Original Article

Comparing Machinability Performance of TISIN Coated HSS Tool with Uncoated HSS Tool for CNC Green Machining (CNC Turning) of High Strength Steel Alloy (EN9) for Improving Machining Rate and Surface Finish

Hari Krishnan.S[1], Sathish T[2*]

[1]Research Scholar,Department of Mechanical Engineering,Saveetha School of Engineering,Saveetha Institute of Medical and Technical Sciences,Saveetha University, Chennai, Tamil Nadu. India. Pincode: 602 105
[2]Project Guide, Department of Mechanical Engineering,Saveetha School of Engineering,Saveetha Institute of Medical and Technical Sciences,Saveetha University, Chennai, Tamil Nadu. India. Pincode: 602 105

Abstract

Aim: The objective of this paper is to minimize surface roughness and increase material removal rate (MRR) in cnc green machining of Novel Titanium Silicon Nitride (TISIN) coated High Speed Steel (HSS) tool with uncoated High Speed Steel (HSS) tool for cnc green machining (cnc turning) of high strength steel alloy (en9). Materials and Methods: The machining performance of high strength steel alloy material is compared with the novel Novel Titanium Silicon Nitride (TISIN) coated High Speed Steel Tool and Uncoated High Speed Steel (HSS) tool. Sample size calculated with the settings of G-power 80%. Total number of groups is 2 and the sample size is 16 per group. Hence total samples involved are 32.
Results: The results revealed that the average material removal rate improved from 57015.09mm^3/min to 9209.18 mm^3/min by use of the noval Titanium Silicon Nitride coated High Speed Steel Tool instead of conventional uncoated tool. Similarly the surface roughness reduced from 1.805125 µm to 0.458 µm. The Significance of P value obtained was 0.012 ($p<0.05$) for material removal rate and $p=0.04$ ($p<0.05$) for surface roughness observations.
Conclusion: Within the limitations of the studies, the performance of high strength steel alloy with Noval Titanium Silicon Nitride coated High Speed Steel Tool recorded a higher material removal rate (14.89%) than the conventional High Speed Steel Tool. Similarly, the proposed coated tool reduced surface roughness 59.43% than the conventional uncoated tool.
Keywords: Novel Titanium Silicon Nitride coated High Speed Steel tool, High Strength steel alloy , Uncoated High Speed Steel Tool, Surface Roughness, Material Removal Rate, Green Machining.

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INTRODUCTION:

CNC turning of high strength steel alloy material with the (070 M55) grade Novel Titanium Silicon Nitride coated High Speed Steel Tool and High Speed Steel.(Chauhan and Kumar 2020) Tool to get more material removal rate and to get low surface roughness for this paper (Kumar, I. K. G. Punjab Technical University, and (PB)-India 2017; S. Rajesh, Chandramohan, and Sathish 2020) Machining of the High strength steel alloy was more difficult because of its high mechanical strength and high hardness (Sathish, Sabarirajan, and Karthick 2020). High strength steel alloy is an austenitic alloy steel which has high strength to make it useful in tool handling and turbine components in thermal power plant and car header applications. (Singh, Jain, and Kumar 2013)(Yang, Xing, and Zhanqiang 2010).

