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Comparing CNC Turning of 2205 Duplex Stainless Steel Using Novel Textured Tool with Untextured Tool for Reducing Flank Wear Under Nano Minimum Quantity Lubrication Condition

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Abstract

The principal objective of this study is to conduct a comparative analysis between newly developed textured carbide tool inserts and their untextured inserts in the CNC turning of 2205 duplex stainless steel. This analysis is focused on mitigating flank wear while operating under nano minimum quantity lubrication (nMQL) conditions. Surface texturing is an environmentally sustainable manufacturing technique that offers an appealing approach to modifying the surface topography of cutting tools, particularly at the rake face. This alteration aims to enhance the wettability of cutting fluid at the cutting edge, facilitating more efficient machining processes. A linear groove texture pattern is engraved on the tool surface using a femtosecond laser technique. A Jobber XL CNC turner used for turning operations on 2205 duplex stainless steel with textured tool inserts and was compared with untextured tool inserts in terms of flank wear. Box benhen design used for conducting experiments. The sample size of each group is 20; there are two groups; the total sample size is 40. The experimental results show a flank wear of 0.252 mm for single-textured tools and 0.187 mm for untextured tools in turning 2205 duplex stainless steel rod. With the study limits, the proposed single linear groove textured tool insert showed a reduction in flank wear (16.45%) compared to the untextured carbide tool inserts.

Keywords

CNC turning, Duplex stainless steel, Flank wear, Nano minimum quantity lubrication, Sustainable production

Introduction

To enhance the lubrication efficiency between the tool chip and the contact surface while simultaneously mitigating tool wear, a coating process was employed on micro-void substrates using graphene nanoparticles. Additionally, these nanoparticles exhibit notable resistance to thermal transfer, effectively managing heat dissipation across the substrates [1]. To increase the tribological behaviour of base fluids and decrease wear loss, frictional force, optimize service performance, and enhance the operating life of sliding parts, several studies have focused heavily on nanoparticles performing as fillers. The material of the workpiece is plastically distorted during machining processes, which causes heat to be produced. In addition to the primary shear zone, heat is also produced by plowing at the newly machined surface and sliding friction at the tool-chip contact. The high heat produced during machining often reduces the tool's life. However, because these materials typically have relatively low thermal conductivity, it can be difficult to machine them because the temperature in the cutting zone rises quickly, leading to rapid tool wear that eventually reduces tool life. Laser surface texturing provides a variety of advantages over other methods, including rectifying surface topography and lowering substrate surface contamination, according to published research. One of the methods to reduce tool wear is to use the minimum amount of lubricant, including nanoparticles. In the manufacturing industry, the entire cost of wear is equal to 15% to 20% of the cost of friction when maintenance expenses related to wear are included [2]. In the context of CNC turning operations involving stainless steel materials, cutting tools were employed while applying both castor oil-based MQL and nMQL with graphene nanoparticles. This dual lubrication approach was implemented to enhance the heat dissipation capabilities of the cutting fluids during machining processes [3]. Vegetable oils are composed of triglyceride chains that enhance boundary lubrication mechanisms. They achieve this by creating a robust lubricating film over contact pairs, thereby augmenting machinability [4].

Numerous researchers suggested using micro-texturing technology to improve cutting performance. A thorough study showed that the technique largely addressed the issues with conventional cutting and minimized tool wear [5]. Micro-texturing has lately attracted attention since it may be used to provide consistent contact stress and reduce the tool-chip contact area. The advancement of micro-texturing technology enhances the tribological characteristics of the contact surface between friction pairs, resulting in a reduction in surface wear and an augmentation of surface bearing capacity. The use of nanoparticles is frequently combined with conventional additives to increase the lubricating qualities depending on the oil, which significantly improves the lubrication condition and reduces friction and wear. Researchers have proposed several wear resistance and friction reduction strategies for various types of nanoparticles [6].

Although there is extensive ongoing study into the machinability of materials and alloys, no papers that are like this work have been found. In this current investigation, the performance evaluation involves a comparative analysis between the CNGA 120408 grade textured tool insert and the untextured CNGA 120408 insert within the context of turning 2205 duplex stainless steel. The assessment specifically focuses on the measurement of insert flank wear and employs wear analysis techniques, including the examination of scanning electron microscope images.

