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Effect of cutting process using cutting insert of grade UTi20T

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ABSTRACT

In the metal-cutting industry, the precision of the metal-cutting process is of paramount importance. Errors in the metal-cutting process not only lead to damage to the cutting tool but also result in the production of low-quality materials. The incorporation of insert materials in the cutting process is aimed at maintaining cutting precision and achieving superior results. This research seeks to investigate the impact of the cutting process utilizing grade KC5410 cutting insert under minimum quantity lubrication (MQL) Conditions. In this study, machining tests were conducted using the ALPHA 1350S 2-axis computer numerical control (CNC) lathe machine under MQL conditions, employing cutting tool inserts UTi20T supplied by Mitsubishi. Two types of tools were utilized in the cutting process, namely UTi20T. Critical aspects such as cutting force, total power consumption, surface roughness, and tool life were analyzed to provide comprehensive insights into the efficiency of the cutting process. The findings of this study significantly contribute to the understanding of how the integration of Grade KC5410 cutting inserts under MQL conditions can enhance the overall efficiency of metal-cutting operations. The successful machinability assessment was conducted by implementing sustainable machining practices.

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1. INTRODUCTION

The metal-cutting process and the metal forming process in the manufacturing industry are activities that are often carried out, especially in producing machine components. The use of cutting tools in the metal-cutting process is the main component in producing machine components desired by consumers according to their needs. This is known as a machining process where the process can produce a product by using cutting tools and machine tools to cut the workpiece [1]–[3]. The metal-cutting operation known as the turning process is most widely used to shape the surface of the workpiece. Cutting parameters such as cutting speed resistance and feed rate [4]–[6].

Production results in all manufacturing industries with quality precision in the automated world are greatly influenced by machine tools such as cutting inserts. Technological advances in the manufacture of components needed by consumers from the manufacturing industry using computer numerical control (CNC) machines that work automatically have widely used cutting inserts to maintain cutting precision [7]–[9]. Implementing more economical processes, conserving natural resources, and increasing the level of safety for workers, communities, and production results in the manufacturing sector is a sustainable practice. Cutting parameters, machine surface quality, cutting tool performance, and power required in the cutting process are also important considerations in implementing a sustainable manufacturing industry [10]–[12].

The global growth of the manufacturing industry and increasing environmentally conscious consumer preferences compel researchers and production plants to seek alternatives to traditional cutting fluids [13]–[15]. Over the past decade, various techniques, such as wet machining, minimum quantity lubricants (MQL), cryogenic cooling, and solid lubricant-assisted machining, have emerged as environmentally friendly solutions [16]. While cutting fluids enhances machining quality through cooling and lubrication, flood cooling, a widely used method, is deemed inefficient from social, economic, and ecological perspectives. MQL, also known as near-dry machining (NDM), has been developed as a low-consumption alternative to conventional methods [17]–[19]. The insert material grade significantly impacts cutting performance, affecting tool wear, heat resistance, surface quality, and tool lifespan. Proper material selection, considering the workpiece type, cutting conditions, and final product requirements, enhances cutting efficiency and quality [20]. Incorporating grade inserts in MQL conditions affects cutting performance and tool lifespan, necessitating careful consideration of factors like workpiece material, cutting speed, and conditions for optimal results. This approach improves cutting efficiency, optimizes tool lifespan, and ensures high-quality cutting results in MQL conditions [21]–[23].

Applying cutting insert grade UTi20T under MQL conditions enhances efficiency, tool life, and cutting results for several reasons. However, research [24] focuses on cutting speed in the cutting process by increasing the cutting parameters to determine the level of roughness of the surface of the object to be cut by paying attention to the occurrence of built-up edge (BUE) in MQL conditions, so the cutting process must be stopped. This still requires some important information in the form of parameters such as cutting force, power consumed, tool wear development, and others. UTi20T is designed with excellent wear properties, increasing the tool's lifespan. MQL reduces friction and heat during cutting, allowing UTi20T to last longer. The high hardness and strength of UTi20T improve cutting efficiency in MQL conditions by minimizing friction, reducing energy losses, and optimizing cutting performance. MQL also decreases the required cutting force by reducing friction. UTi20T's wear and heat-resistant properties reduce the load on the cutting process [8], [25], [26]. Additionally, MQL minimizes fluid use, reducing contamination risks and enhancing surface quality. UTi20T maintains cutting sharpness, delivering better-cutting results. Its thermal stability and toughness ensure consistent performance under varying MQL conditions. This approach aligns with environmental efforts by minimizing cutting fluid use, making grade UTi20T a sustainable choice [27].

