Original Article

Innovative Comparison on the Performance of TiCN Coated Drill Bit and Uncoated Drill Bit in the Novel CNC Drilling of LDX 2205 Duplex Stainless Steel for Maximizing Material Removal Rate

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Abstract

Aim: This research focuses on increasing the Material Removal Rate (MRR) by comparing the performance of conventional uncoated HSS drill bit and TiCN drill bit during the Novel CNC drilling of LDX 2205 Duplex Stainless Steel.
Materials & Methods: Materials used for the drill bits in this research are Titanium Carbonitride (TiCN) coated HSS drill bit and uncoated HSS drill bit. LDX 2205 Duplex Stainless Steel material was used as workpiece. A total of 40 specimens were divided into 2 groups with 80% G-Power calculator, to measure the MRR of two drill bits in novel CNC drilling machine. Cutting force, spindle speed, tool geometry, rate of feed were the controlled factors. Results: The observed results for each drill bit were recorded and analyzed using SPSS software. Final experimental values of MRR were investigated and obtained, having mean MRR value of 0.052645 g/s for the HSS drill bit and mean MRR value of 0.064765 g/s for the TiCN drill bit. These values were obtained with a significance level of 0.032 which is less than 0.05 ($p<0.05$).
Conclusion: Within the limits of this study, TiCN drill bit has comparatively higher MRR than the HSS drill bit in the novel CNC drilling of LDX 2205 duplex stainless steel.
Keywords: LDX 2205 duplex stainless steel, Material Removal Rate , CNC drilling, Novel machining, TiCN drill bit, HSS drill bit.

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INTRODUCTION

In this work, the Material Removal Rate (MRR) of the uncoated High Speed Steel (HSS) drill bit was improved by coating with Titanium Carbonitride (TiCN) to machine LDX 2205 duplex stainless steel by using a novel CNC drilling machine. The MRR of the two drill bits was measured and compared statistically to identify the best tool for this novel machining operation. Computer Numerical Control (CNC) machines can manufacture or machine the products with more precision in dimensions, faster production, less human efforts, cost and errors (Ghatge et al. 2018). Material Removal Rate is defined as the amount of material removed per minute or unit time (g/s). If the cutting tools have high MRR then it takes less time to perform the operation and can have better efficiency. So, the tool having high MRR can save machining time, effort and money. The industry is moving towards the automation process and the demand for precession and accuracy is high within reasonable price range (Sonawane and Sargade 2020) so the CNC machines with the cutting tools of high MRR can achieve this. LDX 2205 Duplex Stainless Steel was selected for the novel machining operation since this material is widely used in various applications like marine, bridges, storage tanks, atomic power plants, automobile, construction, and in many heavy-duty machines due to its high strength, machinability, less fatigue failure and it's better resistance to corrosion (Rosca et al. 2021), (Jayaganth et al. 2018).

There are about 5720 research papers published in Science Direct and 2093 research papers published in Google scholar, similar to this research field in the past 5 years. The MRR of AISI 316 steel was improved by (Mohammed 2016) with optimized parameters during CNC milling process. In that study the researcher analyzed the effect of machining parameters on MRR and surface roughness of the cutting tools and found out optimized

parameters for better MRR and lower SR. Machinability of duplex stainless steel 2205 was studied by (Sonawane and Sargade 2020) during dry turning process. In that work the researchers concluded that coated inserts give better performance than uncoated inserts. The cutting parameters of AISI 304 stainless steel were optimized during drilling by (Balaji, Murthy, and Mohan Rao 2016) using taguchi and ANOVA methods. In that study the researcher mentioned that feed rate, drill depth, cutting forces, and machining environment affect the performance of the cutting tools. MRR of AISI 321 stainless steel was optimized during the turning process by (M, Venkata Ramana, and Kumar 2018) using taguchi methodology. In that study, the author determined a predictive equation for determining MRR with a given set of parameters in turning process. SR, tool wear and cutting forces of duplex stainless steel were studied by (Kadam, Khake, and Mudigonda 2017) during the turning process. In that study, the author proved that coated carbide inserts gives better performance than uncoated inserts in the turning process. Among all these works the best research was carried out by (Sonawane and Sargade 2020). In this experimental work the surface roughness, tool wear, cutting forces of LDX 2205 duplex stainless steel were found during the turning process using tungsten carbide inserts coated with AlTiN and AlTiCrN in dry machining environment. In that work the author highlighted that coated tools give better performance than the uncoated cutting tools. 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; Rajesh et al. 2020; Aurtherson et al. 2021)

