Nano World Journal

https://doi.org/10.17756/nwj.2023-s3-185

Research Article

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

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Received: July 31, 2023
Accepted: November 01, 2023
Published: November 03, 2023

Citation: Jawahar S, Thiyagu M. 2023. Comparing CNC Turning of 2205 Duplex Stainless Steel using Novel Dual Textured Tool with Untextured Tool for Reducing Flank Wear Under Nano Minimum Quantity Lubrication Condition. *NanoWorld J* 9(S3): S1047-S1052.

Abstract

The primary aim of this research is to perform a comparative assessment between novel dual-textured carbide tool inserts and untextured counterparts during the CNC turning operation applied to 2205 duplex stainless steel (DSS). This investigation is conducted under the conditions of nano minimum quantity lubrication (nMQL), with a specific emphasis on the mitigation of flank wear. A modern, contemporary green manufacturing technique called surface texturing is utilised to alter the surface topography of the cutting tool at the rake face, improving the wettability of cutting fluid at the cutting edge. The tool surface is textured with square and linear groove patterns using a femtosecond laser technique that promotes sustainable production. Addressing flank wear, a Jobber XL CNC turner used to turn 2205 DSS employed dual-textured tool inserts compared with untextured tool inserts. The study was executed utilizing a two-group approach, comprising a control group involving samples machined using untextured tool inserts and an experimental group utilizing novel dual-textured carbide tool inserts. Each group was comprised of a sample size of 20, resulting in an aggregate total sample size of 40. The Box-Behnken design methodology was employed as the experimental framework. Each experimental group consisted of a sample size of 20, resulting in a total sample size of 40, divided into two distinct groups. The experimental results show a mean flank wear of 0.321 mm for the experimental group samples and 0.261 mm for the control group samples in turning 2205 DSS rod. The obtained p value (2-tailed) of 0.0024 ($p < 0.05$) from the independent sample t-test results in the CNC turning process with nano MQL machining conditions is statistically significant. Within the limitations of the investigation, the suggested novel dual textured tool insert turned samples exhibit less flank wear than the untextured tool insert turned samples (18.26%). The process is statistically significant, as evidenced by the obtained p value of 0.0024.

Keywords

CNC turning, Duplex stainless steel, Flank wear, Novel dual textured carbide tool, Sustainable production

Introduction

The primary objective of this experimental investigation is to conduct a comparative analysis between dual-textured carbide tools and untextured counterparts concerning their performance metrics, specifically focusing on material removal rate and average surface roughness. These evaluations are carried out within the context of CNC turning operations involving DSS and utilizing nMQL as the cutting medium [1]. Products with excellent surface finishes, precise geometrical forms, and accuracy are in increased demand. However, due to significant tool wear [2, 3] it can be challenging to obtain a good surface quality when CNC turning 2205 duplex stainless rod with nMQL since the feature's extreme hardness causes edge deterioration. Due to the high cutting zone temperature, one machining technique for hard materials results in severe tool wear and poor surface quality. Because the flood cooling approach has a detrimental impact on the environment and the health of the CNC lathe operations, it cannot be utilised to process 2205 duplex stainless rod. Turning is the most common machining method used in the manufacturing sector. To fulfil its environmental obligations, industry has focused on low-volume lubrication machining methods [4].

This type of research has been the subject of around 532 publications, with 206 of those articles appearing in ScienceDirect. The term "machinability" refers to a material's ease of machining. Machinability, as highlighted by Korkmaz et al. [5], is a characteristic that cannot be precisely quantified but is inferred through various estimators. These estimators include cutting force, tool life, wear, chip form, and surface quality, listed in sequential order. Improved performance and productivity across these estimators indicate an enhanced capacity for machining the material. Notably, among lubrication methods, neat lubricating oil emerges as the optimal choice. This preference arises from the observation that in instances where minimum quantity lubrication (MQL) is more prominent than conventional cooling, surface roughness values demonstrate a reduction [6]. One outcome of this tool damage is cost-effective losses due to workpiece blemishing or poor surface quality. Because of their high rates of material removal and superior product quality, manufacturing industries are appealing [7]. The purpose of this experiment is to enhance the evaluation of the effects of process parameters on the surface roughness and material removal rate of work pieces made of LDX 2205 DSS [8]. This experiment uses CNC lathe operations in tool inserts with and without texturing.

Although there is extensive ongoing study into the machinability of materials and alloys, few study that are like this work have been found. In the present study, the performance of the CNGA 120408 grade dual-textured tool insert is compared with the untextured CNGA 120408 insert in turning 2205 DSS in terms of insert flank wear and wear analysis done using scanning electron microscope images [9, 10].

