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Machinability Performance Comparison in CNC Turning of Inconel 718 Using ZnO Nanofluid with Conventional Coolant in Flood cooling Environment

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Abstract

The purpose of this study is to compare the performance of conventional coolant and innovative ZnO nanofluid in a flood cooling environment while enhancing the economy and machining performance of Inconel 718 material in CNC turning. To determine the Material Removal Rate (MRR), CNC turning of Inconel 718 is performed using a variety of parameter settings and observations. With the novel flood coolant of ZnO nanofluid, we machined at varying speeds, feed rates, and depths of cut. Group 1 was made composed of samples machined using nanofluid, while group 2 consisted of samples machined using traditional coolant. Pretest 80% g-power and 5% alpha was used for predicting the minimum samples required per for this investigation. There are 2 groups, 32 samples in total and each group has 16 samples. Both groups are evaluated to determine the optimal coolant for improving MRR. The mean MRR of Inconel 718 using conventional coolant (group 2) was 795.763 mm^3/min, whereas the mean MRR while machining the work material with novel ZnO nanofluid (group 1) was 1085.863 mm^3/min. There is a statistically significant difference between the two groups because the t-test's significant value was less than 0.001 and less than 0.05. During machining with Inconel 718 in CNC turning operations, novel ZnO nanofluid resulted in a greater MRR than the traditional coolant, according to an experimental investigation.

Keywords

Turning, Coolant, Inconel, Novel ZnO nanofluid, Material removal rate, Machining, CNC, Economy

Introduction

Flood cooling is a standard method for machining difficult-to-cut, high-temperature materials. This technique' cutting fluids has been related to a multitude of environmental and health risks [1-6]. Heat accumulates at the tool-to-workpiece surface contact during turning. Poor machining results result from the removal of hard and brittle materials due to increased friction at the shear cutting plane [7-11]. The goal of this study is to ascertain the influence of key machining parameters on performance indicators such MRR and performance when CNC turning Inconel 718. MRR and machining performance were performance factors, whereas spindle speed, feed rate, and depth of cut were all control variables [12-15]. One of the reasons for greater heat transport is the thermal conductivity of nanofluids [16-19].

A lot of articles about this research have been published in recent years. In Google Scholar, there are about 375 papers, while in Science Direct, there are about 260 articles. In accordance with the most pertinent publications to this research topic [20-23], cutting fluid is essential in every metal cutting process because it cools the work piece and the cutting tool, clears chips from the cutting zone, and lubricates the tool-workpiece interface. Cooling techniques and coolant types obviously have a big influence on machining performance [24]. The present research models, evaluates and optimize the least quantity lubrication for turning Inconel 718 using nano-additives [25]. It is detailed in detail [26] how liquid media are used in conjunction with special nanoparticle additions that are carried to the cutting zone. The research claims that, although the degree of improvement depends on several parameters, utilizing nanofluids as cutting fluids increases lubrication and cooling over typical cutting fluids [27].

Previous research on the application of novel ZnO nanofluid as a flood coolant in CNC turning operations has been reported in the literature so far. The present study intends to investigate the possible applications of novel ZnO nanofluid in Inconel 718 CNC machining to enhance MRR and guarantee machining economy.

Materials and Methods

All the essential tools and machines are available at Saveetha University, Chennai Green manufacturing techniques are used in this project, such as carefully turning metallic components with a highly safe CNC machine, biodegradable synthetic nanoparticles, and ecologically friendly coolants. In this experiment, the novel ZnO nanofluid coolant was used in group 1 while the conventional coolant-based CNC turning operation was used in group 2. Each group comprises 16 Inconel 718 specimen samples for CNC turning operations. ClinCalc sample size calculator (open-source software) was used to make the sample size calculation. This investigation used G -power, standard deviation and mean for prediction of minimum samples to be tested were 80%, 0.34056 and 2.666 respectively [28].

In group 1, a novel ZnO nanofluid is employed as a cooler for 16 samples. The programme starts once each sample is clamped to the CNC chuck. The software has several input parameters, including depth of cut, tool feed rate and spindle speed. This information is contained in the programme. With the novel ZnO nanofluid as a coolant, the machining operation is carried out and constantly monitored. The same procedure is configured to execute for each of the 16 samples (Group 1).

