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Exploring the Material Removal Rate of a Novel Al-Zn5Mg Alloy Through Experiments with Cubic Boron Nitride Coated and Uncoated HSS Tools

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Abstract

Aim: This research delves into the material removal rate (MRR) of Al-Zn5Mg alloy when subjected to computer numerical control (CNC) turning. The investigation involves the use of inserts that are coated with cubic boron nitride (CBN) and high-speed steel (HSS).

Methodology: In this study, we're focusing on an Al-Zn5Mg alloy that's 200 mm long and has a diameter of 50 mm. To conduct the investigation, we prepared 20 samples of this alloy (N = 20). These samples were crafted using both a CBN-covered HSS insert (considered the experimental group) and an uncovered HSS tool (the control group). After the machining process, the weight of each set of samples was determined using a digital weight-measuring machine by ASTM standards. We then carried out G-power calculations with an 80% threshold.

Results: The research findings on the MRR for Al-Zn5Mg alloy, when machined with a CBN-covered HSS insert, show a rate of 1.801 mm^3/min. In comparison, the MRR for HSS tools without coverage is lower, measuring at 1.624 mm^3/min. Through in-depth investigations employing statistical analyses, particularly utilizing SPSS and analysis of variance (ANOVA) t-tests, it has been unveiled that there exists a noteworthy distinction between the two groups in question. The derived two-tailed significance value of 0.001 ($p < 0.05$) attests to the statistical significance of this disparity.

Conclusion: In this experimental study, the utilization of a CBN-coated HSS inserts for turning Al-Zn5Mg alloys proved to significantly boost the MRR compared to the samples turned with an uncoated HSS insert, operating within the study's constraints.

Keywords

Al-Zn5Mg alloy, Material removal rate, Independent t-test, CNC turning, Cubic born nitride, Covered insert, High-speed steel

Introduction

When working with machinery, CNC turning stands out as a sophisticated fundamental process carried out using a program with numerical control. This turning, operation needs to fulfill dimensional accuracy and surface integrity for cylindrical machining process industrial fabrication [1]. Many machining processes prioritize achieving higher MRR, minimizing surface roughness, and ensuring both the tool's longevity and the smoothness of the surface produced by machining [2]. The attention and requirement of advanced materials with smart characteristics play a prominent role in automobiles, aerospace, and many applications. Recently, Al-Zn-Mg alloy-based materials are used in several applications like automotive, defense, aerospace, and structural application due to their

enhanced thermal and mechanical performance [3]. The CNC turning machine for aluminum alloy machining employs a variety of inserts, both carbide-coated and uncoated. These inserts are utilized at different spindle speeds, feeds, and depths of cut [4]. The carbide-coated tool performed higher MRR. The ANOVA technique was utilized to optimize the parameters that influence input turning in the context of MRR [5]. The combinations of Al-Si may lead to built-up edges during high-speed machining operations [6]. To overcome the demerits the coated insert is introduced. Under convective cooling conditions, magnesium alloy blends exhibit excellent ease of machining. A CNC turning assessment was conducted to evaluate the machinability of aluminum alloy, employing both PVD-TiB_2 coated and uncoated tool inserts, resulting in enhanced tool lifespan. The PVD-TiB_2 coated insert demonstrated superior surface quality and improved MRR when compared to its uncoated counterpart. However, the cutting force damages the tool and limits the surface quality and the tool quality of life. To overcome the demerits of the present investigation implemented for coated inserts and compared to uncoated inserts. A comparable trend while working with aluminum alloy in the machining process [7].

A comprehensive exploration of the current research landscape for this investigation involved reviewing a total of 1200 recent papers. These were sourced from 900 papers found on Google Scholar, with the remaining papers obtained from the Science Direct platform, all spanning the last five years [8]. Examining the topography of the turned surface post-machining led to enhanced MRR and surface quality in the turning process. Through ANOVA analysis, a researcher pinpointed an effective approach to optimize the machinability of aluminum alloy, particularly when employing both carbide-coated and uncoated inserts [9]. In a related study, ANOVA was used to optimize the MRR for aluminum alloys, both uncoated and titanium nitride-coated inserts, as demonstrated by [10]. The machinability of aluminum alloy composites was investigated using CNC turning, taking into account different spindle speeds, feeds, and depths of cut, utilizing both carbide-coated and uncoated inserts [11]. The highest MRR was observed with the carbide-coated insert [12]. However, the challenge lies in selecting the most suitable experimental and control groups of turning parameters to meet the required surface quality and achieve a high MRR [13]. Researchers utilized familiar CNC machining for turning operations, optimizing its output by employing ANOVA to adjust input parameters [14]. Many researchers have adopted a similar approach to identify optimal input factors for efficient machining operations [15, 16]. Among various studies, the literature focusing on the investigation of aluminum alloy machining with the highest MRR has been pinpointed [17-19].

