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Comparing CNC Turning of S32750 Super Duplex Stainless Steel Under Nano Minimum Quantity Machining Condition by Using Novel Textured Tool with Untextured Tool for Improving Tool Flank Wear

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Abstract

The primary goal of this study was to compare the cutting performance of novel linear- groove-textured carbide tool inserts (CNGA 120408) with untextured tool inserts (CNGA 120408) in CNC turning of S32750 super duplex stainless steel to reduce flank wear under nano Minimum Quantity Lubrication (nMQL). Surface texturing is an appealing green manufacturing approach that supports sustainable production by changing the surface texture of the cutting tool at the rake face and increasing the wettability of the cutting fluid at the cutting edge. A linear groove texture pattern was engraved on the tool surface using Laser Surface Texturing (LST). A Jobber XL CNC turner was used for turning operations on S32750 super duplex stainless steel with novel textured tool inserts and was compared to untextured tool inserts in terms of cutting performance criterion flank wear. The sample size was computed using a G-power of 80% and alpha value of 0.005. There were two groups, the experimental and control groups, with a total sample size of 40. The experimental results show flank wear of 0.245 mm for single-textured tools and 0.282 mm for untextured tools in turning S32750 super duplex stainless steel rods. The independent t-test results for the CNC turning process with textured and untextured tools under nMQL machining conditions are statistically significant with a p value (2-tailed) of 0.001 ($p < 0.05$). Within the constraints of the investigation, the suggested tool inserts with linear groove texturing demonstrated a noteworthy reduction in flank wear, amounting to 16.45%, compared to the untextured carbide tool inserts.

Keywords

CNC turning, Flank wear, Groove texture, Lubrication, Novel textured tool, Nano minimum quantity machining, Untextured tool, Sustainable production

Introduction

Super duplex stainless steels have emerged as a favored alternative to austenitic stainless steel due to their superior strength characteristics. This enhanced strength not only contributes to economic advantages but also results in reduced weight considerations. 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 [1]. Applying graphene nanoparticles to micro-void substrates can improve lubrication at the interface between the tool chip and the tool contact surface, thus reducing tool wear. Furthermore, the integration of these nanoparticles provides exceptional thermal resistance, effectively reducing heat transfer across the substrates [2]. The material of the workpiece is plastically distorted during machining processes, which causes heat to be produced. Together with the primary shear zone, ploughing at the freshly cut surface and sliding friction at the tool-chip contact also generate heat.

The life of a tool is typically shortened by the intense heat produced during machining. However, it can be challenging to machine these materials because the temperature in the cutting zone increases rapidly, causing rapid tool wear that eventually shortens the tool life because these materials often have relatively limited thermal conductivity. LST provides a variety of advantages over other methods, including rectifying surface topography and lowering substrate surface contamination, according to published research [3]. One of the methods to reduce tool wear is to use the nMQL, which includes 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 [4]. Cutting tools were employed in CNC turning under castor oil-based MQL and, moreover, MoS_2 nanoparticle-based nMQL to enhance fluids' capacity to dissipate heat when turning duplex stainless-steel materials [5]. Vegetable oils consist of triglyceride chains, which play a pivotal role in enhancing boundary lubrication. These triglyceride chains form a robust lubricating film over the contact surfaces, leading to an improved performance in boundary lubrication. Consequently, machinability is enhanced, contributing to more efficient and effective machining processes [6].

After an extensive assessment of the literature review, it was found that 234 articles and 401 papers had been published in accordance with the Science Direct database and Google Scholar, respectively. Several studies advocated the use of micro-texturing technology to enhance cutting efficiency. A detailed analysis revealed that the method largely solved the problems with traditional cutting and reduced tool wear [7]. Micro-texturing has lately attracted attention since it may be used to provide consistent contact stress and reduce the tool-chip contact area [8]. The inserts were created through plunge-face grinding and employed in the machining of a beta-titanium alloy (Ti-15Mo). When the tool life criteria were fulfilled, the insert with the least final flank wear value had the smoothest surface and edge, and the least grooves in the rake face perpendicular to the chip flow direction [8, 9]. Advancements in micro-texturing technology have led to notable improvements in the friction properties of surfaces within friction pairs. This process results in a reduction in surface wear and simultaneously enhances the surface bearing capacity [10]. 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 [11, 12]. Researchers have proposed a number of wear resistance and friction reduction strategies for various types of nanoparticles [13].