This research aims to evaluate the impact of the cutting process by utilizing KC5410-grade cutting insert material. In a series of machining tests, a 2-axis CNC lathe ALPHA 1350S was carried out in MQL conditions, using a UTi20T cutting tool insert supplied by Mitsubishi. The analysis focuses on several important aspects such as cutting force, total power consumption, surface roughness, and tool life, with the hope of providing comprehensive insight into the efficiency of the cutting process industry so that cutting results can be obtained according to the user's expectations of the material that has been cut. This paper consists of: section 2 is the methodology which is divided into three parts: first is the experimental setup, second is the workpiece material and third is the cutting tool insert. Section 3 presents experimental results, modeling responses, and discussion. Last section 4 is the conclusion.

2. RESEARCH METHOD

2.1. Experimental setup

Widespread use of statistical experimental design in investigating machining process capabilities. In this paper, a Three-level full factorial design was utilized to examine the effects of cutting parameters such as cutting force, total power consumption, surface roughness, and tool life. The advantage of this design is that it can analyze experimental data using an experimental approach one factor at a time. The experimental design was formulated utilizing Design-Expert software version 7.1. The set of experiments consisted of eleven trials, as detailed in Table 1.

The work material, an austenitic stainless steel American Iron and Steel Institute (AISI) 316L in bar form, was secured using a three-jaw chuck on one end and supported by a center-mounted on the tailstock at the opposite end. Due to the larger diameter of the supplied bar compared to the clamping capacity of the ALPHA 1350S 2-Axis CNC lathe machine, preliminary steps were taken using a larger lathe machine. These steps included reducing the diameter of one end of the bar, creating a center hole with a center drill mounted on the tailstock, and making a groove at the chuck jaws' front to indicate the tool travel endpoint during turning. After completing these preparations, the workpiece was positioned on the lathe for turning experiments. The skinning process followed, aiming to reduce the diameter of the newly mounted bar by approximately 2 mm. The tool holder was carefully placed and clamped onto one of the tool holders' positions.

Table 1. Plan of experimental

No.	Cutting speed *(Vc)* [m/min]	Feed rate (*f*) [mm/rev]	Coded form	
			x_1	x_2
1	90	0.10	–1	–1
2	150	0.10	0	–1
3	210	0.10	1	–1
4	90	0.16	–1	0
5	150	0.16	0	0
6	210	0.16	1	0
7	90	0.22	–1	1
8	150	0.22	0	1
9	210	0.22	1	1

In this research, the ALPHA 1350S 2-axis CNC lathe machine was used for the machining test under dry cutting conditions, employing two distinct cutting tool inserts, namely UTi20T. Both inserts were affixed to the TCLNR 2020K12 tool holder. The machine's motor horsepower was 8.3 kW, and the spindle speed ranged from 100 to 6,000 rpm. Feed rates varied between 0.04 and 10 mm/rev (see Figure 1). Each trial utilized a new insert to eliminate wear-related influences. Machining occurred for a set duration (60 seconds for each cutting process). Upon completion, cutting force measurements and total power consumption data were stored on the PC. The tool holder was then removed for tool wear measurement and capturing images of the worn insert. Surface roughness on the turned surface was measured at five different locations on the work material circumference. Following these tasks, the tool holder was repositioned and clamped onto the same tool holder position, and the entire procedure was repeated. This cycle continued until the tool life was determined based on predefined criteria.

Figure 1. CNC lathe machine with 2 axes, known as ALPHA 1350S

The cutting forces were assessed using a three-component dynamometer connected to a charge amplifier via a well-insulated, low-noise, and high-impedance cable (Kistler, Type 1689 B5). The charge amplifier was linked to the PC using standard cables, with the analog output and RS232C ports on the multi-charge amplifier connecting to the analog-to-digital (A/D) board and communications (COM) ports on the PC, respectively. Total power consumption and related data were gauged with three split-type CT pieces (ZN-CT11) affixed to the three-wire power supply (main power, spindle power, and carriage power) in the panel box. This split was linked to three portable power sensors (ZN-CTX21A) via a branch cable (ZN-CTM11C). Subsequently, the power sensor was connected to a PC using an Ethernet hub and local area network (LAN) cables. For surface roughness measurements in the turning process, a portable surface roughness tester (Mitutoyo Surftest SJ-301) was employed, adhering to ISO97/German Institute for Standardization (DIN) standards, with measuring and cut-off wavelengths set at 4.0 mm and 0.8 mm, respectively.