Nanohorns, nanotubes, nanoparticles, and nanosheets can be formed from boron nitride because of its layered structure, which mimics the structural properties of 2D carbon materials (graphene and its derivatives). As opposed to polymers that may lose their dielectric properties when carbon nanostructures are added, boron nitride retains its dielectric properties when carbon nanostructures are added. Surfactants are often used to improve the dispersibility of boron nitride in aqueous solutions because boron nitride is chemically more stable than carbon nanomaterials. Coatings are essential for ensuring the dispersion of nano-sized boron nitride compounds and preventing subsequent clustering caused by the natural hydrophobicity of the raw material [20].

The primary focus of our current exploration involves examining With a CNC turning machine outfitted with a CBN-coated HSS tool, the MRR of the Al-Zn5Mg alloy. We aim to compare these results with those obtained using an uncoated HSS insert. Both the experimental and control groups adhere to the MRR measurements outlined in the ASTM standard. Notably, we found no similar studies or reports in the existing research literature. The research and development team at Saveetha University has embarked on an innovative journey to advance material development for contemporary industrial applications. This initiative is grounded in an in-depth investigation into the machinability behavior of aluminum alloy. Specifically, our evaluation focuses on comparing the MRR during the machining of the Al-Zn5Mg alloy using CBN-coated (trial set) and uncoated HSS inserts (control set).

Materials and Method

The present study investigates an Al-Zn5Mg alloy's MRR, which was processed using a CNC turning machine. The study involves the utilization of CBN-covered and uncovered inserts. The machining operations and subsequent assessments were conducted with substantial assistance from M/S. Saveetha Industries, Saveetha School of Engineering, Saveetha University, Saveetha Institute of Medical and Technical Science in Thandalam, Chennai (Tamil Nadu, India), leveraging the necessary facilities within the Department of Mechanical Engineering. Research findings suggest that Al-Zn5Mg alloy combinations demonstrate outstanding machinability, ductility, and a favorable ratio of strength to weight. The turning process for the selected Al-Zn5Mg alloy involves the use of both CBN-coated and uncoated HSS inserts, as outlined in the study by [13]. Figure 1 illustrates the CNC machining center utilized in the experiments. Statistical analysis, including a confidence level of 80%, was conducted using G-power with a fixed value of 0.05, along with a standard deviation of 0.27 and a mean value. Totally, 20 experiments were conducted on both groups. The sample size is 200 mm in length and 50 mm in diameter.



Figure 1: CNC turning work center.

The Al-Zn5Mg alloy was subjected to CNC machining using a CBN-coated HSS insert in the experimental group, with various cutting speeds, feeds, and depths of cut as outlined in table 1.

A set of 20 alloy samples, specifically Al-Zn5Mg, were included in this category, we pinpointed the optimal machining settings for attaining the maximum MRR. Figure 2 and figure 3 display the CBN-coated HSS insert alongside the machined samples of Al-Zn5Mg.

The HSS insert from the control group is designed for CNC machining on Al-Zn5Mg alloy. This machining process involves cutting speeds of 700, 1000, 1200, and 1500 mm/min, feed rates of 0.15, 0.20, 0.25, 0.3, 0.35, and 0.40 mm/rev, and varying depths of cut at 1, 1.5, 2, 2.5, and 3 mm, respectively. Similar to the above conditions, 20 samples were turned and the optimum suitable factor for high MRR was chosen from ANOVA studies. Figure 4 and figure 5 showcase the exposed HSS insert along with its machined Al-Zn5Mg specimens.

A digital weight measurement device, equipped with a proximity sensor system boasting an accuracy of ± 0.001 g, was employed to gauge the weight alteration in Al-Zn5Mg alloy samples pre- and post-turning. In both the experimental and control sets, 40 Al-Zn5Mg alloy samples (20 in each) were initially weighed as Wb before the turning process commenced. Subsequently, they were reweighed as Wa after the turning process. The duration of the CNC turning operation was recorded using a digital stopwatch (refer to figure 6). The MRR is determined by the ratio of weight loss to the amount of time, as shown in equation 1, that each sample takes to turn.

$$MRR = Wa/t \times Wb \quad (1)$$

Where Wa is weight of the Al-Zn5Mg alloy after turning and Wb is weight of the Al-Zn5Mg alloy before turning, and t is time is taken between the turning operation on each sample.

