ADVANCING TURNING PERFORMANCE OF C45 STEEL FOR MARINE APPLICATIONS: A COMPREHENSIVE STUDY ON OPTIMIZING CUTTING CONDITIONS

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ABSTRACT

Cutting condition is a pivotal factor affecting cutting performance in the turning process, especially in marine engineering, where materials must withstand the challenges of maritime environments. This study presents an experimental investigation of the impact of cutting process parameters on surface roughness, Vicker hardness, and cutting temperature in the turning of C45 steel, a critical material for marine applications. The experiments are meticulously designed based on input parameters, including cutting speed and various cutting conditions (dry, flood, MQL, and nano-MQL), focusing on their relevance to maritime manufacturing. After collecting and analyzing the experimental data, it becomes evident that increasing the cutting velocity significantly reduces surface roughness and temperature, aligning with the marine industry's need for precision and durability. Additionally, Nano-MQL lubrication is the most effective solution for minimizing cutting temperature and improving surface quality. It is a noteworthy advancement for enhancing cutting performance in marine science and engineering.

Keywords: *Cutting condition, Nano-MQL, surface roughness, temperature*

I. INTRODUCTION

Machining processes are vital in various industries, and the performance of these processes often determines the quality of the product. Cutting conditions are pivotal among the many factors influencing machining performance, particularly pertinent in marine science and engineering [1]. The turning process is widely employed in maritime manufacturing, where materials, especially C45 steel, find extensive use due to their desirable mechanical properties and suitability for marine applications. Understanding the impact of cutting conditions on the turning of C45 steel is crucial for optimizing performance and product quality, especially in the marine engineering domain.

Turning involves removing material from a workpiece to achieve the desired shape and surface finish. It is a commonly employed method in maritime manufacturing, affecting components' quality, precision, and efficiency in various marine applications, from naval shipbuilding to offshore platform construction. C45 steel, known for its mechanical properties and versatility, is particularly interesting among the materials used in turning processes for marine components. Improving turning performance with C45 steel can significantly impact the quality of maritime products and equipment [2].

One of the primary challenges in the turning process, particularly in marine engineering, is achieving the desired surface finish and minimizing cutting temperature. Surface roughness and temperature are critical indicators of machining performance [3], which is paramount in the marine industry. The influence of cutting conditions on these parameters, including cutting speed and lubrication methods, is of great interest, given the need for precision and durability in marine applications [4,5]. To address this issue and enhance machining practices for marine manufacturing, we conducted an experimental investigation to understand how these factors affect the turning of C45 steel.

The main objective of this study is to experimentally investigate the influence of cutting conditions and cutting process parameters on surface roughness, Vicker hardness and cutting temperature in the turning of C45 steel, with a specific focus on their relevance to marine engineering. Specifically, we examine the effects of varying cutting speeds and different lubrication methods, including dry cutting, flood coolant, Minimum Quantity Lubrication (MQL), and nano-MQL, aligning with the demands of marine component fabrication. Through this investigation, we aim to provide insights into optimizing cutting conditions to enhance machining performance and surface quality in marine science and engineering.

This research is of paramount relevance to the maritime manufacturing industry, where efficiency and product quality are critical. By better understanding the interplay between cutting conditions and the turning process's performance, marine sector manufacturers can make informed decisions to improve their operations, leading to more efficient and high-quality production. The findings from this study have the potential to drive the adoption of enhanced machining techniques and more effective lubrication methods in marine manufacturing, ultimately contributing to the production of higher-quality components for marine applications.

In the following sections, we will detail the materials and methods used in our experiments, present the results and their implications, and conclude with recommendations for improving turning performance and surface quality, highlighting the effectiveness of nano-MQL lubrication in this context.

II. MATERIAL AND METHOD

The material chosen for this experimental investigation is C45 steel, a widely utilized engineering material with well-documented mechanical properties. The selection of C45 steel allows us to assess the influence of cutting conditions on a material frequently encountered in various industrial applications.

A nanofluid was incorporated into the Minimum Quantity Lubrication (MQL) system to enhance the cutting performance. The nanofluid was formulated using cutting oil CT232, a product from LONG LUB-TEK company, Taiwan. The dispersion of nanoparticles was achieved using the Ezdo MS-11C stir machine. Specifically, graphite nanoparticles with a size of less than 30 nm were employed. The nanofluid was composed of a 1% volume fraction of graphite nanoparticles and was continuously stirred for 24 hours to ensure uniform dispersion throughout the cutting process. Figure 1 shows the experimental setup and measured parameters of this study.

The experiments were conducted at nine distinct cutting speed levels to systematically investigate the influence of cutting speed on machining performance. These levels, ranging from 100 m/min to 260 m/min, were selected to cover a broad spectrum of cutting velocities typically encountered in machining applications.

This comprehensive approach to material selection, nanofluid preparation, cutting conditions, and output parameter measurements ensures a thorough and systematic examination of the effects of cutting conditions on the turning of C45 steel. The subsequent section will present and analyze the experimental results of this methodology.