2.2. The material of workspace

While previous researchers have explored the use of stainless steels, the investigation of the austenitic stainless steel AISI 316L grade has been relatively rare, likely due to its higher cost. In recent years, this steel type has gained popularity, particularly in biomedical implant applications. This study focuses on the turning process, employing a workpiece made of austenitic stainless steel AISI 316L with a diameter of 150 mm and length of 300 mm. Refer to Tables 2 and 3 for the detailed composition and general properties of AISI 316L.

Table 2. AISI 316L composition

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
316L	Min	-	-	-	-	-	16.0	2.00	10.0	-
	Max	0.03	2.0	0.75	0.045	0.03	18.0	3.00	14.0	0.10

Table 3. AISI 316L general properties

Grade	Tensile strength (MPa) min	Yield Strength 0.2 % proof (MPa) min	Elongation (% in 50 mm) min	Hardness	
				Rockwell c (HRC)	Brinell (HB)
316L	485	170	40	89.5	181

2.3. The cutting tool inserts

Mitsubishi supplied the cutting tool inserts for this experiment, specifically the UTi20T. The UTi20T is an uncoated cemented carbide designed for various materials, including steel, cast iron, and stainless steel. The specific UTi20T insert used is CNMG120408-MS, positioned in the right tool holder labeled TCLNR 2020K12 which can be seen in Figures 2 and 3.

Figure 2. UTi20T cutting insert [28]

Figure 3. Tool holder of TCLNR 2020K12 [28]

3. EXPERIMENTAL RESULT AND DISCUSSION

The experimental outcomes, focusing on tool wear and surface roughness, are regularly documented during the conducted experiments following the outlined procedures in the previous section. Post-machining analysis results obtained through optical microscope examination are also outlined. This chapter broadly covers various aspects, including cutting force, overall tool lifespan, power consumption, tool failure modes, surface roughness, experimental design analysis, and ensuing discussion. Figure 4 illustrates how cutting forces (Fr, Ff, and Fc) are affected by cutting conditions during the turning process of austenitic stainless steel with UTi20T inserts. Figure 4 illustrates the correlation between cutting forces and feeds for UTi20T at different cutting speeds. Fc consistently emerged as the primary force, followed by Ff. The forces increased with higher feed rates, with Fc showing a notably steeper rise compared to Ff and Fr. Similar trends were observed across all instances for UTi20T tools.

Figure 5 depicts the impact of cutting conditions on total power consumption during the turning of austenitic stainless steel using UTi20T tools. The noticeable trend reveals a slight rise in total power consumption as the feed increases. This indicates that a higher material removal rate, resulting from increased cutting speed and feed, demands more power to drive the spindle motor.

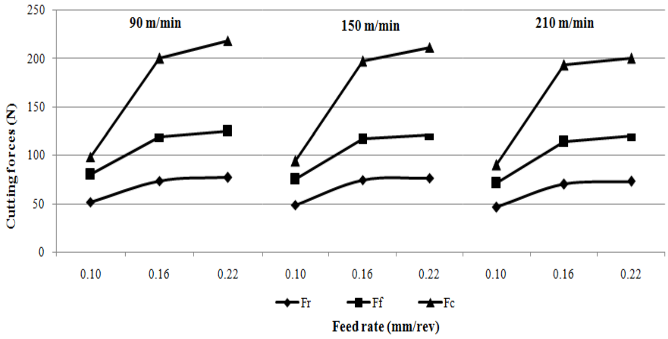

Figure 4. Cutting forces are impacted by different feed rates across various cutting speeds when using UTi20T