For the past 5 years, research identified with CNC Green Machining of high strength steel alloy zeroing in on surface roughness has come about in around 774 papers in google scholar and 419 papers in science direct. Impact of cutting velocity and feed rate was found more on yield parameters.(Altintas 2012). Change in shaft speed and profundity of cut outcomes in change in surface unpleasantness quality.(Chauhan and Kumar 2020). Device way systems have the most noteworthy level of impact on the exhibition qualities followed by cutting velocity and feed rate .(Saglam, Yaldiz, and Unsacar 2007).En9 is normally utilized in high temperature aviation applications like turbine shaft in airspace and furthermore for assembling cylinders in responding siphons. So working on its mechanical properties, dissolving point and hardness of the amalgam will bring about better execution in high temperature conditions.(Lim 1995) Better surface roughness as far as its unpleasantness is acquired by diminishing the cutting rate Vs than on account of expanding the feed per tooth (Hamidon, Adesta, and Riza 2015; Üstünyagiz et al. 2018). With higher axle speed of 1400rpm, lower feed pace of 0.03mm/fire up and lower profundity of cut of 0.6mm machined surface contributed the better ideal surface completion worth of 0.339µm. Reinforcement is done with 94% of C-0.43% + Si-0.35% + Mn-0.60% + Cr-7.32% + Fe 91% by the stir casting process. It is because of the good mechanical properties, high melting point and outstanding hardness of boron carbide to improve performance of the alloy (Dhara and Su 2005). Feed rate is the main plan variable to foresee the surface unpleasantness reaction when contrasted with others. Out of every one of these articles,(Sathish, Sabarirajan, and Karthick 2020) was the best investigation and more like this work as I would see it.Our team has extensive knowledge and research experience that has translate into high quality publications(Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar, Ravel, and Perumal 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al. 2021; Arun Prakash et al. 2020; Kamath et al. 2020; Shanmugam et al. 2021; Rajasekaran et al. 2020; Adhinarayanan et al. 2020; A. Rajesh et al. 2020; Aurtherson et al. 2021)

To the best of our knowledge, no research has been carried out to investigate by comparing uncoated HSS Tool with Novel Titanium Silicon Nitride coated High Speed Steel Tool in this process to suggest the best suitable surface finishing for this particular reinforced composite. Comparing conventional HSS Tools with modern Novel Titanium Silicon Nitride coated High Speed Steel Tool can show which one is better when it comes to the economical machining process. It is realized that customary devices are less known with regards to surface completion despite the fact that assessing the HSS instrument execution for this specific support so it tends to be plainly expressed that the Novel Titanium Silicon Nitride coated High Speed Steel Tool is required or not.

MATERIALS AND METHODS

This study was administered at Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai. No human sample employed in this research so no ethical approval needed.Total number of groups involved in this investigation is 2 (experimental group and control group). Novel Titanium Silicon Nitride coated High Speed Steel Tool is used as an experimental group and the HSS Tool is used as a control group. Total sample size used for the Groups is 32 and 80% of G power is set for calculating sample size with the use of means such as 0.808562, 0.614625 and SD 0.1321464 were used (Sathish 2018). The sample size is 16 per group and 32 in total.

In Group 1 samples the EN9 High Strength Steel Alloy grade round rods. Which are commonly supplied in rolled condition. That can be flame or induction hardened to produce a high surface hardness with excellent wear resistance for a carbon steel grade. EN9 shafts of 15mm diameter which were cutted with are available in full lengths or can be cut into 65mm length. These samples are to be machined by uncoated tool (HSS)

Similarly, for the group 2, another EN9 shafts of 15mm diameter which were cutted with are available in full lengths or can be cut into 65mm length.the sample of 16 number of EN9 is a High Strength Steel Alloy grade prepared for conducting machining experiment with the proposed Novel Titanium Silicon Nitride coated High Speed Steel Tool.

The machining operation is performed in CNC turning Machine center has the Specifications of Swing carriage 260mm, Maximum turning diameter is 290mm, Maximum turning length 400/500mm, Swing bed 500mm, Max spindle speed 4000 rpm, no of stations 8, Chuck size 200/250mm.

After machining the sample for predefined sample length the MRR and Surface Roughness is calculated by having the weights and Roughness average of the sample before and after machining. The procedure repeated and average (µm) of them was taken into consideration for avoiding errors. The input specifications furnished in Table 2 Presented the CNC machining process parameters, this work took off three parameters. Table 3 & Table 4 Presented the Experimental investigation summary of the material Removal Rate (MRR) and Surface roughness with the utilization of two Tools namely High Speed Steel and Novel Titanium Silicon Nitride coated High Speed Steel Tool. The MRR is calculated by having the weights of the sample before and after machining in eqn 1.