Although there is extensive ongoing study into the machinability of materials and alloys, no papers that are similar to this work have been found. This study compared the performance of a CNMG 120408 grade linear groove textured tool inserts with an untextured CNMG 120408 insert when turning S32750 super duplex stainless steel, in terms of tool flank wear. Wear analysis was conducted using scanning electron microscope (SEM) images.

Materials and Method

This study was conducted at the Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, with the use of the CNC turning machine on-site. This experimental study utilized a S32750 super duplex stainless steel rod. The turning trials were conducted using cylindrical rods purchased from SAAJ in Chennai, which had a diameter of 25 mm and a length of 110 mm. MET Mech LAB, Chennai (Tamil Nadu, India), 602105 verified the chemical composition of S32750 super duplex stainless steel. Table 1 shows the chemical composition of S32750 super duplex stainless steel.

Table 1: Mechanical properties of S32750 super duplex stainless steel.

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
S32750	Min	-	-	-	-	-	22.0	2.0	4	0.12
	Max	0.03	1.20	0.80	0.03	0.02	24.0	3.0	6.00	0.24

In this research, the effectiveness of a novel linear groove textured CNGA 120408 insert and an untextured CNGA 120408 carbide tool insert employed in the CNC turning of S32750 super duplex stainless steel is evaluated in terms of output response tool insert flank wear. Ethical approval was not required because this experiment did not use human samples. The new CNGA 120804 was used as the experimental group and the same insert without texture was used as the control group. The new CNGA 120804 had a linear groove surface texture. With a total sample size of 40, there were two groups: control and experimental. Using an alpha value of 0.05 and a G-power of 80%, the sample size was calculated [14, 15].

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 [16].

Laser surface texturing

The term "laser" refers to the equipment that is frequently used to intensify coherent radiations that have wavelengths in the violet, visible, and infrared regions of the electromagnetic spectrum. When the highly energetic pulse is applied, material is eliminated through laser ablation or by quickly melting and evaporating. LST has a variety of advantages over other approaches, including optimal surface topography and reducing substrate surface contamination, according to published studies. Tool wear is the result of chemical, thermodynamic, and mechanical interactions between the elements of the work-

Table 2: Combinations of the input parameters for comparing the flank wear of a 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 linear textured tool
1	55	0.12	1.0	0.245	0.282
2	113	0.12	1.0	0.321	0.245
3	55	0.22	1.0	0.314	0.321
4	113	0.22	1.0	0.192	0.213
5	55	0.12	2.0	0.275	0.278
6	113	0.12	2.0	0.286	0.214
7	55	0.22	2.0	0.243	0.264
8	113	0.22	2.0	0.324	0.246
9	35	0.17	1.6	0.236	0.241
10	133	0.17	1.6	0.177	0.198
11	84	0.09	1.6	0.243	0.264
12	84	0.25	1.6	0.234	0.198
13	84	0.17	1.6	0.331	0.231
14	84	0.17	2.0	0.254	0.241
15	84	0.17	1.6	0.276	0.297
16	84	0.17	1.6	0.255	0.246
17	84	0.17	1.6	0.321	0.187
18	84	0.17	1.6	0.314	0.348
19	84	0.17	1.6	0.289	0.246
20	84	0.17	1.6	0.245	0.244

piece and the tool. Flank wear and crater wear, the two primary types of tool wear that can signal the end of a tool's useful life, are largely caused by these interactions [3]. The extent of the tool flank is frequently related to the efficiency of the procedure. Many studies have demonstrated that as flank wear develops, cutting forces rise, and industrial machinery power consumption follows.

The proposed technique for calculating microscope wear involves the following steps: when positioning the machine tool, consider the features of the cutting tool holder, starting with the front clearance angle, when defining the characteristics of the worn-out cutting insert, particularly the nose radius [16]. When using the SEM picture to quantify tool wear, position the insertion such that the wear on the flank is parallel to the microscope image [17]. Align its unpolished edge with the microscope's horizontal reticle [18, 19]. Calculate the maximum flank wear by measuring at each of the insert's five points while keeping the vertical reticle of the microscope positioned at the end of wear to divert measurements away from the insert's nose radius [20].