Materials and Methods

This research was conducted at the Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences in Chennai, utilizing an on-site CNC turning machine. The experimental material employed for this study was a 2205 duplex stainless steel rod, procured as cylindrical rods from SAAJ in Chennai, measuring 25 mm in diameter and 126 mm in length for turning experiments. The chemical composition verification of the 2205 duplex stainless steel was conducted by MET Mech LAB, Chennai, 602105, which also provided authentication for the material's composition, as detailed in table 1. The primary focus of this research is to evaluate the efficacy of a novel linear groove textured CNGA 120408 inserts in comparison to an untextured CNGA 120408 carbide tool insert, utilized during CNC turning operations involving 2205 duplex stainless steel. The assessment centres on the output response parameter of insert flank wear. Ethical approval is not required for this investigation as it does not involve human samples. This project is being conducted by two distinct groups, with the experimental group employing the new CNGA 120804 insert featuring a linear groove surface texture, while the control group uses the same insert without any texture. There are two groups, a control group, and an experimental group, with a total sample size of 40.

Table 1: Chemical composition of 2205 duplex stainless steel round bar.

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
2205	Min	-	-	-	-	-	21	2.5	4.5	0.08
	Max	0.03	2	1	0.03	0.02	23	3.5	6.5	0.2

The turning trials are carried out in experimental group samples utilizing a Box-Behnken design and response surface approach, as shown in table 2. A unique linear groove texturing was done on the rake face of the CNGA 120804 insert using pulse laser engraving method. A linear groove of width 150 microns and depth 100 microns was made on the rake face perpendicular to the cutting edge. After acetone cleaning, the newly textured inserts were used to conduct 20 turning experiments on a CNC lathe. In the control group samples, 20 turning experiments were run using a new untextured CNGA 120804 tool insert in a CNC lathe. Graphene based nano lubricants in nMQL conditions for cooling and lubrication promote sustainable production [7].

Tool wear arises because of intricate chemical, thermal, and mechanical interactions transpiring between the materials of the tool and the workpiece. These interactions constitute the principal determinants for the manifestation of the two primary types of tool wear, specifically flank wear and crater wear. These wear patterns are often indicative of the approaching conclusion of a tool's operational lifespan. The degree of flank wear is commonly linked to how well the process functions. Numerous studies have shown that increasing flank wear causes cutting forces to rise, which in turn increases machine tool power consumption [8]. The following steps make up the proposed methodology for calculating the wear on the microscope: When determining the features of the worn-out cutting insert, particularly the nose radius, when positioning the machine tool, consider the features of the cutting tool holder, starting with the front clearance angle [9]. Place the insert such that the wear on the flank is perpendicular to the microscope image, and the SEM image is being used to measure the tool wear [10]. Align the unworn edge with the horizontal reticle of the microscope, Place the vertical reticle of the microscope at the end of wear to direct measurements toward the cutting tool's tip (avoiding the nose radius of the insert), measure at each of the insert's five points, and then calculate the maximum flank wear [11]. The tool insert flank wear was studied using scanning electron microscope images taken near the tool cutting edges. SPSS v.26 was used to calculate mean, standard deviation, and standard error of experimental data on flank wear, with an independent sample t-test identifying

Table 2: Box-Behnken design matrix for comparing the flank wear of novel linear groove textured carbide tool insert (CNGA 120804) with an untextured carbide tool insert (CNGA 120804).

S. No.	Cutting speed, Vc (m/min)	Feed rate, f (mm/rev)	DoC, d (mm)	Flank wear (mm)	
				Untextured tool	Single textured tool
1	55	0.12	1.0	0.350	0.282
2	113	0.12	1.0	0.296	0.245
3	55	0.22	1.0	0.398	0.321
4	113	0.22	1.0	0.264	0.213
5	55	0.12	2.0	0.345	0.278
6	113	0.12	2.0	0.244	0.214
7	55	0.22	2.0	0.327	0.264
8	113	0.22	2.0	0.305	0.246
9	35	0.17	1.6	0.316	0.241
10	133	0.17	1.6	0.246	0.198
11	84	0.09	1.6	0.327	0.264
12	84	0.25	1.6	0.246	0.198
13	84	0.17	1.6	0.312	0.231
14	84	0.17	2.0	0.299	0.241
15	84	0.17	1.6	0.368	0.297
16	84	0.17	1.6	0.305	0.246
17	84	0.17	1.6	0.252	0.187
18	84	0.17	1.6	0.432	0.348
19	84	0.17	1.6	0.305	0.246
20	84	0.17	1.6	0.303	0.244

statistical significance.