Material Removal Rate (MRR) = $\frac{\text{□□□□□□□□□□□□□□□□□□□□□□□□}}{\text{□□□□□□□□□□□□□□□□□□□□□□□□} \times \text{□□□□□□□□□□□□□□□□□□□□□□□}}$ ……………..(1)

The roughness of surfaces of machined jobs were tested in Surface roughness tester of Mitutoyo SJ-410 has 0.001 Micron least count. The CNC Turning center YCM – EV 1020A, The Spindle Speed 45 ~ 1000 RPM, Spindle Nose Taper BT40, Spindle Motor (Std.) (cont./15min) 5.5 / 7.5 kW. used for conducting machining experiments.

STATISTICAL ANALYSIS

Statistical Analysis was administered with the utilization of 'IBM SPSS statistics 26' software. The independent sample test performed for comparing means of both the control group and therefore the intervention group. The independent variables are cutting speed, feed rate, and depth of cut and therefore the variable was MRR and Surface Roughness. The statistical analysis like t-Test and independent samples test conducted.

RESULTS:

Table 1 shows the Machining Parameters for surface roughness. The four levels and four factors show that the minimum surface roughness and high MRR at the speed of 1400, feed 0.12mm/rev, depth of cut 0.8mm at the optimum values. Table 2 shows the Taguchi L16 type Input Parameters for both Experiments With cutting speed from 500 to 1400 rpm and feed from 0.4 to 1.6mm and depth of cut from 0.08-0.16mm. Table 3 and Table 4 Show the MRR and surface finish values for the Novel Titanium Silicon Nitride coated High Speed Steel Tool with the parameters speed, feed and depth of cut calculated. Group statistics -Novel Titanium Silicon Nitride coated High Speed Steel Tool provides higher MRR values and low surface finish than High Speed Steel Tool. Table 5 shows the results of T-test for samples of EN 9 High Strength Steel Alloy which were machined by two methods. Group 1 samples are machined by High Speed Steel Tool and Group 2 samples are machined by Novel Titanium Silicon Nitride coated High Speed Steel Tool. The sample means of the proposed method (Group 2) significantly gives Higher Material Removal Rate (MRR) than the conventional High Speed Steel Tool used in the sample Group 1 Table 6 shows the Results for Independent samples test for CNC milling of EN 9 High Strength Steel Alloy machined with conventional High Speed Steel Tool (Group 1) and proposed Novel Titanium Silicon Nitride coated High Speed Steel Tool (Group 2). The observed results are statistically significant as the significance value of 0.012 is less than 0.05 Table 7 shows the results of T-test for sample of EN 9 High Strength Steel Alloy which were machined by two methods. Group 1 samples are machined by High Speed Steel Tool and Group 2 samples are machined by Novel Titanium Silicon Nitride coated High Speed Steel Tool. The sample means of the proposed method (Group 2) significantly gives Lower Surface finish than the conventional High Speed Steel Tool used in the sample group 1 Table 8. Results for Independent samples test for CNC Green Machining of EN 9 High Strength Steel Alloy machined with conventional High Speed Steel Tool (Group 1) and proposed Novel Titanium Silicon Nitride coated High Speed Steel Tool (Group 2). The observed results are statistically significant as the significance value of 0.047 is less than 0.05