Materials and Methods

This research was conducted at the Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, and involved the utilization of an on-site CNC turning machine. The experimental material of choice for this study was a 2205 DSS rod, which was procured in cylindrical form with dimensions of 50 mm in diameter and 100 mm in length, specifically for the purpose of conducting turning trials. The chemical composition of the 2205 DSS is outlined in table 1. The primary focus of this research is to assess the efficacy of a novel linear groove and square textured CNGA 120408 inserts in comparison to an untextured CNGA 120408 carbide tool insert, during CNC turning operations applied to 2205 duplex stainless steel. The evaluation encompasses an examination of output response parameters and insert flank wear. It is pertinent to note that ethical approval was not required for this investigation, as it did not involve human samples. The research project is being executed by two distinct groups, with the experimental group utilizing the new CNGA 120804 insert featuring a linear groove surface texture. Meanwhile, the control group employs the same insert devoid of any texture. This study encompasses a total of two groups, namely the control and experimental groups, with a combined sample size of 40 [11].

Table 1: Chemical composition of 2205 DSS round bar.

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
2205 (S31803)	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 utilising a box-Behnken design and response surface approach, as shown in table 2. A unique linear groove texture and square texture were done on the rake face of the CNGA 120804 insert using the pulse laser engraving method. A linear groove and square texture tool insert of width 150 microns and depth 100 microns were made on the rake face perpendicular to the cutting edge. After acetone cleaning, the fabricated dual textured inserts were used to conduct turning experiments on a CNC lathe.

In the control group samples, 20 turning experiments were run using an untextured CNGA 120804 tool insert in a CNC

Table 2: Combinations of the input parameters for comparing the flank wear of a novel linear groove with a square 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	Dual textured tool
1	55	0.12	1.0	0.321	0.261
2	113	0.12	1.0	0.287	0.224
3	55	0.22	1.0	0.405	0.314
4	113	0.22	1.0	0.234	0.192
5	55	0.12	2.0	0.326	0.257
6	113	0.12	2.0	0.226	0.193
7	55	0.22	2.0	0.299	0.243
8	113	0.22	2.0	0.297	0.225
9	35	0.17	1.6	0.290	0.236
10	133	0.17	1.6	0.218	0.177
11	84	0.09	1.6	0.299	0.243
12	84	0.25	1.6	0.288	0.234
13	84	0.17	1.6	0.251	0.213
14	84	0.17	2.0	0.312	0.254
15	84	0.17	1.6	0.339	0.276
16	84	0.17	1.6	0.277	0.225
17	84	0.17	1.6	0.315	0.256
18	84	0.17	1.6	0.421	0.314
19	84	0.17	1.6	0.277	0.225
20	84	0.17	1.6	0.283	0.223

lathe. Graphene based nano lubricants in MQL conditions used for cooling and lubrication promote sustainable production. According to published research, Laser surface texturing has several benefits over other techniques, including optimum surface topography and minimizing substrate surface contamination [12].

Tool wear is caused by interactions between the materials of the tool and the workpiece that are chemical, thermal, and mechanical in nature. The two main types of tool wear, flank wear and crater wear, which may mark the end of a tool's usable life, are mostly caused by these interactions. The extent of flank wear is frequently related to the efficiency of the procedure. Numerous studies have demonstrated that rising cutting pressures due to growing flank wear result in higher machine tool power consumption [13]. 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 [14]. 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 [15]. 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. The tool insert flank wear was studied using scanning electron microscope images taken near the tool cutting edges. The statistical analysis involved the utilization of IBM-SPSS software for the computation of key statistical parameters, including mean values, standard deviations, and standard errors. Additionally, t-tests were employed to assess the statistical significance of the observed data.

Results

The proposed surface dual texturing strategy of CNGA 120804 tool inserts produces an average flank wear of 0.250mm on a CNC turning of 2205 DSS, whereas untextured CNGA 120804 tool inserts provide an average flank wear of 0.312mm. Table 2 presents the Box-Behnken design matrix, detailing the input parameters utilized for the comparative assessment of flank wear between a novel dual-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. Figure 1 presents the dual textured tool inserts preparation. Figure 2 shows the CNC lathe along with the MQL setup used for turning experiments. The carbide tool inserts CNGA 120408 with 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 used for experimental trials is shown in figure 3. Figure 4 shows the dual textured CNGA 120408 inserts used for experimental trails. Figure 5 displays an optical microscope with 10x magnification for flank wear measurement. Figure 6 depicts scanning electron microscope (SEM) images captured in proximity to the cutting edge of the tool insert, revealing the presence of tool flank wear. Figure 7 presents optical microscope images, magnified at 45X, displaying the extent of flank wear observed on both untextured and textured tool inserts. Figures 8 show the SPSS bar graphs generated from the t-test results for mean flank wear.