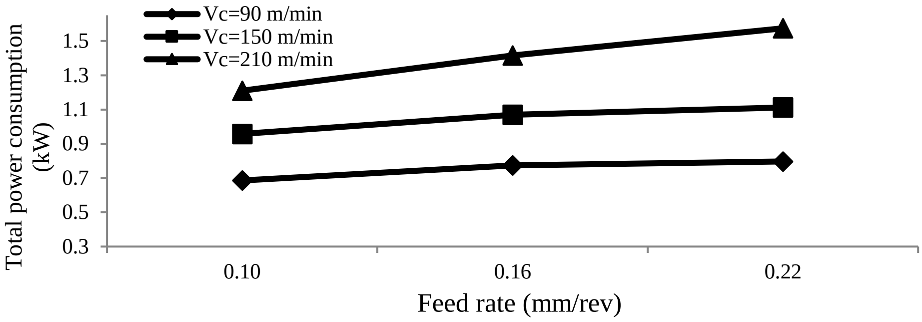

Figure 5. The total power consumption is affected by different feed rates across various cutting speeds for UTi20T

The correlation between the average surface roughness value and feeds for UTi20T, under different cutting speeds, is depicted in Figure 6. The data distinctly indicates that the average surface roughness values rise with an increase in feed. Ra values tend to increase with higher feed rates but decrease with increasing cutting speed. The tool wear growth over time was plotted for different cutting speeds (90, 150, and 210 m/min) and feed rates (0.10 mm/rev) in Figure 7. The graph shows that the cutting tool experienced rapid wear during the initial machining. Wear readings were taken at corresponding machining times. Following the initial period, wear steadily propagated until it reached the VB_N tool life criterion. Tool life, determined by the VB_N criterion, generally increased as cutting speed and feed rate decreased. Tool life ranged from 180 seconds (3 minutes) to 2,020 seconds (33.67 minutes), with the shortest observed at the highest cutting speed and feed rate, while the longest occurred at the lowest cutting speed and feed rate.

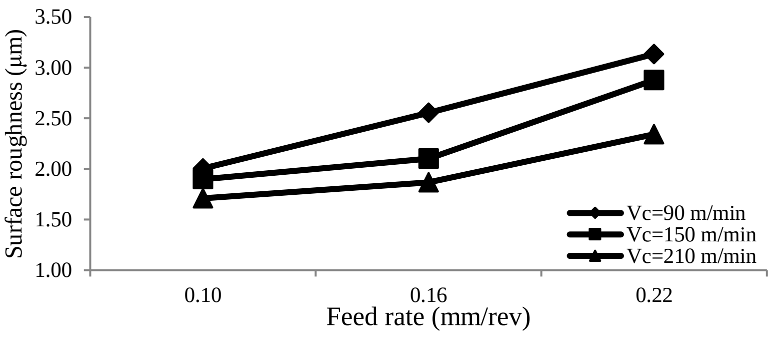

Figure 6. The surface roughness is affected by different feed rates at various cutting speeds for UTi20T

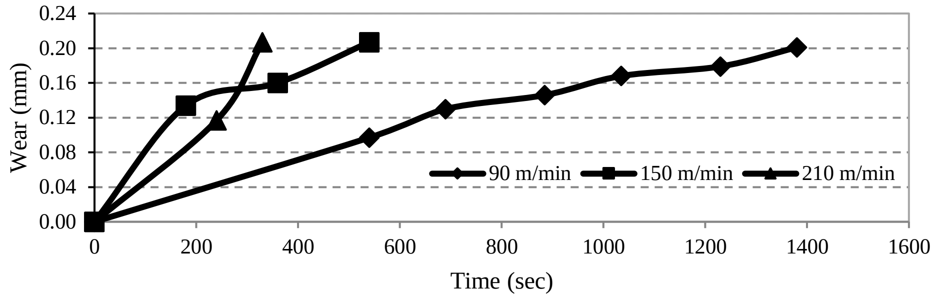

Figure 7. Tool wear progression for UTi20T at different cutting speeds and 0.10 mm/rev

Figure 7 illustrates that lower cutting speeds correspond to lower tool wear rates. As cutting speed increases, tool wear rates rise, leading to shorter tool life. The impact of cutting speed and feed rate on the tool life for the UTi20T insert during the turning of AISI 316L is presented in Figure 8. These figures reveal a decrease in tool life with higher cutting speed and feed rate. Tool life diminishes significantly with the escalation of cutting speed and feed rate, likely attributed to the elevated temperature generated during cutting. Increased temperature weakens the tool's strength, consequently reducing tool life. This decline in tool life with increasing cutting speed and feed rate is observed when turning duplex stainless steel using CVD-coated carbide (CTC 1135). The phenomenon is attributed to abrasive actions, resulting in higher wear intensity at the cutting edge.