Figure 1 shows the Specifications of CNC turning Machine center of Swing carriage 260mm, Maximum turning diameter 290mm, Maximum turning length 400/500mm, Swing bed 500mm, Max spindle speed 4000 rpm, No of stations 8, Chuck size 200/250mm. Figure 2 shows the Specification of Novel Titanium Silicon Nitride coated High Speed Steel Tool. Tool include the thickness 4.8mm, Corner radius 0.4mm, Fixing hole diameter - 3.81mm**.** Figure 3 shows the Specification of HSS Tool Grade of TNMG 16040 (M7) Tool includes the thickness 4.8mm, Corner radius 0.4mm, Fixing hole diameter - 3.81mm. Figure 4 shows the Novel Titanium Silicon Nitride coated High Speed Steel Tool and another with High Speed Steel Tool. Figure 5 shows the Surface testing machine of Mitutoyo SJ-410 that has 0.001Micron least count. Figure 6 shows the sample bar between the Ra values of machined surfaces using High Speed Steel Tool and Novel Titanium Silicon Nitride coated High Speed Steel Tool. From the graph, the lower Mean Ra values were obtained as 0.103 micrometers using the Novel Titanium Silicon Nitride coated High Speed Steel Tool compared to the HSS tool which has 0.284 micrometers. X-axis: HSS and Novel Titanium Silicon Nitride coated High Speed Steel Tool, Y-axis: Mean surface roughness ± 1 SD. Figure 7 shows the Graph for dominating both Novel Titanium Silicon Nitride coated High Speed Steel Tool and uncoated High Speed Steel Tool cutters in Material Removal Rate (MRR). From these cutters the Novel Titanium Silicon Nitride coated High Speed Steel Tool produced high Material Removal Rate (MRR) even in variation of cutting speed, feed and depth of cut. X-axis: un coated HSS and Novel Titanium Silicon Nitride coated High Speed Steel Tool, Y-axis: Mean MRR of detection ± 1 SD.\

DISCUSSION

Using High Speed Steel (HSS Tool), the minimum Surface Roughness was found to be 0.634 micrometers using 1400 m/min of speed, 0.12 mm of depth of cut and a couple of 0.8 mm/rev feed. Maximum Surface Roughness was registered as 0.975 micrometers. Employing a Novel Titanium Silicon Nitride coated High Speed Steel Tool, the minimum surface roughness was obtained as 0.471 micrometers with the influence of 1400 m/min of speed, 0.12 mm of depth of cut and 0.8 mm/rev of feed. Maximum Surface Roughness was registered as 0.778 micrometers.

The significance value 0.012 was obtained within the results of the independent samples test. The results of them and thus the bar chart of comparing means which were obtained. Test results show that Novel Aluminium Chromium Nitride coated Tungsten carbide Tool gives lesser surface roughness as compared to HSS Tool. The test result for significance is a smaller amount than 0.05 ($p<0.05$). The above result shows that the Material removal rate increased and Surface Roughness is decreased when used Novel Aluminium Chromium Nitride coated Tungsten carbide Tool and Performance and durability of the parts are increased (George and Mallery 2019) ; (Aldrich 2018).

From the Bar graph, it shows the parameters of speed, feed, depth of cut. This formula is used for both Novel Titanium Silicon Nitride coated High Speed Steel Tool and HSS Tool (Yang, Xing, and Zhanqiang 2010). The influence of cutting conditions on cutting force evolutions shows that the cutting speed has a small effect compared with that of the feed rate and the depth of cut and this can be noted in SPSS analysis. The Signal to noise ratio by main effect is plotted for data mean. It was observed that Cutting forces were small compared with that of the feed rate and depth of cut. In general, a decrease in cutting force can be achieved as speed increases, and Tool nose radius is increased. The progression of Tool wear was examined with increasing time at high cutting speed at different levels of feed and depth of cut.

This reduction was probably caused by increase in the temperature at the cutting zone which leads to the workpiece softening. Limitations involved in this study of High Strength Steel Alloy- EN9 material was hard to machine and the coolants are essential for the machining in CNC Green Machining. It has a Low Mechanical strength and poor cutting Performance. In Future Scope, Different cryogenic parameters will be compared in the machining test using a broad number of Tools. From the above discussions, it is understood that apart from standard input variables (feed, speed, and depth of cut) the Tool hardness and cutting zone temperatures play an enormous role in MRR. Because the Novel Titanium Silicon Nitride coated High Speed Steel Tool is way harder than the HSS Tool the MRR and Surface Finish results improved significantly.

CONCLUSION

Within the limitations of this study, the high strength steel alloy with Novel Titanium Silicon Nitride coated High Speed Steel Tool recorded a higher material removal rate (averagely increased material removal rate from 5980.54249 mm^3/min to 9361.57mm^3/min that is 13.41%) and lesser surface roughness (averagely Reduced surface roughness from 1.805125 microns to 0.471 microns that is 59.43%) than the conventional High Speed Steel Tool.

