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A Comparative Study on CNC Turning of S32750 Super Duplex Stainless Steel with Novel Dual Textured Tool Inserts with Untextured Tool Inserts for Improving Material Removal Rate and Surface Roughness Under Nano Minimum Quantity Lubrication Condition

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Abstract

This research involves a comparative study between novel dual-textured tool inserts and untextured tool inserts during CNC turning of S32750 super duplex stainless steel (SDSS), with a specific focus on nano-Minimum Quantity Lubrication (nMQL) conditions. The primary aim is to optimize the Material Removal Rate (MRR) and surface finish through a comprehensive analysis of the performance exhibited by these two categories of tool inserts. Surface texturing is an innovative green manufacturing technology that enhances the wettability of the cutting fluid at the cutting edge by modifying the surface texture of the cutting tool at the rake face. A novel dual textured tool with square and linear groove texture patterns is engraved on the tool surface using a femtosecond laser technique. The MRR and workpiece quality of a Jobber XL CNC turner used for turning operations on S32750 SDSS employing dual-textured tool inserts and untextured tool inserts were compared. In this study, each group (Control and experimental) is composed of 20 samples, yielding a cumulative sample size of 40. The calculation of the sample size is performed with a statistical power (G-power) of 80% and a significance level (alpha) set to 0.0024. The experimental results show an average surface roughness of 1.276 μm for dual-textured tools and 1.072 μm for untextured tools when turning S32750 SDSS rod. A better MRR of 13.126 cc/min is obtained when turning with dual- textured tools when compared to 10.846 cc/min with an untextured tool insert. The independent t-test results in the CNC turning process with nMQL machining conditions are statistically significant for surface roughness with a "p" value (2-tailed) of 0.001 ($p < 0.05$) and for MRR data, it is $p = 0.0074$ ($p < 0.05$). Based on the findings of this experimental investigation, the application of the proposed dual-textured tool insert resulted in a significant augmentation of the MRR by 17.12%, coupled with a corresponding reduction in surface roughness by 19.35%, in comparison to the utilization of the untextured carbide tool inserts.

Keywords

Material removal rate, Nano minimum quantity lubrication, Novel dual textured tool, Surface roughness, Sustainable production

Introduction

The primary objective of this study is to investigate the feasibility of enhancing the machinability of S32750 SDSS during CNC turning. This will be achieved by employing a novel dual-textured tool insert and optimizing the process parameters, with a specific focus on comparing the outcomes with those obtained using an untextured tool insert. The study aims to achieve lower surface roughness and higher MMR through these interventions [1]. Obtaining a good surface quality while machining S32750 SDSS with nMQL is rather difficult due to edge degeneration caused by the future's extreme hardness in the process of the cutting effect on the spindle speed and feed rate of the surface roughness of the machining in stainless steel in the CNC turning process [2]. This study's findings can be applied to the turning process used in the automotive sector to achieve the greatest results with the fewest rejections when using S32750 SDSS and innovative dual-textured tool inserts [3]. Duplex S32750 SDSS has been extensively utilized by manufacturers, especially in industries such as oil and gas, petrochemical, and pulp and paper [4]. They frequently replace austenitic stainless steels, which are sensitive to chloride stress corrosion cracking or pitting while employed in aqueous, chloride-containing environments [5].

Cutting depth, feed, and cutting speed were chosen as the cutting parameters for the turning operation [6]. In this research, the main objective is improving the good surface finish and high MRR during the CNC turning process of aluminum alloys under machining with nMQL by using a novel dual-textured tool [7]. With the addition of MoS_2 nanoparticles and castor oil for lubrication, the cutting zone temperature is reduced while machining when using nMQL in this case, performance is enhanced by using a rotary tool with ultrasonic vibration applied to the tool and the workpiece [8]. Using CNC lathe operations and MoS_2 based nanofluids under nMQL conditions, this experiment evaluates the effects of process variables on surface roughness and MRR in titanium alloy workpieces. Promoting sustainable production is the intent [9].

Although there is a lot of active study into the machinability of various materials and alloys, no papers that are similar to this one has been discovered. This study aims to compare the unique dual-textured CNMG120408 tool inserts with the untextured CNMG120408 tool inserts in terms of workpiece surface roughness and MRR in CNC turning SDSS under nMQL condition.