Statistical analysis

The mean, standard deviation, and standard error of the experimental data were calculated using Statistical Package for the Social Sciences v.26 statistical software. Flank wear is the dependent variable, while feed, speed, and depth of cut are the independent variables. An independent sample t-test was used to analyze the flank wear data and determine statistical significance. Statistical significance is established when the obtained p value is less than 0.05.

Results and Discussion

The suggested surface texturing strategy of CNMG 120804 tool inserts provides an average flank wear of 0.250 mm on a CNC turning of S32750 super duplex stainless steel, while untextured CNMG 120804 tool inserts produce an average flank wear of 0.321 mm. Table 2 presents combinations of the input variables for comparing the flank wear of a unique linear groove textured carbide tool insert (CNGA 120804) and an untextured carbide tool insert (CNGA 120804). The output parameter, flank wear, is measured and tabulated. Table 3 The group statistics of flank wear data obtained from the independent sample t-test. Table 4 results of an independent sample t-test: With a p value of 0.001 ($p < 0.05$), a significant difference between the control and experimental groups is found.

Figure 1 presents textured tool inserts preparation. Figure 2 shows the Jobber XL CNC machine set- up. Figure 3 shows carbide tool inserts with ISO specification CNMG 120408. Figure 4 presents an optical microscope with 10x magnification for flank wear measurement. Figure 5 presents SEM images of linear grooved texture tool showing flank wear. Figure 6 presents optical microscope images showing flank wear of untextured insert and novel textured tool insert at 200X mag-

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

	Groups	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

Table 4: Outputs of independent sample t-test: A significant difference between the control and experimental group is observed with p value of 0.001 ($p < 0.05$).

		Levene's test for equality of variances		T-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% CI of the difference	
									Lower	Upper
Flank wear (mm)	Equal variance assumed	0.459	0.502	4.271	38	0.001	0.0618	0.0145	0.033	0.091
	Equal variance not assumed			4.271	36	0.001	0.0618	0.0145	0.033	0.091

(a) (b)

Figure 1: (a) Laser tool texturing process and **(b)** textured tool.

Figure 2: Jobber XL CNC machine set-up.

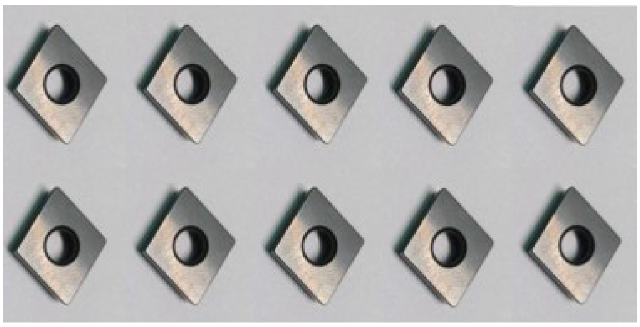


Figure 3: Carbide tool inserts with ISO specification CNMG 120408.

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

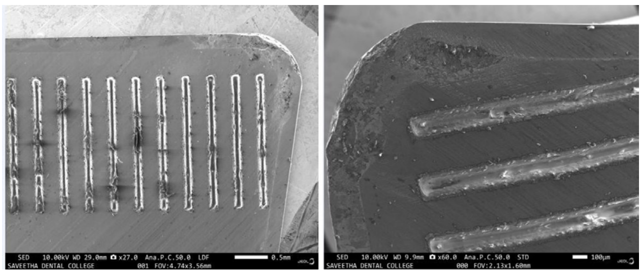
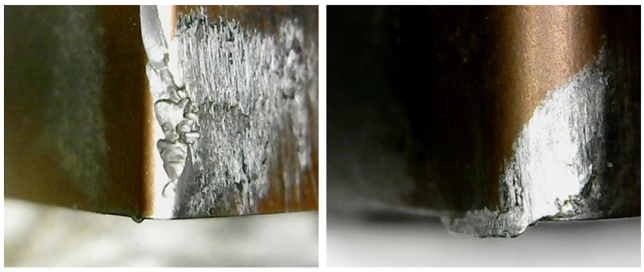


Figure 5: SEM images of linear grooved texture tool showing flank wear.