DECLARATIONS:

Conflict of interests

The authors of this paper declare no conflict of interest.

Author Contribution

Author HK was involved in data collection, data analysis, manuscript writing. Author TS was involved in conceptualization, guidance and critical review of manuscript.

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Tables and figures

Table 1. Machining Parameters for surface roughness

Parameter	Value
Standard ISO	4287 (1997)
Sampling Length	16
Machining Speed	1400 RPM
Cut Off Length	20 mm

Table 2. Taguchi L16 type Input Parameters for both Experiments

Trail	Speed (RPM)	Depth of Cut (mm)	Feed (mm/rev)
1	500	0.08	0.4
2	500	0.12	0.8
3	500	0.16	1.2
4	500	0.2	1.6
5	800	0.08	0.4
6	800	0.12	0.8
7	800	0.16	1.2
8	800	0.2	1.6
9	1100	0.08	0.4
10	1100	0.12	0.8
11	1100	0.16	1.2
12	1100	0.2	1.6
13	1400	0.08	0.4
14	1400	0.12	0.8
15	1400	0.16	1.2
16	1400	0.2	1.6

Table 3. Calculated Surface Roughness, Material Removal Rate and CNC Run Time for High Speed Steel Tool

Trail	Surface Roughness (μm)	Weight (g)		Material Removal Rate mm^3/min	CNC Run Time (sec)
		Before m/c	After m/c		
1	0.978	97.81	92.74u	4961.7915	7.81
2	0.977	97.81	92.45	5218.8726	7.85
3	0.988	97.81	92.54	5184.0739	7.77
4	0.972	97.81	92.51	5206.8835	7.78
5	0.864	97.81	92.74	5504.4875	7.04
6	0.871	97.81	92.45	5819.3398	7.04
7	0.874	97.81	92.54	5681.8771	7.09
8	0.877	97.81	92.51	5770.3917	7.02
9	0.748	97.81	92.74	5925.3199	6.54
10	0.744	97.81	92.45	6293.1110	6.51
11	0.742	97.81	92.54	6216.0887	6.48
12	0.740	97.81	92.51	6184.6647	6.55
13	0.641	97.81	92.74	6692.8484	5.79
14	0.634	97.81	92.45	7015.0946	5.84
15	0.645	97.81	92.54	7005.2617	5.75
16	0.642	97.81	92.51	7008.5733	5.78

Table 4. Calculated Surface Roughness, Material Removal Rate and CNC Run Time for Novel Titanium Silicon Nitride coated High Speed Steel Tool

Trail	Surface Roughness (µm)	Weight (g)		Material Removal Rate mm^3/min	CNC Run Time (sec)
		Before m/c	After m/c		
1	0.778	82.31	77.55	5625.558611	7.98
2	0.791	82.02	77.26	5661.25786	7.93
3	0.778	82.11	77.35	5668.45349	7.92
4	0.772	82.08	77.32	5690.153253	7.89
5	0.657	82.24	77.48	6389.642944	7.12
6	0.655	81.95	77.19	6510.102464	6.99
7	0.654	82.04	77.28	6724.883393	6.77
8	0.655	82.01	77.25	6755.298174	6.74
9	0.545	82.24	77.48	7490.885305	6.09
10	0.546	81.95	77.19	7618.813502	5.99
11	0.548	82.04	77.28	7737.813847	5.9
12	0.551	82.01	77.25	7805.574986	5.85
13	0.485	82.88	78.12	7778.326102	5.23
14	0.458	81.81	77.05	9209.481249	5.1

15	0.49	81.9	77.14	9246.979047	5.08
16	0.471	81.87	77.11	9361.355177	5.02

Table 5. Results of T-test for sample of EN 9 High Strength Steel Alloy which were machined by two methods. Group 1 samples are machined by High Speed Steel Tool and Group 2 samples are machined by Novel Titanium Silicon Nitride coated High Speed Steel Tool. The sample means of the proposed method (Group 2) significantly gives Higher Material Removal Rate (MRR) than the conventional High Speed Steel Tool used in the sample Group 1