Methodology

This study was conducted at the Saveetha Institute of Medical and Technical Sciences in Chennai, at the CNC turning facility of the Saveetha School of Engineering. The investigation's workpiece is a 125 mm long, 25 mm diameter rod of S32750 SDSS. The chemical make-up of S32750 SDSS is shown in table 1. In this study, the effectiveness of a special dual-textured tool insert used in CNC turning is compared to that of an untextured carbide tool insert. This project is being worked on by two different groups. The experimental group in this study utilizes the new CNMG120804 carbide insert with a surface texture comprising a linear groove and square pattern. In contrast, the control group employs the same insert without any surface texture. The total sample size determined for each group was 20, with a mean of 0.2502 to 0.3120 and a standard deviation of 0.04086 to 0.05017. A pre-test G-power of 80% was used [10, 11]. The sample size of each group is 20; there are two groups, viz., the control group and the experimental group; the total sample size is 40; and the sample size is calculated with a G-power of 80% and an alpha of 0.0024. The test workpiece samples used in the two groups were S32750 SDSS [12]. According to table 1, the chemical composition of S32750 SDSS has carbon at 0.35 which is lower in proportion. Table 2 presents physical properties. Table 3 displays the mechanical characteristics of S32750 SDSS, which has high tensile strengths of 797.18 MPa and yield strengths of 701.64 MPa.

MQL set-up

The MQL equipment's flow rate was set to 120 ml/h. The compressed air was introduced into the system using a pressure regulator set to 4 bars. The system incorporates two separate systems to control the flow of oil and air. Two distinct coaxial tubes are used to provide the air and lubricant flows to the 2 mm-diameter nozzles; at the terminal portion, the oil is mixed and nebulized. In the current work, plain castor oil is combined with nanofluids made of graphene nanoparticles. It promotes sustainable production, is non-toxic, and is created from renewable raw materials. In experimental group samples, the turning trials are conducted using a Box-Behnken design in response surface methodology. Twenty turning experiments were conducted using a novel linear groove-textured and square textured CNMG 120804 tool insert in a CNC lathe [13]. In the control group samples, 20 turning process experiments were run using an untextured new CNMG 120804 tool inserted in a CNC lathe [14]. Graphene based nanofluids in nMQL conditions for cooling and lubrication promote sustainable production [15].

With a sampling length of 4 mm, the Mitutoyo-SJ-410 surface roughness tester is used to quantify average surface roughness. The average surface roughness value (Ra) for each of the 20 samples was calculated after three readings. The

Table 2: Physical properties of S32750 SDSS round bar.

Physical properties	Value
Density	0.278 lb/in³
Melting range	2525 - 2630 °F
Specific heat capacity at 212 °F	0.119 Btu/lb/°F
Thermal conductivity at 212 °F	8.4 Btu/hr-ft-°F
Poisson's ratio	0.3
Elastic modulus at 72 °F	29 x 10 psi

Table 3: Mechanical properties of S32750 SDSS round bar according to ASTM A 370-08a.

Material name	S32750 super duplex stainless steel
Tensile strength (N/sq.mm)	797.18
Yield strength (N/sq.mm)	701.64
Elongation (%)	280.14

Table 1: S32750 SDSS round bar chemical composition.

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
S32750	Min	-	-	-	-	-	22.0	2.0	4	0.18
	Max	0.03	1.20	0.80	0.03	0.02	24.0	3.0	6.00	0.24

Table 4: Experiment findings for surface quality and their input variable levels in CNC turning using cutting-edge dual-textured and untextured tool inserts.

S. No.	Cutting speed, Vc (m/min)	Feed rate, f (mm/rev)	Tool nose radius, Nr (mm)	Surface roughness, Ra (µm)	
				Untextured insert	Dual textured insert
1	55	0.12	0.2	2.923	2.456
2	113	0.12	0.2	2.154	1.737
3	55	0.22	0.2	3.346	2.812
4	113	0.22	0.2	1.711	1.437
5	55	0.12	0.8	3.030	2.546
6	113	0.12	0.8	1.954	1.642
7	55	0.22	0.8	2.992	2.337
8	113	0.22	0.8	1.276	1.072
9	35	0.12	0.4	3.319	2.789
10	133	0.17	0.4	1.289	1.084
11	84	0.09	0.4	1.910	1.553
12	84	0.25	0.4	2.143	1.801
13	84	0.17	0.4	2.560	2.207
14	84	0.17	0.80	2.348	1.973
15	84	0.17	0.4	2.177	1.829
16	84	0.17	0.4	1.819	1.529
17	84	0.17	0.4	2.700	2.045
18	84	0.17	0.4	2.232	1.875
19	84	0.17	0.4	2.365	1.987
20	84	0.17	0.4	2.015	1.737

amount of material or metal removed in a given amount of time is known as the MRR. It measures in cc/min. MRR, and sustainable production rate are inversely proportional. Productivity increases with increasing MRR values, and vice versa. Each specimen was subjected to the following calculation of the MRR:

$$MRR\ (cc/min) = D \times F \times S \quad (1)$$

Where, D = Depth of cut (mm), F = feed rate (mm/rev), and S = cutting speed (m/min).