(a) (b)

Figure 6: Optical microscope images showing flank wear of **(a)** untextured insert and **(b)** textured tool insert at 200x magnification.

nification. Figure 7 presents comparison of the control group and the experimental group in terms of tool insert flank wear.

The mean flank wear value using an untextured carbide insert (control group) is high compared to the novel linear groove textured carbide tool insert (experimental group), and the standard deviation of the experimental group samples is better than that of the control group samples. X-axis: Sample groups, Y-axis: Mean flank wear with error ± 1 Standard de-

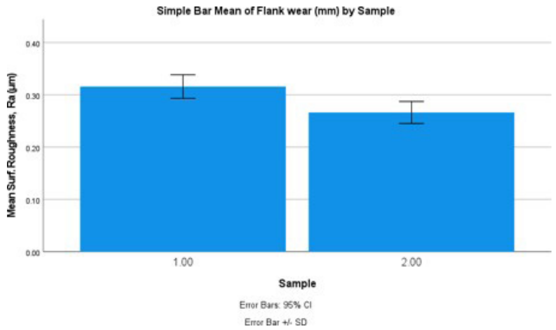


Figure 7: Comparison of the control group and the experimental group in terms of tool insert flank wear. The mean flank wear value using an untextured carbide insert (control group) is high compared to the novel linear groove textured carbide tool insert (experimental group), and the standard deviation of the experimental group samples is better than that of the control group samples. X-axis: Sample groups, Y-axis: mean flank wear with error ± 1 standard deviation.

viation.

CNC turning using a novel liner groove textured CNMG 120804 tool insert produces an average flank wear of 0.250 mm during CNC turning of S32750 super duplex stainless steel, while non-textured CNMG 120804 tool insertion produces an average flank wear of 0.312 mm. As a result, when CNMG 120804 tool inlays were used in the planned investigation, there was a decreased wear rate. The acquired results agree with other studies' conclusions [3]. The results show that using unique linear groove texture tool inserts in CNC turning of S32750 super duplex steel with nMQL with MOS_2-based nano lubricants improved tool insert flank wear. The ability of the nanoscale materials to act as miniature ball bearings, converting sliding into rolling, and thereby lowering resistance at the chip-chip interference zone, has been revealed [21]. Due to this, the tribological performance of the nanoscale materials was exceptional [22]. To make the surface hydrophobic, micro-texturing is applied. To evaluate the tribological characteristics of the chip-tool and work-tool interfaces, this micro-texturing technique has been used on the rake surface of the cutting insert [8]. The main advantage of micro-texturing is that it reduces the coefficient of friction at the chip-tool interface. Furthermore, as a chip moves along a rake face, it gets stuck in the texture groove and breaks apart, creating short, irregular chips that make machining simpler. As there is less direct contact between the chip and the tool's rake face when using textured tools, the chips slide along a shorter section of the rake face, thus decreasing tool wear [9, 23].

The trend of tool flank wear was assessed using 20 different combinations of cutting speeds, feed rates, and depth of cut. As the chip comes into contact with the geometric texture, it shatters and slides away from the rake surface, thus prolonging the tool's lifespan. Most notably, it is conceivable to view the micro-texture on the rake surface as an elongated fin with a consistent cross section that would assist in more efficient heat transfer to the environment. The results showed a reduction in tool flank wear. Furthermore, it can act as a container to absorb and hold cutting fluid [9]. Future machining research will include the use of nano-textured tool inserts and will evaluate different cryogenic lubrication conditions [24].

Conclusion

Within the study's limitations, the proposed novel groove-textured CNMG120408 tool insert flank wear was 0.312 mm compared to the untextured CNMG120408 tool insert flank wear of 0.243 mm in turning S32750 super duplex stainless steel under nMQL conditions using MOS_2-based nanofluids sustainable production. The statistical significance is evident from the p value of 0.001. The novel groove textured CNMG120408 tool inserts reduced flank wear by 16.45% when compared to untextured CNMG120408 tool inserts in CNC turning of duplex stainless steel under nMQL machining conditions.

Acknowledgements

None.

Conflict of Interest

None.

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