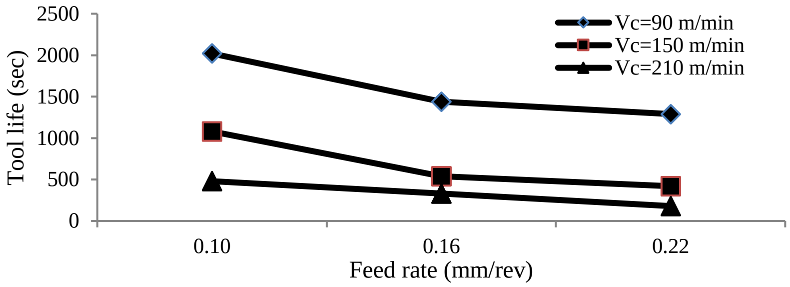

Figure 8. Tool life affected by different feed rates at various cutting speeds for UTi20T

Figure 9 displays worn carbide inserts under various cutting conditions for the UTi20T insert. The two-dimensional views captured using an optical microscope depict worn inserts on the flank face and rake face. Figures 9(a), (b), and (c) show a comparison of the results of the cutting process with different feet rate (f) and time (T) but the same time. The wear pattern, identified as notch wear, primarily occurs in the nose region of the insert. Notch wear, a specific type of flank wear, develops at the intersection of the major cutting edge and the workpiece surface. This wear is a consequence of abrasion and is particularly prevalent when machining parts experiencing localized effects, such as the formation of a hardened layer on the uncut surface due to previous cutting, the presence of an oxide scale, and localized high temperatures resulting from the edge effect. Notch wear is common in the machining of materials with high work-hardening characteristics, including many stainless steels and heat-resistant nickel or chromium alloys. In this experiment, notch wear predominated over other tool wear phenomena. The maximum width of the notch wear (VBN) can serve as a tool wear measure according to the International Organization for Standardization (ISO) 3685.

The primary wear mechanism observed when turning Inconel 718 with coated carbide, both in wet and dry cutting, is notch wear. This dominant wear mechanism results in tool life being consistently less than 10 minutes in all scenarios. Similarly, when investigating the impact of cutting speed on the rate of tool wear during the turning of NiTi shape memory alloys using a TiB2-coated KC5410 cutting insert, it was observed that notch wear was notably high within the first minute of the cutting process under both dry and minimum quantity lubrication (MQL) conditions. Notably, under MQL conditions, the most substantial notch wear occurred after one minute of cutting, followed by a gradual increase in wear with extended cutting time.

An elevation in the feed rate during the cutting process would lead to a rise in cutting forces across all cutting speed conditions. This is because the primary force exerted on the tool was the tangential force, significantly surpassing the feed force and radial force under any given experimental conditions. The cutting process that has been carried out with the insert material Using a cutting insert of grade UTi20T in MQL conditions provides an assessment result of the sustainability of the manufacturing industry by looking at several characteristics of the cutting results with the presence of insert cutting material.