The established values of input parameters in different combinations of low, below medium, above medium, and high ranges were utilized to observe weight loss by machining at sample lengths. Weight loss is measured using precision weight balance. A timer was used to record the amount of time it took to machine each of the different combinations. The input parameters are listed and are then imported into the CNC programme for machining.

The mass of the sample before and after turning was determined using a precision weight balance. The time it takes to machine a single sample length (25 mm). Using the observed data, the MRR was determined. Hence, the MRR estimated for all 32 samples from the observations when used novel ZnO nanofluid and conventional coolant for machining. The experiment's repetitions were incorporated 3 times, and their averages were taken into consideration to reduce the inaccuracy. The determined MRR is the result of this research project.

A ClinCalc sample size calculator was used to calculate the necessary minimum sample size, and IBM SPSS software version 26 was used for statistical analysis. The experiment's independent variables are the type of cooling used at the machining zone, feed rate, and spindle speed of cutting. The dependent variables are the weight of the metal block observed, the machining time, and the volume of material removed [29].

Results

In terms of decreased cutting zone temperature, tool wear, surface roughness, chip removal, and machining lubrication to reduce frictional losses, novel ZnO nanofluid was the coolant that produced the best cooling performance. Novel ZnO nanofluid is reusable it is economical. The novel ZnO nanofluid considerably improves machining performance over conventional coolants. The more comprehensive an optimization strategy is, the better. 0.1 mm per revolution, 150 m/min, 0.5 mm cut depth the feed rate is ideal when it comes to maximizing the MRR. Cutting at a speed of 150 m/min, a cut depth of 0.5 mm, and a feed rate of 0.1 are the ideal process parameters.

Figure 1 exhibits the DNC machine involved in this study. The workpiece is tightly fastened in the machine spindle, as seen in the image. The single point tool is utilized for cutting the edges and machining. Each sample's MRR is meticulously recorded. This MRR data is then used for statistical analysis, which is carried out using SPSS software. Table 1 lists the chemical components of Inconel 718, as well as its physical properties. Table 2 lists both the input parameters, such as spindle speed, cut depth, and feed rate, as well as the resultant MRR.

After computing the MRR, the statistical analysis was carried out. The reported values are statistically computed using SPSS software. The mean MRR of Inconel 718 using novel ZnO nanofluid as coolant in group 1 is around 1085.8634, with a standard deviation of 564.176, according to the group data calculated in table 3. According to table 4, the mean MRR for the conventional coolant is 795.763, with a standard deviation of 382.151. Levene's test for equality of means is

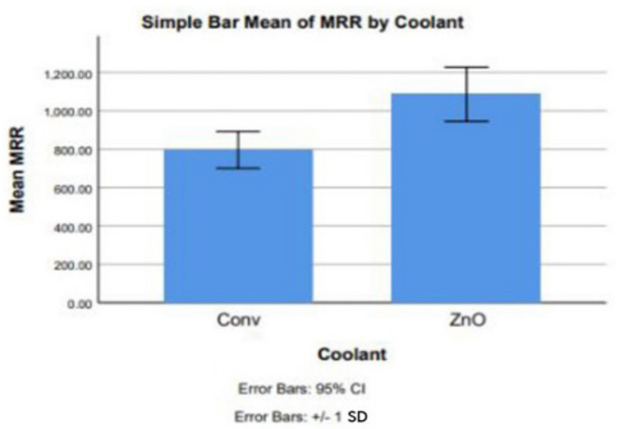

Figure 1: CNC turning center.

Table 1: Chemical constituents (%) of Inconel 718.

Constituents	Percentage (%)
Ti	0.65 to 1.15
Mo	2.80 to 3.30
Mn	0.35
C	0.08
P	0.015 max
Cr	17-21
Si	0.35
S	0.015 max
Ni	50-55

Table 2: Important physical properties of work material (Inconel 718).