Statistical analysis

The mean value, standard deviation, and standard error were determined in this study using Statistical Package for the Social Sciences version 26 statistical software. The MRR and surface roughness are the dependent variables being examined. On the other hand, the independent variables considered are tool feed, cutting speed, and depth of cut. To analyze the data and determine the significance of the use of novel dual textured tool CNMG120408 inserts and untextured inserts for machining S32750 SDSS, the t-test was used.

Results

The dual-textured insert exhibits a mean value of 0.2502, accompanied by a standard deviation ranging from 0.5017 to 0.4086. A dual-textured insert's standard error mean is 0.00914, while an untextured insert's is 0.1122. The surface roughness was tested using a t-test on independent samples, with a significant value of $p = 0.001$. The dual-textured insert has a mean value between 0.414 and 0.314 and a standard deviation range between 0.126365 and 0.126132. According to table 1, Si has the greatest percentage value of 0.80 and the lowest percentage value of 0.25% in S32750 SDSS chemical makeup.

The physical characteristics of S32750 SDSS, which has a high melting point of 1425 °C, are provided in table 2. The mechanical characteristics of S32750 SDSS are shown in table 3. The 20 distinct input parameter combinations for examining the performance of a unique dual-textured SS tool insert and an untextured ceramic tool are shown in table 4. Table 4 experiment findings for surface quality and their input variable levels in CNC turning using cutting-edge dual-textured and untextured tool inserts computed MRR values using speed, feed, and depth of cut for innovative dual- textured inserts and untextured inserts. For the suggested and standard ways of machining, respectively. Table 4 and table 5 present a concise summary of the collected observations, encompassing measured surface roughness and computed MRR. Table 6 and table 7 group statistics and independent t-test analysis for surface roughness, respectively. Table 8 and table 9 group statistics and independent t-test analysis for MRR, respectively.

Figure 1 shows the MoS_2 nanofluid preparation. Figure 2 depicts the CNC turning with MQL nozzle. Figure 3 presents turning inserts with ISO specifications CNMG 120408 for turning experiments. Figure 4 gives the details of the dual linear groove with dimple textured CNMG 120408 insert with include angle 80°, insert thickness 4.8 mm. The experimental facility for a CNC turning center is shown in figure 5. Mitutoyo model SJ-410 surface finish analyzer for surface roughness measurement is given in figure 6. It enables highly accurate measurement using a handheld tester. It has a profile assessment without printout and validation of measurement data. The bar graphs produced from the outcomes of the independent samples' tests for surface roughness and MRR observations, respectively, are shown in figure 7 and figure 8. That of control group samples. X-axis: Sample groups, Y-axis: mean surface roughness with error ± 1 standard deviation.

Table 5: Output parameter MRR and their input parameter levels in the CNC turning process using novel dual textured and untextured tool inserts.

S. No.	Cutting speed, Vc (m/min)	Feed rate, f (mm/rev)	Tool nose radius, Nr (mm)	MRR (cc/min)	
				Untextured insert	Dual textured insert
1	55	0.12	0.2	6.2304	5.28
2	113	0.12	0.2	12.90912	10.848
3	55	0.22	0.2	11.7128	9.68
4	113	0.22	0.2	24.06448	19.888
5	55	0.12	0.8	6.5472	5.28
6	113	0.12	0.8	13.12608	10.848
7	55	0.22	0.8	11.7128	9.68
8	113	0.22	0.8	24.06448	19.888
9	35	0.12	0.4	4.0656	3.36
10	133	0.17	0.4	22.06736	18.088
11	84	0.09	0.4	7.31808	6.048
12	84	0.25	0.4	20.496	16.8
13	84	0.17	0.4	13.82304	11.424
14	84	0.17	0.80	13.82304	11.424
15	84	0.17	0.4	13.82304	11.424
16	84	0.17	0.4	13.82304	11.424
17	84	0.17	0.4	13.82304	11.424
18	84	0.17	0.4	13.82304	11.424
19	84	0.17	0.4	13.82304	11.424
20	84	0.17	0.4	13.82304	11.424

Table 6: Group statistics result for control and the experimental group. The surface roughness mean, standard deviation, and standard error mean are shown below.