Group Statistics					
	Group	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
MRR	1	16	5980.542494	688.9293705	172.2323426
	2	16	7204.661213	1295.574241	323.8935603

Table 6. Results for Independent samples test for CNC milling of EN 9 High Strength Steel Alloy machined with conventional High Speed Steel Tool (Group 1) and proposed Novel Titanium Silicon Nitride coated High Speed Steel Tool (Group 2). The observed results are statistically significant as the significance value of 0.012 is less than 0.05

Independent Samples Test										
Levene's Test for Equality of Variances										
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	**Upper**
MRR	**Equal variances assumed**	7.208	0.012	-3.33	30	0.002	-1224.118	366.83922	-1973.30436	-474.9330
	Equal variances not assumed			-3.33	22.8	0.003	-1232.22	395.65656	-1983.25017	-464.9872

Table 7. Results of T-test for sample of EN 9 High Strength Steel Alloy which were machined by two methods. Group 1 samples are machined by High Speed Steel Tool and Group 2 samples are machined by Novel Titanium Silicon Nitride coated High Speed Steel Tool. The sample means of the proposed method (Group 2) significantly gives Lower Surface finish than the conventional High Speed Steel Tool used in the sample group 1

Group Statistics					
	Group	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Surface_Roughness	1	16	0.808562	0.1321464	0.0330366
	2	16	0.614625	0.1187158	0.029679

Table 8. Results for Independent samples test for CNC Green Machining of EN 9 High Strength Steel Alloy machined with conventional High Speed Steel Tool (Group 1) and proposed Novel Titanium Silicon Nitride coated High Speed Steel Tool (Group 2). The observed results are statistically significant as the significance value of 0.04 is less than 0.05

Independent Samples Test										
Levene's Test for Equality of Variances										
		F	**Sig.**	**t**	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% Confidence Interval of the Difference**	
									Lower	Upper
Surface_Roughness	**Equal variances assumed**	0.519	0.04	4.367	30	0	0.1939375	0.0444101	0.10324	0.284635
	Equal variances not assumed			4.367	29.66	0	0.1832323	0.0322005	0.103196	0.2846784

Fig. 1. CNC turning Machine center - Specifications: Swing carriage - 260mm, Maximum turning diameter - 290mm, Maximum turning length - 400/500mm, Swing bed - 500mm, Max spindle speed - 4000 rpm, no of stations - 8, Chuck size - 200/250mm

Fig. 2. Aluminium Chromium Nitride (AICrN) coated Tungsten carbide Tool. Tool include the thickness 4.8mm, Corner radius 0.4mm, Fixing hole diameter - 3.81mm

Fig. 3. High Speed Steel Tool, Tool include the thickness 4.8mm, Corner radius 0.4mm, Fixing hole diameter - 3.81mm

Fig. 4. Machined surface of Novel Titanium Silicon Nitride coated High Speed Steel Tool and another with High Speed Steel Tool