Four distinct cutting conditions were explored to comprehensively investigate their effects on the turning of C45 steel: dry, flood cooling, MQL (coconut oil), and nanofluid MQL. Three key output parameters were measured to evaluate the effects of these cutting conditions: surface roughness, Vicker hardness, and cutting temperature.

III. RESULTS AND DISCUSSION

In this section, we present and discuss the results of our experiments, which were designed to investigate the influence of cutting conditions on the turning of C45 steel. The experimental data from all 36 trials are summarized in Table 1.

Surface roughness, a key indicator of machining quality, was measured in all experiments. As expected, the results demonstrate a clear trend: increasing cutting

(a) Cutting tool (b) Nanofluid

(c) Setup experiments (d) Thermal image

(e) SJ-310 Mitutoyo surface test (f) HV hardness test

Figure 1. The details of the experimental setup

Table 1

	Surface roughness (*Ra, μm*)				
No.	**Cutting speed**	**Dry**	**Flood cooling**	**MQL with coconut**	**Nanofluid**
1	100	2.165	2.719	2.809	1.921
2	120	1.973	2.508	2.507	1.779
3	140	1.774	2.421	2.313	1.652
4	160	1.662	2.325	1.952	1.491
5	180	1.476	1.999	1.695	1.421

	Surface roughness (*Ra, µm*)				
No.	**Cutting speed**	**Dry**	**Flood cooling**	**MQL with coconut**	**Nanofluid**
6	200	1.281	1.836	1.449	1.253
7	220	1.152	1.512	1.211	1.157
8	240	1.148	1.271	1.072	1.093
9	260	0.998	1.065	0.951	0.914
	Vicker hardness (*HV*)				
	Cutting speed	**Dry**	**Flood cooling**	**MQL with coconut**	**Nanofluid**
1	100	170	177	177	168
2	120	167	175	173	166
3	140	165	174	170	165
4	160	164	173	168	161
5	180	161	170	162	159
6	200	154	167	158	157
7	220	151	160	149	150
8	240	148	152	144	145
9	260	139	143	136	138
	Cutting temperature (^0C)				
	Cutting speed	**Dry**	**Flood cooling**	**MQL with coconut**	**Nanofluid**
1	100	70.4	37.7	58.5	43.2
2	120	72.3	38.2	59.5	46.3
3	140	74.8	38.9	61.6	47.7
4	160	78.3	39.4	65.3	53.6
5	180	80.1	39.8	71.9	55.2
6	200	82.3	40.6	74.6	62.3
7	220	85.5	41.5	78.1	65.5
8	240	87.2	42.3	80.7	66.2
9	260	90.6	44.1	84.7	69.8

speed leads to a decrease in surface roughness. This phenomenon aligns with the fundamental principles of metal cutting, where higher cutting speeds result in reduced tool-workpiece interaction time, contributing to smoother surface finishes [1, 6].

Additionally, our results reveal the influence of different cutting conditions on surface quality. The order of increasing surface quality, based on surface roughness measurements, is as follows: flood cutting, MQL with coconut oil, dry cutting, and nanofluid MQL. Notably, the nanofluid MQL condition consistently produced the smoothest surfaces, validating the effectiveness of nanofluid as a cutting lubricant for enhancing surface quality. This outcome underscores the potential of nanofluids to optimize machining processes by achieving superior surface finishes (Figure 2) [7,8].

Our investigation also encompassed the assessment of Vicker hardness (HV), a crucial measure of material hardness. Similar

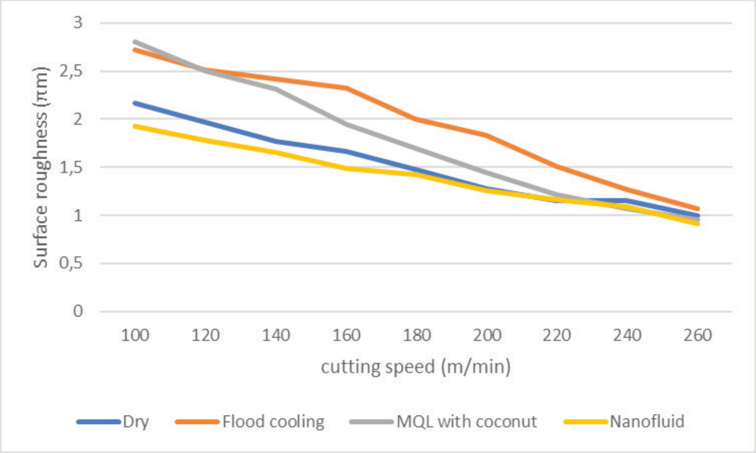

Figure 2. Compare surface roughness at different cutting speeds and cutting conditions.

to the trends observed in surface roughness, increasing cutting speed was found to decrease HV values. This phenomenon can be attributed to the rise in cutting temperature as cutting speed increases. The elevated temperature softens the surface layer of the workpiece, resulting in a reduction in Vicker hardness. The influence of HV can vary depending on the specific machining requirements, where certain applications may necessitate lower or higher hardness values for the machined components (Figure 3).