There were many researches done before regarding novel machining of duplex stainless steel, comparing the performance of two tools, improving MRR, etc, but the comparison of MRR of TiCN drill bit with the uncoated HSS drill bit in novel CNC drilling of LDX 2205 duplex stainless steel was not done previously. Effective coating of the tool will reduce the tool wear and thermal stresses and increase its durability, hardness, and strength, thus improving the material removal rate during the drilling process (Sultan, Sharif, and Kurniawan 2015), (Babatunde 2017). The aim of this experimental research is to improve MRR of conventional HSS tools by applying a coating of TiCN and the statistical comparison between the two drill bits to find out the best tool for this novel machining operation.

MATERIALS AND METHODS

The Novel CNC drilling of the workpieces was conducted in Saveetha Industries, Saveetha School of Engineering (SSE), Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai. The sample size of the specimens was predicted using an online clinical sample size calculator and it was found to be 20 specimens per each group with 80% G-Power value for better accuracy during novel machining process. 40 specimens of workpieces were divided into 2 groups and named as control group and experimental group. Drilling with an uncoated HSS drill bit was considered as a control group and drilling with TiCN drill bit was considered as an experimental group. In the research work done by (Bhanu Prakash and Thiagarajan 2021) the mean MRR value for PCD insert was 0.22593 with standard deviation of 0.251379 and mean MRR value for uncoated insert was 0.07600 with standard deviation of 0.02373 during novel CNC drilling process.

In this research, LDX 2205 duplex stainless steel was used as the workpiece material. Workpiece samples were machined into the dimensions of 50 mm height and 20 mm diameter as required for the drilling, shown in Fig. 1. Material composition of LDX 2205 duplex stainless steel is shown in Table 1 and physical properties are mentioned in Table 2. In this research work, an uncoated High-Speed Steel (HSS) drill bit with 10 mm diameter was used for novel CNC drilling of LDX 22205 duplex stainless steel samples. It is cost efficient and can maintain hardness in high temperatures that occur during drilling operation. This HSS drill bit used in this experiment is purchased from Addison & Co., Ltd which is shown in Fig. 2. Tool composition is shown in Table 3.

In this research, TiCN coated High-Speed Steel (HSS) drill bit with 10 mm diameter was used for novel CNC drilling of LDX 2205 duplex stainless steel samples. Titanium carbonitride is a very hard ceramic material which is used for coating of the cutting tools to improve the hardness, wear resistance, performance, tool life. TiCN coated tools give better performance in cutting, punching and molding operations. This tool was purchased from Addison & Co., Ltd which is shown in Fig. 3. Tool composition is shown in Table 3.

This experiment was carried out by using the YCM EV1020A Novel CNC machine which is shown in Fig. 4. Maximum spindle speed was set to 4000 rpm and positioning accuracy of 0.01mm with overall maximum power consumption of 50 KVA. The drill bit was fixed to an automatic tool changer's tool holder. The tool holder is adjustable for fixing the tool and the specimen is fixed in the machine. Machining parameters such as spindle speed, drill depth and rate of feed were programmed in the CNC machine's program memory. Initially the uncoated HSS drill bit was fixed to the tool holder in the CNC spindle for drilling the first 20 specimens from the control group.

After the 20 specimens were drilled, then the uncoated HSS drill bit was replaced with TiCN drill bit for drilling the next 20 specimens from the experimental group.