Fig. 5. Surface testing machine of Mitutoyo SJ-410 has 0.001Micron least count

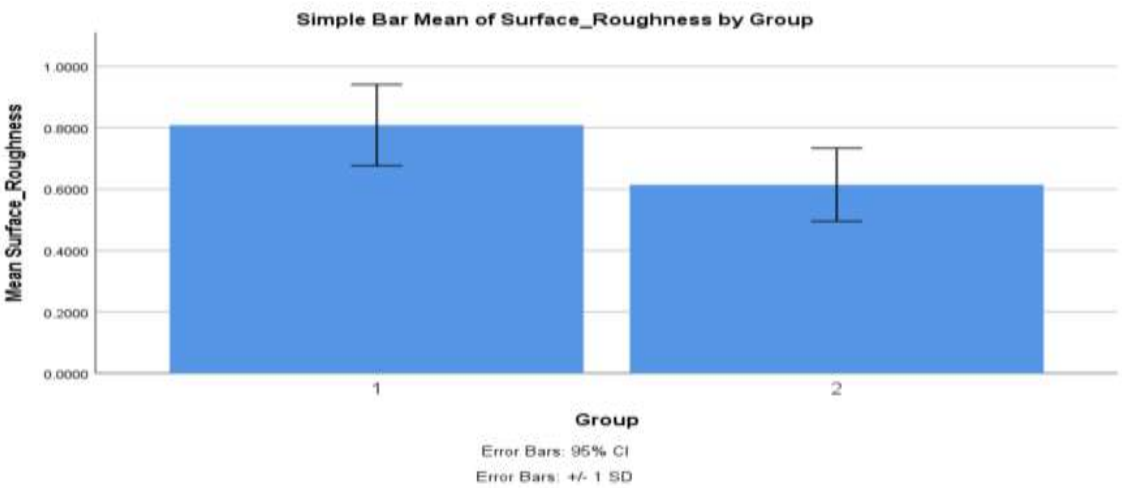

Fig. 6. Shows the sample bar between the Ra values of machined surfaces using High Speed Steel Tool and Novel Titanium Silicon Nitride coated High Speed Steel Tool. From the graph, the lower Mean Ra values were obtained as 0.103 micrometers using the Novel Titanium Silicon Nitride coated High Speed Steel Tool compared to the HSS tool which has 0.284 micrometers. X-axis: HSS and Novel Titanium Silicon Nitride coated High Speed Steel Tool, Y-axis: Mean surface roughness ± 1 SD

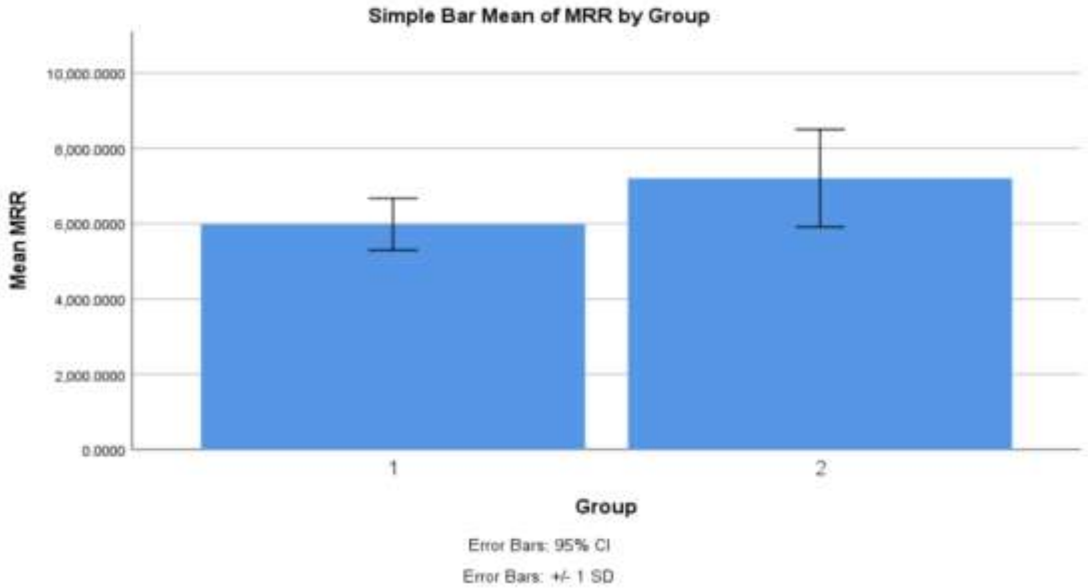

Fig. 7. Shows the Graph for dominating both Novel Titanium Silicon Nitride coated High Speed Steel Tool and uncoated High Speed Steel Tool cutters in Material Removal Rate (MRR). From these cutters the Novel Titanium Silicon Nitride coated High Speed Steel Tool produced high Material Removal Rate (MRR) even in variation of cutting speed, feed and depth of cut. X-axis: un coated HSS and Novel Titanium Silicon Nitride coated High Speed Steel Tool, Y-axis: Mean MRR of detection ± 1 SD