Results

In the context of CNC turning of 2205 duplex stainless steel, the proposed surface texturing technique involving CNGA 120804 tool inserts demonstrates an average flank wear measurement of 0.250 mm. In comparison, untextured CNGA 120804 tool inserts yield an average flank wear measurement of 0.312 mm. Combinations of input parameters for this comparative analysis between a novel textured carbide tool insert (CNGA 120804) and an untextured counterpart (CNGA 120804) are outlined in table 2, with the output parameter, flank wear, being measured and tabulated. Table 3 presents the group statistics derived from an independent sample t-test for flank wear data. Figure 1 illustrates the preparation process for the novel textured carbide tool inserts. Additionally, figure 2 depicts the CNC lathe setup, accompanied by the MQL configuration employed during the turning experiments. The specific characteristics of the carbide tool insert CNGA 120408 used for experimental trials are presented in figure 3, showcasing an included angle of 80°, insert thickness of 4.8 mm, corner radius of 0.8 mm, and fixing hole diameter of 3.81 mm. Figure 4 provides an optical microscope image at 10x magnification for the measurement of flank wear. Figure 5 and figure 6 capture SEM images near the cutting edge of the tool insert, highlighting the tool flank wear land. Optical microscope images at 45x magnification, illustrating flank wear for both untextured and textured tool inserts, are presented. Figure 7 displays SPSS bar graphs generated from the results of the independent sample t-test for flank wear data.

Table 3: The group statistics of flank wear data obtained from the independent sample t-test.

Group statistics					
	Group	N	Mean	Std. deviation	Std. error mean
Flank wear (mm)	Control group	20	0.3120	0.05017	0.01122
	Experimental group	20	0.2502	0.04086	0.00914

Discussion

In CNC turning of 2205 duplex stainless steel, using liner groove CNGA 120804 tool inserts produces an average flank wear of 0.250 mm, whereas untextured CNGA 120804 tool inserts produce an average flank wear of 0.312 mm. Hence, reduced wear rate noticed in using CNGA 120804 tool inserts in the proposed study. The obtained results are in accordance with other researchers' findings. The above results show that the tool insert flank wear improved by using novel linear groove textured tool inserts in CNC turning of 2205 duplex stainless under nMQL using graphene based nano lubricants promote sustainable production. It was discovered that the nano-sized materials might perform as nano-sized ball bearings to convert sliding into rolling, reducing friction at the tool chip interference zone. This resulted in the nano-sized materials having outstanding tribological performance [8]. To make the surface hydrophobic, micro-texturing is applied. Investigating the tribological characteristics at the interfaces of chip-tool and work-tool, a micro-texturing approach has been implemented on the rake surface of the cutting insert. The primary advantage of micro-texturing lies in its capability to reduce the coefficient of friction at the chip-tool interface. Moreover, as chips traverse the rake face, they tend to become trapped within the textured grooves, leading to the generation

Figure 1: Novel textured carbide tool inserts preparation.

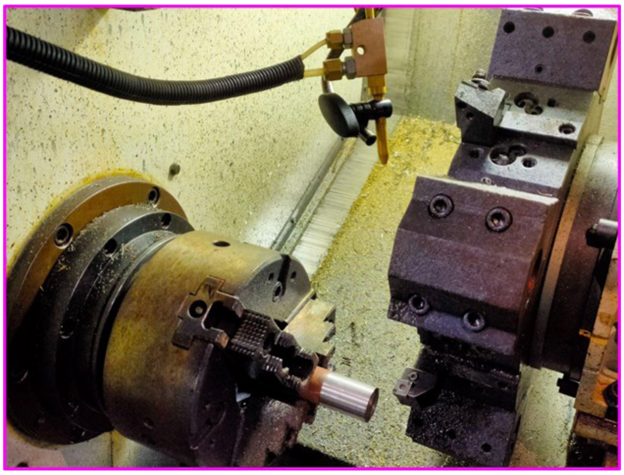

Figure 2: Jobber XL CNC turning machine set-utp.