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

Group statistics						
	Group	**N**	**Mean**	**Std. deviation**	**Std. error mean**
Flank wear (mm)	Control group	20	0.2983	0.05096	0.01139
	Experimental group	20	0.2392	0.03548	0.00793

Discussion

In CNC turning of 2205 DSS, using liner groove and square texture CNGA 120804 tool inserts produce an average flank wear of 0.250mm, whereas untextured CNGA 120804 tool inserts produce an average flank wear of 0.312mm. Hence, a reduced wear rate was noticed when using CNGA 120804 tool inserts in the proposed study [16]. 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 and square textured tool inserts in CNC turning of 2205 duplex stainless under nMQL using graphene based nano lubricants promotes sustainable production [17]. It was discovered that the nano-sized materials might

Figure 1: Dual textured tool insert preparation.

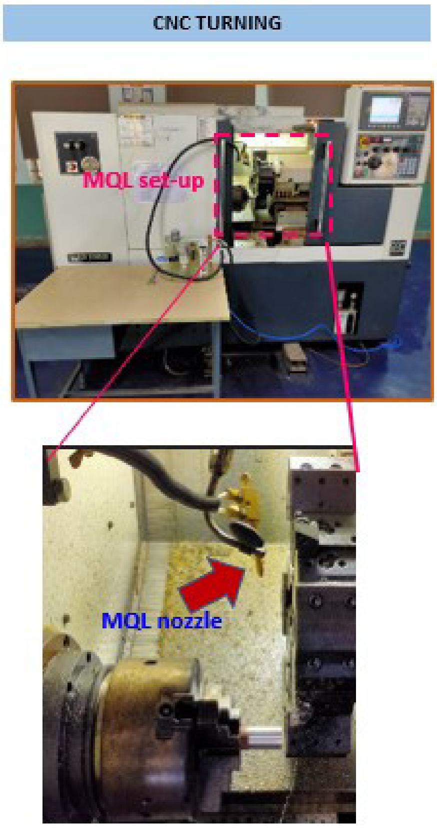

Figure 2: Jobber XL CNC turning machine set-utp.

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

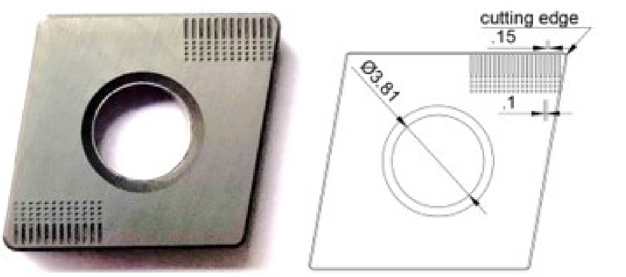

Figure 4: Dual textured CNGA 120408 inserts with texture specifications.

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 to make the surface hydrophobic, micro-texturing is applied [18]. To examine the tribological characteristics at the chip-tool and work-tool interfaces, this micro-texturing approach has been applied to the rake surface of the cutting insert [19]. The principal advantage of micro-texturing resides in its capability to reduce the coefficient of friction at the chip-tool interface. Furthermore, as chips traverse the rake face, they tend to become entrapped within the textured grooves, leading to the generation of shorter and irregularly shaped chips, thereby facilitating the machining process. Since there is less real contact between the chip and the tool's rake face when using dual textured tools, the chips slide along a shorter portion of the rake surface and thus reducing tool wear [20].

The trend of tool flank wear was assessed using 20 different combinations of cutting speeds, feed rates, and depth of cut, and the results agreed with the findings of previous authors. Significantly, one can conceptualize the micro-texture on the rake surface as an extended fin characterized by a uniform cross-sectional profile, which enhances the transmission of heat to the surrounding environment. The findings reveal a notable reduction in tool flank wear. Additionally, the micro-texture can function as a reservoir for the collection and retention of cutting fluid [21, 22]. Future machining studies