Furthermore, we evaluated the well-being and studied how input parameters influenced the output response by analyzing the MRR of 40 Al-Zn5Mg alloy samples according to the ASTM standard. The values obtained were subjected to analysis using the SPSS statistical tool. The influence of factors was further investigated through ANOVA. A comparison was made between the MRR experimental and control groups using the alloy Al-Zn5Mg. After that, the results of turning the Al-Zn5Mg alloy were compiled to determine the best outcomes. With a need for $p < 0.050$, the assessment report, which can be acquired via the t-test, shows statistical significance within the range of 0.003.

Statistical analysis

Researchers utilized the SPSS tool to statistically assess the machining of Al-Zn5Mg alloy through CNC operations, employing various inserts such as CBN-covered and uncovered HSS inserts. While turning, we considered various factors as independent variables, including the speed of cutting (measured in mm/min), feed rate (measured in mm/rev), and depth of cut (measured in mm). The outcome we focused on was identified as the MRR (measured in mm^3/min). The analysis using SPSS unveiled a significant MRR value. Further investigation into t-test outcomes delved into the average variations between the groups subjected to experimentation and those in the control group. In addition, the ANOVA Taguchi method was employed to identify the best turning parameters in the machining process of aluminum alloy. This information is elaborated upon by [5].

Table 1: CNC turning parameters of Al-Zn5Mg alloy machining.

S. No.	Turning parameters	Units	Input level
1	Cutting speed	mm/min	700, 1000, 1200, 1500
2	Depth of cut	mm	1, 1.5, 2, 2.5, 3
3	Feed rate	mm/rev	0.15, 0.2, 0.25, 0.3, 0.35



Figure 2: CBN covered HSS insert (experimental group).



Figure 3: CBN covered HSS insert obtained Al-Zn5Mg alloy samples.

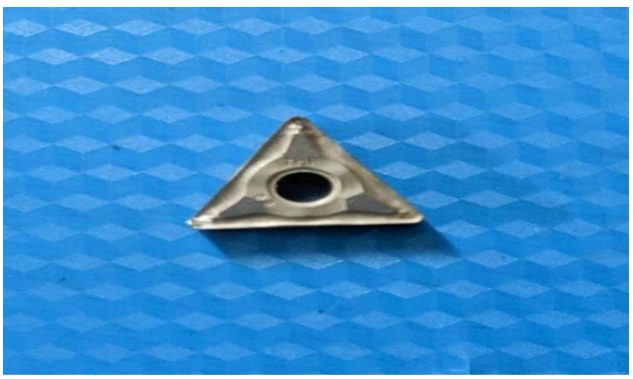


Figure 4: Uncovered HSS inserts (control group).



Figure 5: Uncovered HSS insert obtained Al-Zn5Mg alloy samples.



Figure 6: Digital stopwatch.

Results

In table 2, you can find the MRR values achieved while machining Al-Zn5Mg alloy through CNC, showcasing changes in cutting speed, feed, and depth of cut. Using a CBN-coated HSS insert for turning Al-Zn5Mg alloy yielded an average MRR of 1.509 mm^3/min. In contrast, using an uncoated HSS insert for turning Al-Si12Cu alloy resulted in an average MRR of 1.214 mm^3/min. The data examination involves calculating the average, standard deviation, and standard error of the mean, was performed on 40 samples of turned Al-Zn5Mg for both the experimental and control groups (Each group having 20 samples), and their values are mentioned in table 3. The ANOVA t-test analysis in the evaluation report revealed a significant result, with a p-value of less than 0.050, specifically 0.003. Figure 7 visually represents the variance in mean MRR values between the CBN-covered and uncovered HSS insert performances through a standard bar chart. The corresponding standard deviation, indicated as ±1, is detailed in table 4.

Discussion

Utilizing the SPSS statistical tool and ANOVA, we effectively compared the computed MRR results for Al-Zn-5Mg alloy machining with both CBN-covered and uncovered HSS inserts. This analysis, as presented by [6], revealed that the MRR achieved with the CBN-covered HSS insert surpassed that of the uncovered HSS insert. The CBN-covered HSS insert demonstrated superior machinability conditions, indicating a higher MRR. This performance can be attributed to its elevated thermal stability during high-speed machining, as discussed by [8].

Table 2: The real test outcomes were determined for the MRR in the course of turning Al-Zn5Mg alloy, using both CBN-covered and uncovered HSS inserts.