The program cycle was set to drill the samples one by one. The time taken for the novel machining of each specimen was noted. Each specimen was measured using the vernier caliper for their internal diameter to be maintained at 10 mm. The readings were used to calculate the MRR of each drill bit using the simple formula (Equation 1). The calculated values are then tabulated as shown in Table 4.

$$\text{MRR (g/s)} = \frac{\square - \square}{\square}\_\ \_\ \_[1]$$

Statistical Analysis

The SPSS v.28 statistical software was used to calculate mean, standard error and standard deviation. The significance level is considered when the probability value $p < 0.05$. In this work a total of 40 samples were taken for analysis so that a 95% confidence level can be achieved (Senthilkumar, Tamizharasan, and Anandakrishnan 2014). In this experiment, the independent variables were: Cutting speed, feed rate, and tool type. The dependent variable involved in this experiment was MRR. The Independent sample T-test was used to identify the significance among the HSS drill bit and TiCN drill bit.

RESULTS

Material composition of LDX 2205 duplex stainless steel and properties have been shown in Tables 1 and Table 2 respectively. Chemical composition of both drill bits is shown in Table 3. After the novel machining process, the MRR of the drill bit for each specimen was calculated and tabulated as shown in Table 4. For both experimental group and control group the machining parameters like feed rate, cutting velocity, spindle speed, type of coolant and machining environment were the same to avoid any external factor affecting the MRR of the tools. From the group statistical analysis which is shown in Table 5, it is observed that the mean MRR of TiCN drill bit was 0.064765 g/s with standard deviation of 0.0139794 and standard error mean obtained was 0.0031259.

In the control group of HSS drill bit the mean MRR was 0.052645 g/s with standard deviation of 0.0189792 and standard error mean of 0.0042439. Table 6 shows the Independent sample T-test output values. From the table it is observed that the significance value $p = 0.032$ ($p < 0.050$). Mean difference between the MRR of the experimental group and control group is 0.0121200 g/s as shown in Table 7. Workpiece dimensions were shown in Fig. 1, the nomenclature of the HSS drill bit and TiCN drill bit are shown in Fig. 2 and Fig. 3 respectively. Fig. 4 illustrates the image of the CNC machining center. In Fig. 5, the comparison between the MRR values of TiCN drill bit and HSS drill bit is shown in graphical form. This graph clearly shows that TiCN drill bit gives better mean accuray with lower error deviation in this novel machining operation.

DISCUSSION

There is a significant difference between the mean MRR of TiCN drill bit which was 0.064765 g/s with standard deviation of 0.0139794 and mean MRR of HSS drill bit which was 0.052645 g/s with standard deviation of 0.0189792 as shown in Table 5. Significance of this comparative study is found to be 0.032 which was less than 0.05, and the analysis was performed with a confidence level of 95%, as shown in Table 7. Comparison of mean MRR of uncoated HSS drill bit and TiCN drill bit was represented using a clustered bar graph as shown in Fig. 5. From the graph it is proven that the coated tools give better MRR than the uncoated tools (Bhanu Prakash and Thiagarajan 2021). This is due to higher hardness, better abrasion resistance and high material adhesion of TiCN coated cutting tools (Maruda and Szczotkarz 2016). The results of the above researchers are in compliance with the findings of this study. Outcome of this research is inline with the work of (Kumar and Packiaraj 2018). In their work, the mean MRR of uncoated HSS during drilling of OHNS steel was similar to the result obtained in this research and got even more MRR due to coated tools used in this research. Drill depth, cutting forces, rate of feed were significant factors in achieving more MRR of tools (Jusof 2008). The conclusion achieved by that author was not inline with the results of this work. This conflict arises due to the reason that machining parameters were varying by the researchers in each drilling process in order to obtain better MRR but in this research the input parameters were kept constant and used coated tools (TiCN drill bit) to obtain better MRR.

In the novel drilling process the parameters play an important role(Gupta and Gupta 2019), (Kamarudin 2012) In this research the machining parameters like cutting speed, feed rate, type of tool are the factors which affect the MRR of the tool. While performing this experiment some limitations were noticed. They were: cost of TiCN coating, inconsistent tool wear, varying machining parameters and very slight deformations in the tool coating while machining. In the future the experimental study can be carried out using different material coating on drill bits, effect of drill bits with internal coolant supply, different workpiece materials, different layers of coatings, which can

further improve MRR.

CONCLUSION

From this research work, it is proven that MRR of conventional HSS drill bit can be improved by applying a coating of TiCN in the novel CNC drilling of LDX 2205 Duplex Stainless Steel, by concluding from the mean MRR result obtained for the uncoated HSS drill bit as 0.052645 g/s and for TiCN drill bit as 0.064765 g/s which shows significant improvement. The MRR of both drill bits were collected, analyzed, and statistically compared using independent sample t-test by using SPSS software. After the comparison it had been found that the TiCN drill bit gives better performance in this novel machining process.