	Groups	N	Mean	Std. deviation	Std. error mean
Surface roughness	Control group	20	0.3120	0.05017	0.01122
	Experimental group	20	0.2502	0.04086	0.00914

Table 7: Results of independent sample t-test: A significant difference between the control and experimental group is observed - Significance value p = 0.001 (p < 0.05) and the t value is 4.271.

		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
Surface roughness	Equal variance assumed	0.459	0.502	4.271	38	0.001	0.0618	0.01447	0.0325	0.0911
	Equal variance not assumed			4.271	36	0.001	0.0618	0.01447	0.0325	0.0911

Table 8: Group statistics result for control and the experimental groups. The MRR mean, standard deviation, and standard error mean are tabulated.

	Groups	N	Mean	Std. deviation	Std. error mean
MRR	Control group	20	14.1925	5.68256	1.27066
	Experimental group	20	17.6392	7.28435	1.62883

Discussion

The results show that the proposed linear groove textured, and square textured tools outperform a conventional untextured carbide tool insert in terms of MRR and surface finish. The independent samples t-test reveals statistical significance for the MRR observations, with a p-value of 0.001 ($p < 0.05$), as well as for surface roughness observations. Hence, the observations did not violate statistical assumptions.

Achieving an ideal surface finish poses challenges due to various influential parameters, including tool geometry, workpiece microstructure, tool interaction with the workpiece, build-up edge formation, and chip interface dynamics, etc. [16]. At the lower cutting speed of 55 m/min, the surface roughness attained its maximum value of 2.525 μm. As the cutting speed was increased, the surface roughness exhibited a decreasing trend. This observation can be attributed to the adverse effect of build-up edge formation, which adversely affects the surface quality at slower cutting rates [17]. A single linear groove textured insert can achieve a maximum average MRR of 27.36 cc/min at a maximum cutting speed of 133 m/min, a nominal feed rate of 0.17 mm/rev, and a nose radius

Table 9: Results of independent sample t-test: A significant difference between the control and experimental group is observed - Significance value p = 0.0074 (p < 0.05) and the t value is - 1.668.

		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
MRR	Equal variance assumed	0.474	0.495	-1.668	38	0.0074	-3.447	2.066	-7.628	0.735
	Equal variance not assumed			-1.668	35.8	0.0074	-3.447	2.065	-7.636	0.743

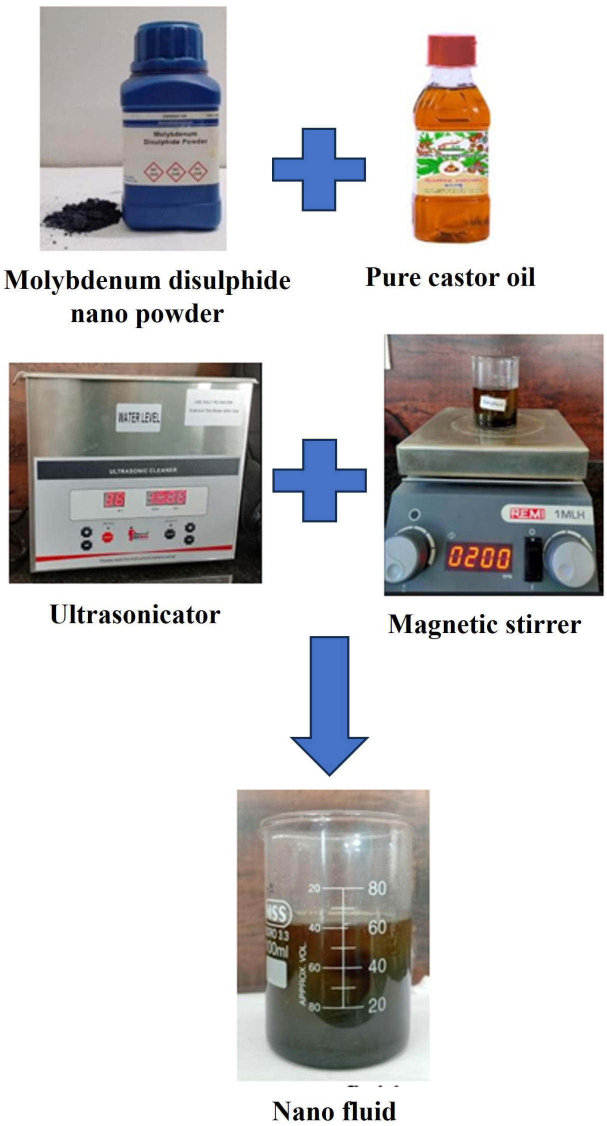

Figure 1: MoS_2 nanofluid preparation.