S. No.	Cutting speed, mm/min	Depth of cut, mm	Feed rate, mm/rev	MRR, mm^3/min	
				CBN covered HSS insert	Single textured tool inserts
1	700	1	0.15	1.156	0.893
2	700	1.5	0.2	1.234	0.918
3	700	2	0.25	1.357	0.943
4	700	2.5	0.3	1.336	0.936
5	700	3	0.35	1.428	0.983
6	1000	1	0.15	1.362	0.976
7	1000	1.5	0.2	1.293	1.052
8	1000	2	0.25	1.378	1.103
9	1000	2.5	0.3	1.458	1.169
10	1000	3	0.35	1.636	1.214
11	1200	1	0.15	1.653	1.294
12	1200	1.5	0.2	1.567	1.366
13	1200	2	0.25	1.629	1.467
14	1200	2.5	0.3	1.715	1.525
15	1200	3	0.35	1.731	1.578
16	1500	1	0.15	1.703	1.592
17	1500	1.5	0.2	1.746	1.606
18	1500	2	0.25	1.801	1.624
19	1500	2.5	0.3	1.782	1.661
20	1500	3	0.35	1.823	1.698

Table 3: Both the experimental and control groups carried out CNC turning on the Al-Zn5Mg alloy, determining standard values, mean, and standard deviation in the process.

	Group	N	Mean	Std. deviation	Std. error mean
MRR	CBN covered HSS insert	20	1.509	0.20871	0.041901
	Uncovered HSS inserts	20	1.214	0.29261	0.069043

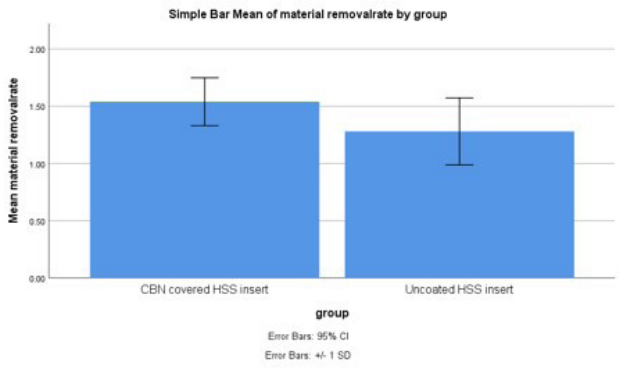


Figure 7: The average MRR for Al-Zn5Mg alloy was calculated using CNC turning operations with both CBN-covered and uncovered HSS inserts. On the X-axis, we plotted the group mean MRR values for the turned Al-Zn5Mg alloy with both types of inserts. Meanwhile, on the Y-axis, you'll find the average MRR values for both the experimental and control groups. This includes a range of ±0.25 standard deviation and a 95% confidence interval (CI).

Table 4: The MRR significance results from ANOVA t-tests ($p = 0.003$, $p < 0.05$) indicate variations in the machining of Al-Zn5Mg alloy with CNC, employing HSS inserts covered and uncovered with CBN.

MRR	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
Equal variance assumed	5.430	0.005	3.229	38	0.003	1.598	0.208745	0.085702	0.321910
Equal variance not assumed	-	-	3.229	34.362	0.003	1.254	0.292581	0.085702	0.321910

The CBN covered inserts are gained importance for high hardness material machining due to its owing good mechanical and thermal characteristics [2, 6, 8] and also withstand high cutting force [19]. The novel CNC machining technique was adopted for material machining with high precision for industrial applications. When working with various input parameters, the machinability of aluminum alloy is most significantly influenced by the feed rate and cutting force, according to the results of machining the alloy with both PVD-TiB_2 coated and uncoated tools, accounting for 64.28% and 54.9%, respectively. This finding is supported by studies conducted by [2, 6, 8, 18].

Comparing the uncoated insert with the turning operation performed by titanium nitride coated insert found a 35% of increased in MRR. The carbide-coated insert showed the highest MRR while maintaining a favorable surface quality, as reported by [5].

The study's findings come from examining the turning process of an Al-Zn5Mg alloy using a CNC turning machine and employing CBN-coated HSS and non-coated HSS inserts. The insert coated with CBN demonstrates a superior MRR of 1.801 mm^3/min in CNC machining. This performance is observed at a cutting speed of 1500 m/min, a feed rate of 0.25 mm/rev, and a 2 mm depth. Notably, there's an 11% boost in MRR when compared to the insert without coating.

Conclusion

In our recent study, we delved into the MRR of Al-Zn-5Mg alloy while performing CNC turning. We made a comparison between using inserts with CBN coverage and those without it, both made of HSS. According to ASTM standards, the MRR values were determined for each group, with the experimental group (CBN covered) showing a mean value of 1.801 mm^3/min and the control group (uncovered HSS insert) exhibiting a mean value of 1.608 mm^3/min. Each group comprised 20 samples. Upon analyzing the results with SPSS and conducting ANOVA t-tests for both dependent and independent variables concerning the mean value of Al-Zn5Mg alloy (20 + 20 samples), a notable significance was observed with CBN-covered inserts compared to uncovered HSS inserts, maintaining a significance level of $p = 0.003$ ($p < 0.05$). The data reveals that the CBN-covered inserts outperformed uncovered HSS inserts, demonstrating a higher MRR.

Acknowledgements

None.

Conflict of Interest

None.

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