DECLARATION

Conflict of interest

The authors declare that there is no conflict of interest.

Authors Contribution

Author VSK was involved in data collection, data analysis, manuscript writing, Author CT was involved in conceptualization, data validation, and critical review of manuscript.

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Tables and Figures

Table 1. LDX 2205 duplex stainless steel - Material composition.

Material	Weight Percentage (%)
Chromium (Cr)	21.8 - 23.5
Nickel (Ni)	4.55 - 6.50
Molybdenum (Mo)	3.00 - 3.50

Manganese (Mn)	2.00 max
Silicon (Si)	1.00 max
Carbon (C)	0.30 max
Nitrogen (N)	0.14 - 0.20
Phosphorus (P)	0.30 max
Sulfur (S)	0.20 max
Iron (Fe)	Balance

Table 2. LDX 2205 duplex stainless steel - Properties (Mechanical & Physical).

Property	**Value**
Melting Point	1450 °C
Density	7820 Kg/m3
Tensile Strength	620 - 750 MPa
Fatigue strength	767 MPa
Yield Strength	450 MPa
Young's Modulus	200 MPa
Poisson's Ratio	0.32
Specific Heat	418 J/kg-K
Thermal Expansion	13.7 µm/m-°C at 100^0 C
Thermal Conductivity	19 W/m-K at 100^0 C
Electrical Resistivity	850 nΩ.m

Elongation	25%
Rockwell Hardness (HR C)	31 max
Brinell Hardness (HB)	293 max

Table 3. Chemical composition of drill bits (wt %).

Tool	Cr	W	C	Mo	Co	V	Ti	N	O
TiCN	1.3-2.0	-	25-38	-	-	-	23-35	20-30	8-12
HSS	4.0-4.5	18	1.3-1.5	9.60	5	1.20	-	-	-

Table 4. Obtained Material Removal Rate (MRR) values of both sample groups: TiCN drill bit & HSS drill bit.

Sample No:	TiCN drill bit (g/s)	Sample No:	TiCN drill bit (g/s)	Sample No:	HSS drill bit (g/s)	Sample No:	HSS drill bit (g/s)
1.	0.0295	11.	0.0657	1.	0.0229	11.	0.0313
2.	0.0483	12.	0.0608	2.	0.0416	12.	0.0395
3.	0.0597	13.	0.0716	3.	0.0697	13.	0.0367
4.	0.0389	14.	0.0645	4.	0.0322	14.	0.0309
5.	0.0633	15.	0.0653	5.	0.0566	15.	0.0493
6.	0.0912	16.	0.0707	6	0.0848	16.	0.0666
7.	0.0652	17.	0.0690	7.	0.0516	17.	0.0583
8.	0.0845	18.	0.0697	8.	0.0840	18.	0.0616
9.	0.0700	19.	0.0801	9.	0.0750	19.	0.0780
10.	0.0618	20.	0.0655	10.	0.0385	20.	0.0438

Table 5. Group statistics: Mean MRR, Std. Deviation, and Std. Error mean obtained for uncoated HSS drill bit & TiCN drill bit for a total sample size of 20 specimens per group.

Group	N	Mean	Std. Deviation	Std. Error Mean
TiCN drill bit	20	0.064765	0.0139794	0.0031259
HSS drill bit	20	0.052645	0.0189792	0.0042439

Table 6. Levene's test for equality of variances & the T-test for the equality of means for TiCN drill bit & HSS drill bit with a considered significance value of 0.032 ($P < 0.05$).

Hypothesis	F	Sig	t	df
MRR - Equal variances assumed	4.933	0.032	2.299	38
MRR - Equal variances not assumed			2.299	34.928

Table 7. T-Test for the equality of means of the MMR. The assumed hypothesis of existence of the equal variance among the control group is true with the obtained significance value of 0.032.