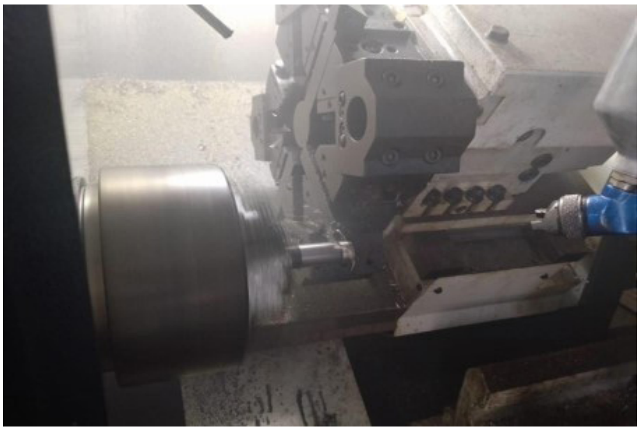

Figure 2: CNC turning with MQL nozzle.

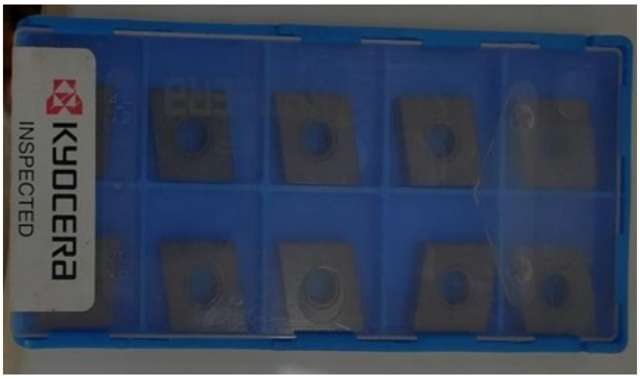

Figure 3: Turning inserts with ISO specifications CNMG 120408 for turning experiments.

of 0.4 mm. The results obtained are consistent with those of Kaladhar [18]. The quantitative analysis revealed that rake face texturing could potentially reduce the overall thrust forces by approximately 10.57% and 14.68% at cutting speeds of 80 m/min and 140 m/min, respectively, with a groove aspect ratio of 0.6 and a groove spacing of 90 µm [19].

The linear groove texturing and square texturing configuration enhance emulsion penetration and can serve as micro-reservoirs, facilitating constant emulsion replenishment. Consequently, these improvements promote better cooling and lubrication during machining operations [20]. The limitations of this study lie in the dual textured linear groove and square texture spacing and groove aspect ratio of dual textured tool inserts. The future scope of this research involves analyzing the influence of tool wear on rake face texturing and its overall impact on the machining efficiency of dual-textured, uncoated tungsten carbide tools.

Conclusion

Within the study's limitations, the proposed novel textured CNMG 120408 carbide tool insert improved the MRR