Figure 3: Carbide tool inserts with ISO specification CNGA 120408.

Figure 4: An optical microscope with 10x magnification for flank wear measurement.

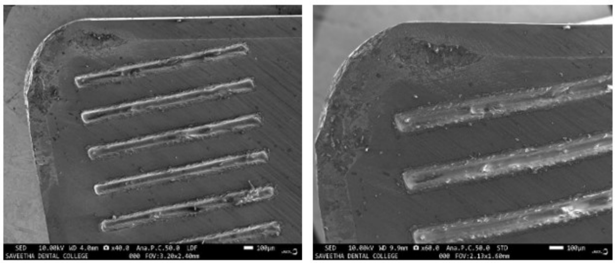

Figure 5: SEM images of linear grooved texture and flank wear.

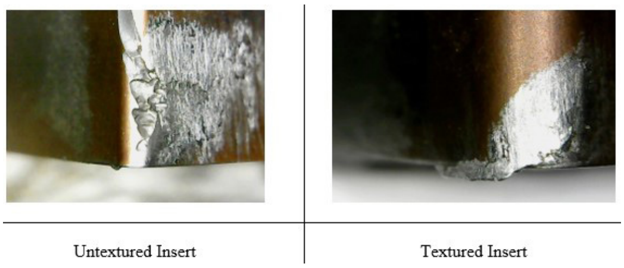

Figure 6: Optical microscope images showing flank wear of untextured insert and textured tool insert at 45x magnification.

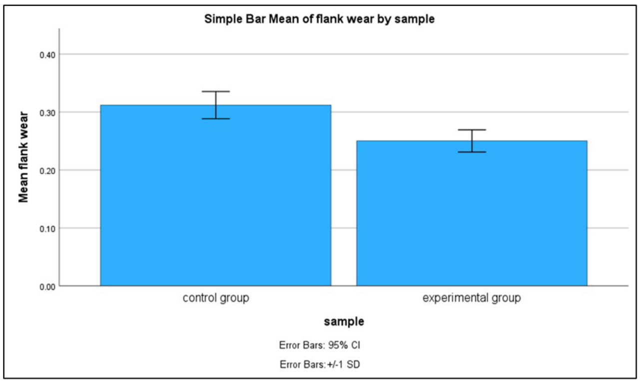

Figure 7: Comparison of tool insert flank wear among control group and experimental group.

of shorter, irregular chips that facilitate the machining process. The utilization of textured tools results in reduced actual contact between the chip and the tool's rake face, consequently causing the chips to traverse a shorter section of the rake surface and thereby diminishing tool wear [12].

Tool flank wear trends were assessed using a comprehensive experimental matrix involving 20 distinct combinations of cutting speeds, feed rates, and depth of cut. The outcomes of this assessment were consistent with the findings reported by Jurko et al. [13]. It was observed that chips undergo fracture and displacement from the rake surface upon encountering the geometric texture, thereby extending the operational life of the tool. Notably, the micro-texture on the rake surface can be conceptualized as an extended fin with a uniform cross-sectional profile, which facilitates more efficient heat dissipation to the surrounding environment. These results indicate a reduction in tool flank wear and highlight the potential of the micro-texture to act as a reservoir for the collection and containment of cutting fluid. Subsequent machining investigations will explore the implementation of nano-textured tool inserts and assess the impact of various cryogenic lubrication conditions [14].

Conclusion

Within the study's limitations, the proposed novel groove-textured CNGA120408 tool insert flank wear was 0.3120 mm compared to the untextured CNGA120408 tool insert flank wear of 0.2502 mm in turning 2205 duplex stainless steel under nMQL conditions using graphene-based nanofluids promote sustainable production. The statistical significance is evident from the p value (2-tailed) of 0.0024. The novel groove-textured CNGA120408 tool inserts reduced flank wear by 16.45% when compared to untextured CNGA120408 tool inserts in CNC turning of duplex stainless steel under nano minimum quantity machining conditions.

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None.

Conflict of Interest

None.

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