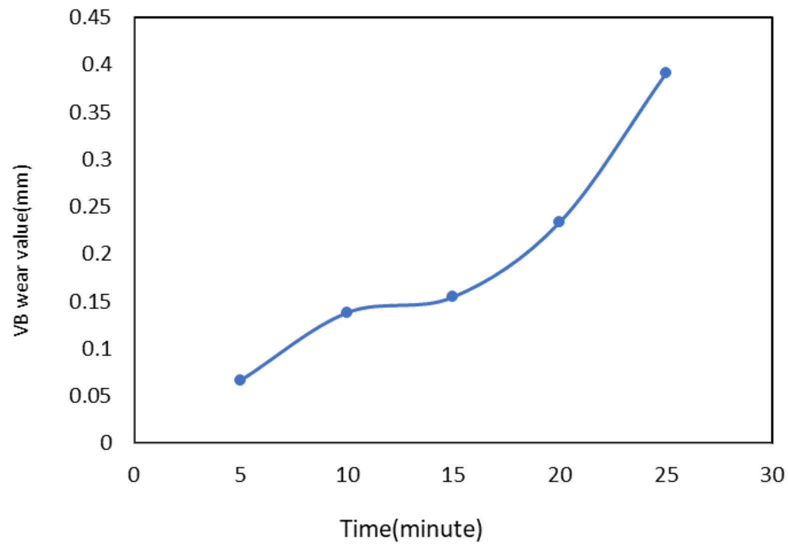

Figure 9. The value of tool wears versus cutting time at a cutting speed of 220.48 m/min.

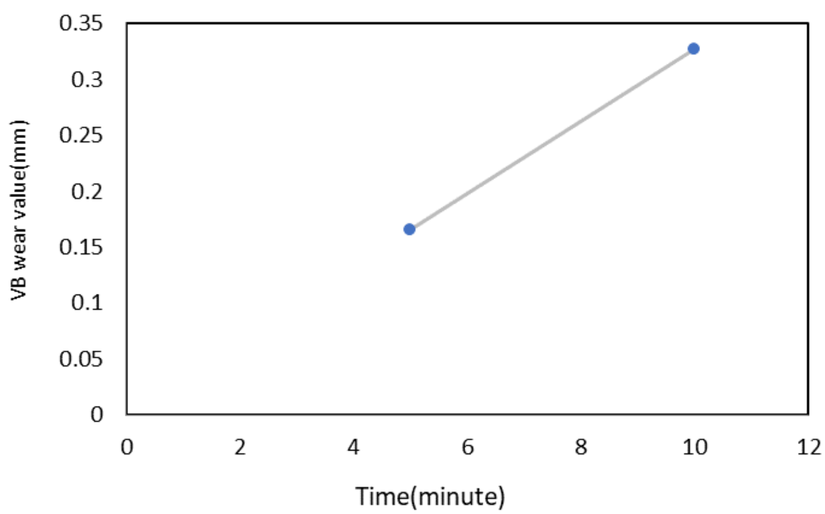

Figure 10. The value of tool wear versus cutting time at a cutting speed of 351.85 m/min.

Based on the graphs above, it can be seen that the wear rate is very fast at a cutting speed of 351.85 m/min, while the wear rate is slower at a cutting speed of 141.3 m/min. Tool wear is caused by various factors, including the elastic and plastic properties of the workpiece material, friction between the cutting tool and the workpiece that generates heat, and resulting abrasive and adhesive wear. Additionally, tool wear is influenced by spindle cutting speed, depth of cut, and feed rate. In this study, the depth of cut is kept constant at 0.5 mm, and the feed rate is also constant at 0.16 mm/rev. Meanwhile, spindle cutting speed is varied among three levels: 450 rpm, 710 rpm, and 1120 rpm. At a speed of 450 rpm, the tool reaches a wear value of VB = 0.3 mm in 45 minutes. At 710 rpm, the tool reaches the same wear value in 25 minutes, and at 1120 rpm, wear occurs in 10 minutes. This indicates that as spindle cutting speed increases, the tool reaches the wear point more quickly. Conversely, at lower spindle cutting speeds, the tool takes longer to reach the wear point.

This study provides more specific and detailed data on tool wear, especially with respect to varying spindle cutting speeds. In the work by Devillez et al. (2019), while the focus was on dry machining of Inconel 718 and surface integrity, their findings align with the results in showing that increased cutting speed leads to higher tool wear. However, the study lacks the precise wear time data across different spindle speeds, which is a key strength of this research. Ghani et al. (2021), in their optimization of end milling parameters using the

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Taguchi method, also observed increased wear at higher spindle speeds, but did not provide detailed wear progression times, as this study. Similarly, while Aminy et al. (2024) found that spindle speed influences tool wear in milling AISI 4340 steel, they did not break down the exact wear times at different speeds, making this research a more valuable contribution by offering precise wear measurements over time.

The main advantage of this research is the focused analysis on the relationship between spindle speed and tool wear. By controlling both the depth of cut (0.5 mm) and the feed rate (0.16 mm/rev), this study isolates the spindle speed as the primary factor influencing tool wear. This precise control enables a clearer understanding of how spindle speed impacts wear, which was not as rigorously explored in the studies of Ghani et al. (2021), Devillez et al. (2019), or Aminy et al. (2024). Additionally, this study's granular measurement of wear times at three distinct spindle speeds (450 rpm, 710 rpm, and 1120 rpm) provide insights into the wear progression, offering a more practical approach for optimizing machining conditions.

4. CONCLUSION

In conclusion, the findings of this study highlight the critical relationship between spindle cutting speed and tool wear, specifically in terms of the time required for the tool to reach a wear value of VB = 0.3 mm. The results show that as spindle speed increases, tool wear occurs more rapidly. At 450 rpm, it takes 45 minutes for the tool to reach a wear value of 0.3 mm; at 710 rpm, this happens in 25 minutes, and at 1120 rpm, the tool reaches the same wear value in just 10 minutes. These results indicate that while higher spindle speeds lead to faster production, they also result in faster tool degradation, which could lead to more frequent tool replacements and higher operational costs. Therefore, selecting an optimal cutting speed is a balance between maximizing productivity and minimizing tool wear. For practical applications, operators should consider the wear rate at different spindle speeds to select the most efficient cutting speed for a given operation, taking into account the trade-off between machining efficiency and tool life. Specifically, the results suggest that turning at moderate spindle speeds such as 710 rpm may offer a good balance, providing reasonable tool life while maintaining higher cutting efficiency.

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