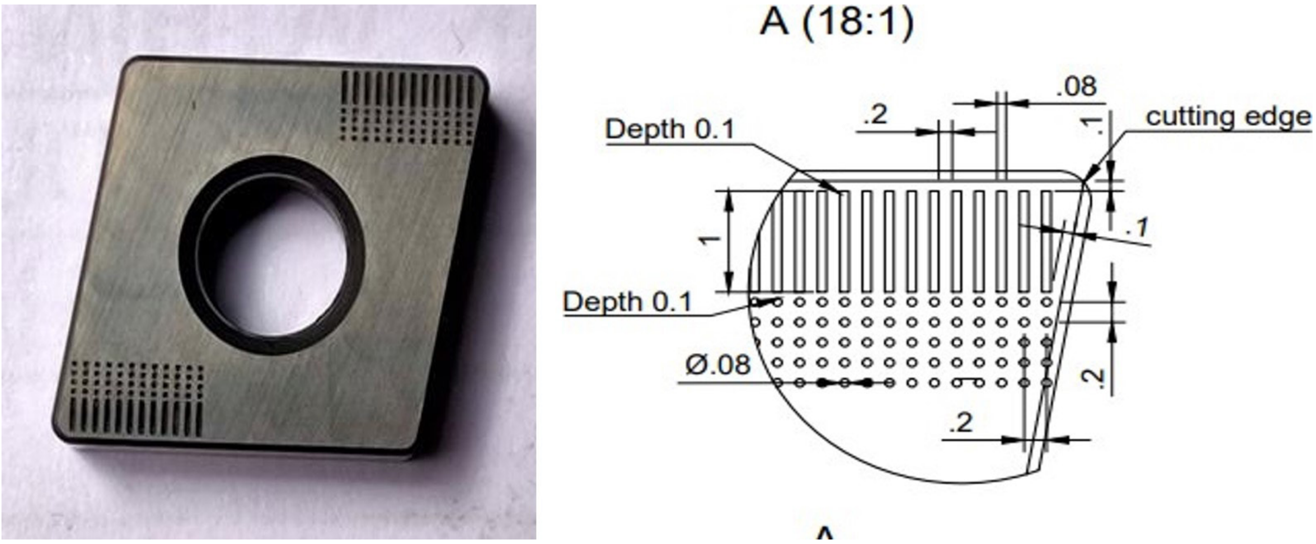

Figure 4: Dual linear groove with dimple textured CNMG 120408 insert with include angle 80°, insert thickness 4.8 mm, fixing hole diameter 3.81 mm.

Figure 5: Experimental setup - Jobber XL CNC lathe, specifications: swing carriage - 260 mm, maximum turning diameter - 290 mm, maximum turning length - 400/500 mm, swing bed - 500 mm, max spindle speed - 4000 rpm, number of stations - 8, and chuck size - 200/250.

Figure 6: Mitutoyo model SJ-410 surface finish analyzer for surface roughness measurement.

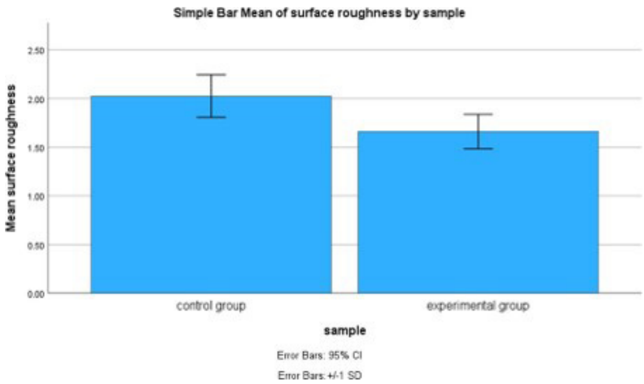

Figure 7: Comparison of control group and experimental group in terms of surface roughness. The mean surface roughness value of machined surfaces using untextured carbide insert (control group) is high compared to the novel dual textured carbide tool insert (experimental group) and the standard deviation of experimental group samples is better than.

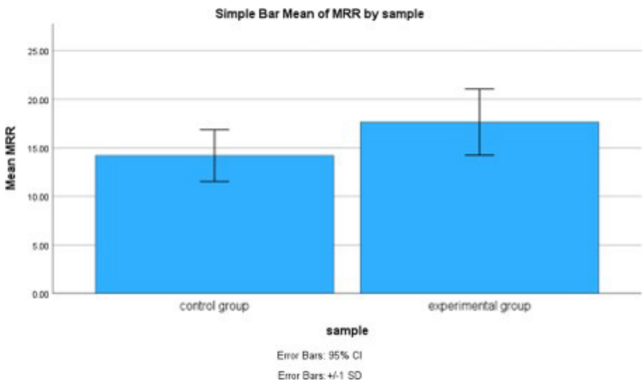

Figure 8: Comparison of control group and experimental group in terms of mean MRR. The mean MRR values of machined surfaces using untextured carbide insert (control group) is low compared to the novel dual textured carbide tool insert (experimental group) and the standard deviation of experimental group samples is better than that of control group samples. X-axis: Sample groups, Y-axis: mean MRR with error ± 1 standard deviation.

performance from 14.193 cc/min to 17.126 cc/min under nMQL machining conditions. An improvement of 17.12% in MRR is noticed. The textured tool inserts yielded average surface roughness values of 1.661 µm when compared to the untextured tool insert's 2.025 µm. When employing the novel textured CNMG 120408 tool insert in CNC turning of S32750 SDSS, a significant improvement of 18.46% in surface roughness is observed compared to the performance of the untextured tool insert.

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None.

Conflict of Interest

None.

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