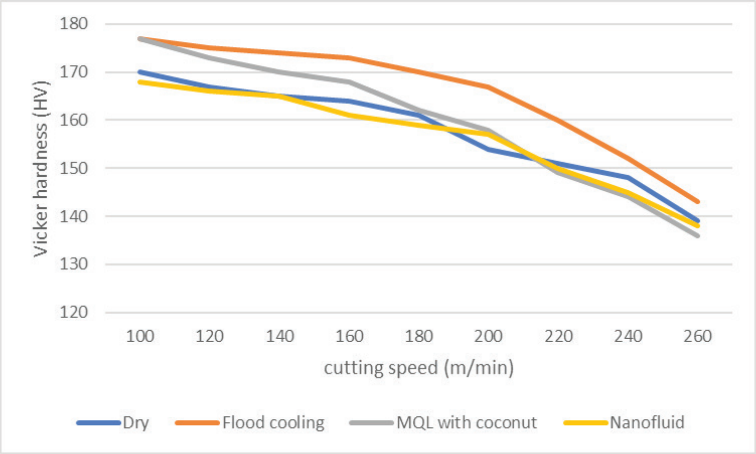

Figure 3. Compare HV hardness at different cutting speeds and cutting conditions.

Cutting temperature, a critical factor in machining operations was monitored throughout the experiments. Consistent with metal cutting principles, the results indicate that increasing cutting speed correlates with elevated cutting temperatures. The rapid tool-workpiece interaction at higher cutting speeds generates greater heat, in line with the expectations of metal cutting theory (Figure 4).

Further analysis of different cutting conditions reveals variations in the order of decreasing cutting temperature. Dry cutting exhibited the highest cutting temperatures, followed by MQL with coconut oil, nanofluid MQL, and flood cooling. Notably, a significant difference in performance was observed with the nanofluid MQL condition. Including nanoparticles in the cooling oil (nanofluid) was pivotal in efficiently dissipating heat, resulting in lower cutting temperatures. This outcome underscores the cooling efficiency of nanofluids in the machining process, further

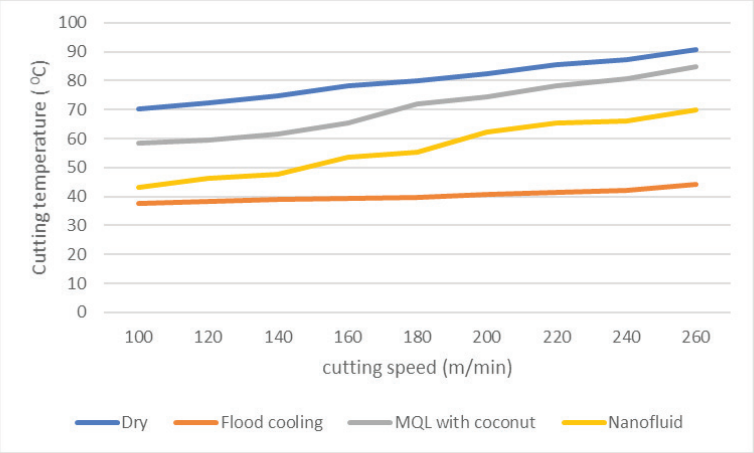

Figure 4. Compare cutting temperature at different cutting speeds and cutting conditions.

supporting their application in optimizing cutting performance.

In summary, our experimental results validate fundamental principles of metal cutting, where cutting speed influences surface roughness, hardness Vicker, and cutting temperature. Moreover, our findings demonstrate the potential of nanofluids, particularly nanofluid MQL, as an effective means of improving surface quality and reducing cutting temperature when turning C45 steel. These insights offer valuable guidance for enhancing machining processes and achieving higher-quality components in various industrial applications.

IV. CONCLUSION

In this study, we conducted a comprehensive experimental investigation into the influence of cutting conditions on the turning of C45 steel. Through a systematic approach, we examined the effects of cutting speed and various cutting conditions, including dry cutting, flood cooling, Minimum Quantity Lubrication (MQL) with coconut oil, and nanofluid MQL with graphite nanoparticles, on three critical parameters: surface roughness (Ra), Vicker hardness (HV), and cutting temperature (To).

The results of our experiments have provided valuable insights into the intricacies of machining C45 steel and optimizing cutting performance. Several key findings and conclusions can be drawn from this research:

Cutting speed influences surface roughness, Vicker hardness, and cutting temperature. Higher speeds lead to smoother surfaces and reduced hardness.

Nanofluid MQL, with graphite nanoparticles, emerged as the most effective cutting condition for achieving superior surface quality.

Nanofluid MQL proved highly efficient in lowering cutting temperatures, making it a promising solution for cutting temperature control.

These insights offer valuable guidance for optimizing machining processes and improving product quality in various industrial applications. We encourage further research to fully harness the potential of nanofluids and enhance the field of mechanical engineering.

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