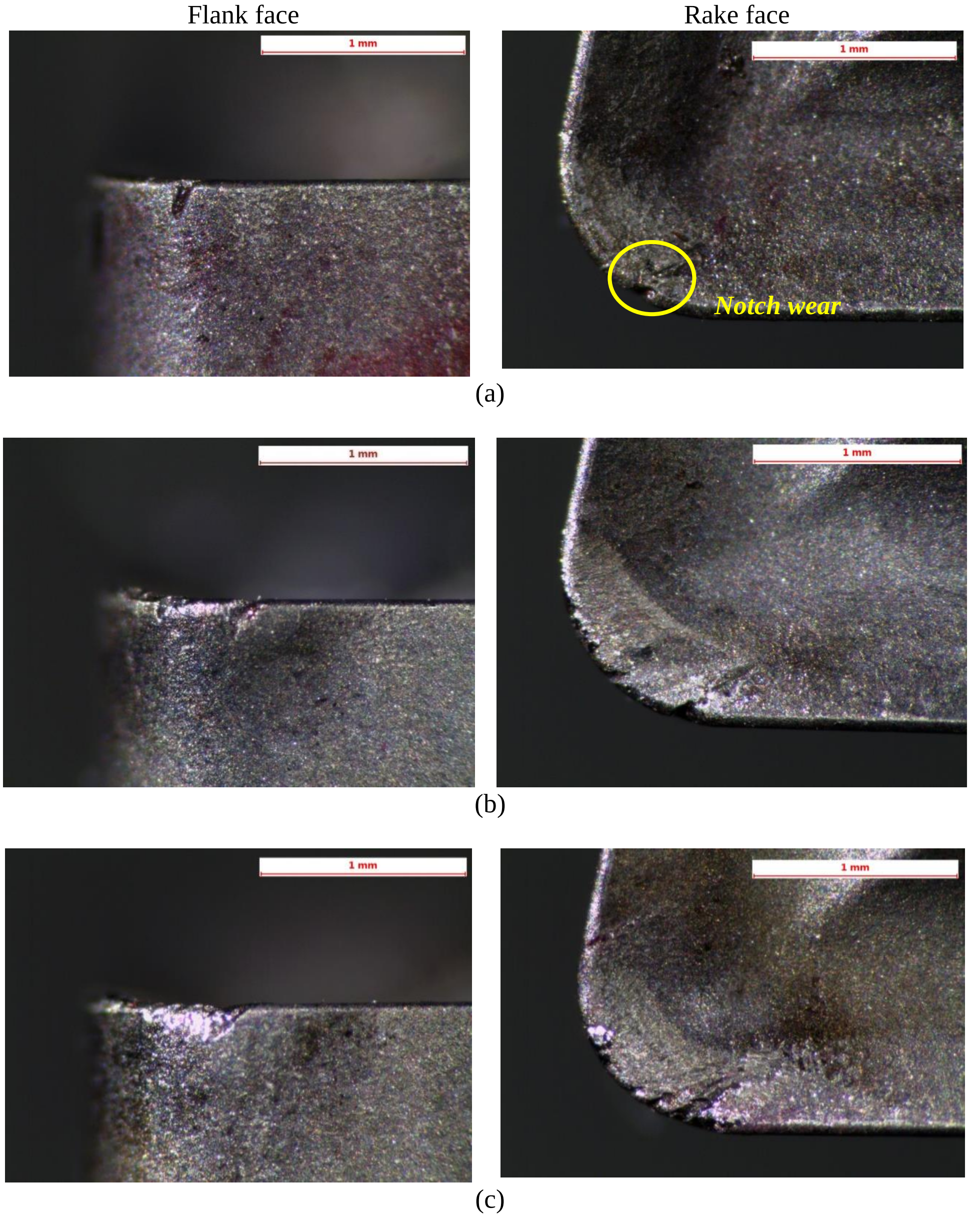

Figure 9. Optical microscope pictures of UTi20T inserts that have experienced wear during the turning process of austenitic stainless steel in condition (a) Vc=90 m/min, f=0.10 mm/rev, T=2,020 second, (b) Vc=90 m/min, f = 0.16 mm/rev, T=1,440 second, and (c) Vc=90 m/min, f=0.22 mm/rev, T=1,290 second

4. CONCLUSION

The experimental design utilized a 2-factor, three-level full factorial design with two center points to assess the impact of cutting parameters on machinability responses in turning AISI 316L on MQL condition. Cutting forces were predominantly influenced by the feed rate while cutting speed had a limited impact. Increasing the feed rate raised cutting forces across all cutting speeds. Tangential force, surpassing feed and radial forces, was the primary force on the tool. Total power consumption increased with cutting speed and was influenced to some extent by higher feed rates, with cutting speed having the most substantial impact. Surface quality improved with higher cutting speeds but declined sharply with increased feed rates. The optimal condition for minimal surface roughness was achieved with high cutting speed and low feed rate. Surface roughness was mainly affected by feed force and temperature rise during cutting. Elevated cutting speeds reduced surface roughness due to softened material, enhancing cutting performance. Tool life decreased with higher cutting speed and feed rate, with coated carbide inserts outlasting uncoated ones. The successful machinability assessment employed sustainable machining practices. Future work recommendations include residual stress measurements on the machined surface, sustainability assessments for turning and exploring power consumption potential in other machining processes, particularly milling and drilling. Apart from that, our further research also assesses the cutting process using cutting insert of other grades as a comparative material in MQL conditions for sustainability in the manufacturing industry.

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