Hypothesis	Significance (2-Tailed)		Mean Difference	Std. Error Difference	95% Confidence interval of the Difference	
	1- sided p	2- sided p			Lower	Upper
MRR - Equal variances assumed	0.014	0.027	0.0121200	0.0052708	0.0014498	0.0227902
MRR - Equal variances not assumed	0.014	0.028	0.0121200	0.0052708	0.0014189	0.0228211

FIGURES

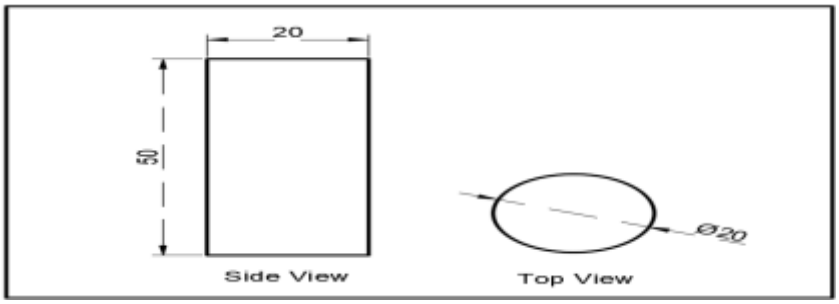

Fig. 1. Workpiece dimensions.

Fig. 2. High-speed steel (HSS) twist drill bit (10 mm) with high heat resistance and easily machinable, widely used for application for drilling. HSS is the most commonly used cutting tool in industries.

Fig. 3. Novel Titanium Carbonitride coated on HSS twist drill bit (10 mm) having yellow refractory coating on High-speed steel that improves hardness, wear resistance and gives more tool life**.**

Fig. 4. YCM EV1020A CNC machining center. Specifications: Maximum spindle speed- 4000 rpm, Cutting speed- 150 m/min, Feed rate- 0.50 mm/min, drill depth- 30 mm, Swing over bed- 500 mm, Swing over carriage- 260 mm, N

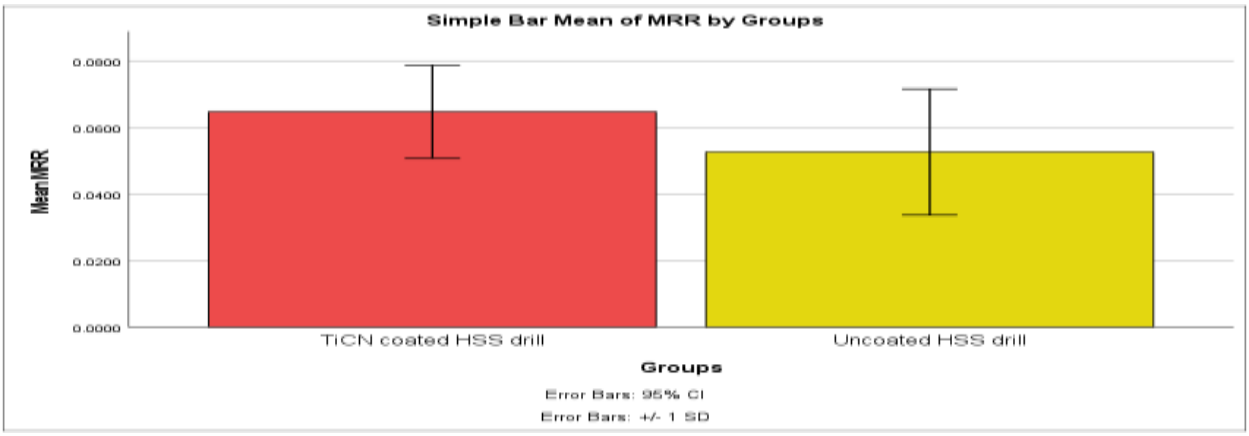

Fig. 5. In this bar graph the mean MRR difference between the two groups is shown. Comparison of TiCN drill bit and HSS drill bit in terms of mean accuracy. Mean MRR for TiCN drill bit is 0.064765 g/s and mean MRR for HSS drill bit is 0.052645 g/s. The mean accuracy of the TiCN drill bit is better than HSS drill bit with lower error deviation. X-axis denotes type of tool and Y-axis denotes the mean Material Removal Rate. Mean accuracy of detection $\pm$ 1 SD.