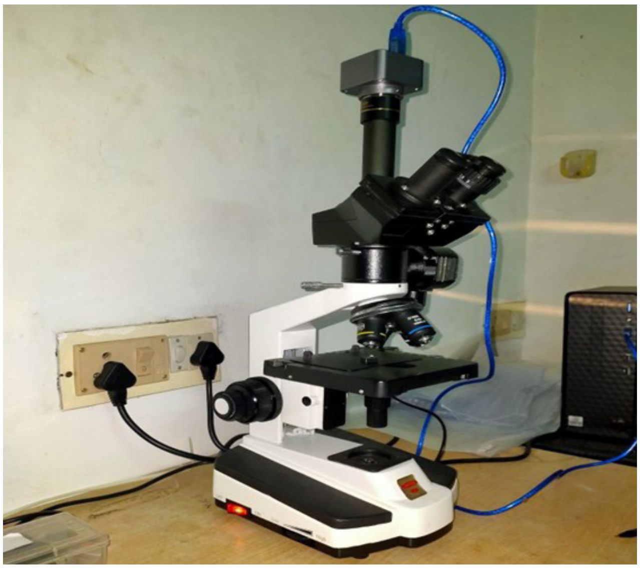

Figure 5: An optical microscope with 45x magnification for flank wear measurement.

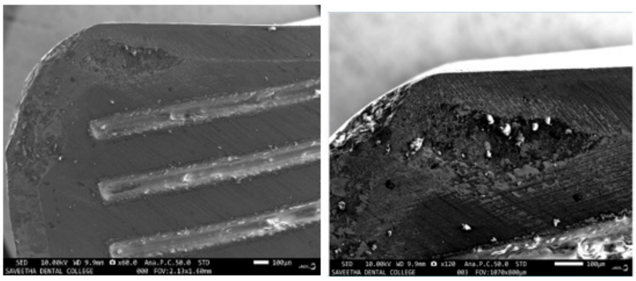

Figure 6: SEM images of dual textured inserts showing flank wear near cutting edges.

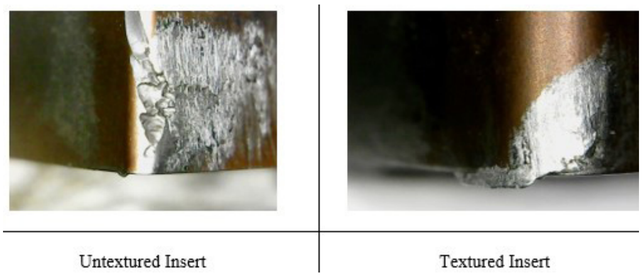

Figure 7: Optical microscope images showing flank wear of untextured insert and dual textured tool insert at 45x magnification.

will involve nano-dual textured tool inserts, as well as assess different cryogenic lubrication conditions [19].

Our university has had success in several areas and is committed to undertaking high-quality, fact-based research. Our research is intended to carry on that illustrious tradition. The material 2205 stainless steel employed in this study has limits due to its challenging machining and need for nMQL for CNC machining [23]. The most likely reason for this drop is the rise in cutting zone temperature, which affects the workpiece surface. Due to the need for nMQL and graphene nanoparticles for CNC machining, producing the 2205 stainless steel used in this work is difficult [24]. future reach machining tests using ceramic inserts and evaluating various cryogenic settings.

Conclusion

Within the constraints of the investigation, turning 2205 DSS with graphene-based nanofluids resulted in a proposed unique dual-textured CNGA 120408 tool insert flank wear of 0.3120 mm as opposed to the untextured CNGA 120408 tool insert flank wear of 0.2502 mm. The statistical significance is evident from the p value (2-tailed) of 0.0024.The novel dual textured CNGA 120408 tool inserts reduced flank wear by 18.26% when compared to untextured CNGA 120408 tool inserts in CNC turning of DSS under nMQL machining conditions is promotes sustainable production.

Acknowledgements

None.

Conflict of Interest

None.

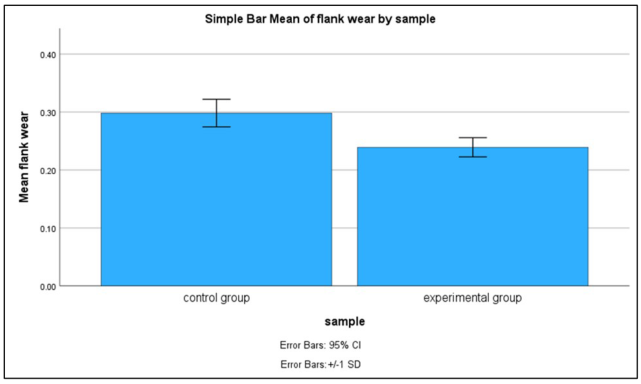

Figure 8: Comparison of control group and experimental group in terms of tool insert flank wear. The mean flank wear value using untextured carbide insert (control group) is high compared to the novel linear groove and square textured carbide tool insert (experimental group) and the standard deviation of experimental group samples is better than that of control group samples. X-axis: Sample groups, and Y-axis: mean flank wear with error ± 1 SD.

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