Description of the physical property	Quantity
Density	8192 mg per cubic cm
Specific gravity	8.19
Melting range	1370 - 1430 °C

included in the independent sample T-test, and the results are displayed in table 5 as well. The level of significance gained from this study is 5%, and the obtained significance value is 0.024, which is less than ($p < 0.05$). In Figure 2, the mean MRR of CNC turning of Inconel 718 is compared to the novel ZnO nanofluid and conventional coolant. In comparison to conventional coolant, the mean MRR of machining with novel ZnO nanofluid (Group 2) is much higher. Detection accuracy on average was ± 1. Mean MRR is on the Y axis, while the X axis contrasts group 1 (Traditional coolant) with group 2 (Novel ZnO nanofluid).

Table 4: MRR T-test results of the group statistics of group size, group means, SD and standard error mean.

	Group	N	Mean MRR	Std. deviation of MRR	Std. error mean for MRR observations
MRR	ZnO NF	16	1085.863	564.176	141.044
	Conventional	16	795.763	382.1512	95.537

Discussion

Conventional coolant group's MRR values were 795.763, 382.1512, and 95.537. The ZnO NF group enhanced MRR by 1085.863, with a standard deviation of 564.176 and an std. error mean of 141.044 (mm^3/min), using novel ZnO nanofluid as a coolant. The results of the independent sample test, which employed the Levene's Test for equality of variances and had a significance level of 0.024, are displayed in table 5. As the 2 tailed significant value 0.001 which is less than 0.05, there are significant differences in the observations.

Table 3: Experiment wise process parameters including speed, feed, and depth of cut also the calculated MRR is shown below.

Expt no.	The spindle angular velocity (m/min)		Tool working depth (mm)		Longitudinal feed rate of tool (mm/rev)		Expt. No.	
	Description of level	Quantity of level set	Description of level		Description of level	Quantity of level set	Con-cool	ZnO_NF
1	L	90	L	0	L	0.05	202.23	204.102
2	L	90	B	0	B	0.1	353.9	433.871
3	L	90	A	1	A	0.15	471.9	650.97
4	L	90	H	1	H	0.2	505.59	699.013
5	B	110	L	0	B	0.1	336.93	394.888
6	B	110	B	0	L	0.05	606.53	797.909
7	B	110	A	1	H	0.2	749.83	952.783
8	B	110	H	1	A	0.15	943.8	1303.67
9	A	130	L	0	A	0.15	674.14	899.516
10	A	130	B	0	H	0.2	808.96	1105.28
11	A	130	A	1	L	0.05	1011.2	1409.19
12	A	130	H	1	B	0.1	1179.73	1649.23
13	H	150	L	0	H	0.2	842.66	1161.72
14	H	150	B	0	A	0.15	1179.73	1649.23
15	H	150	A	1	B	0.1	1348.29	1909.38
16	H	150	H	1	L	0.05	1516.8	2157.87

Table 5: T-Test results are displayed below after the statistical analysis is done for the obtained MRR data. Significance of this research study is shown below as 0.001 which is less than (5%) level of significance.

Equal variances in MRR observations	F	Sig.	t	df	Sig. (2- tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
								Lower	Upper
Assumed	2.53	0.024	1.703	30	< 0.001	290.0996	170.355	-57.8123	638.011
Not assumed	-	-	1.703	26.37	< 0.001	290.099	170.355	-57.8123	640.03

Figure 2: MRR during CNC turning of Inconel 718 was compared using conventional coolant vs a novel ZnO nanofluid. When comparing Group 2 (ZnO nanofluid) with group 1 (Conventional coolant), group 2 has a much higher mean MRR. Detection efficiency on ± 1 standard deviation. Group 1 (traditional coolant) and group 2 (ZnO nanofluid) are shown on the X axis, while the mean of the MRR is shown on the Y axis.

The proposed coolant is economical as it can be reused. The most significant aspect is cutting speed, followed by cut depth. Statistical assumptions were not contradicted by the findings. Coolant was essential for speeding up material removal and minimizing surface roughness. As a result, the findings are acceptable, and the recommended intervention could be used in everyday practice [30].

Due to its exceptional high temperature strength and corrosion resistance, Inconel 718, a superalloy based on nickel, is frequently employed in high-temperature applications [31]. By applying novel ZnO nanofluid to the tool's top surface, which boosted heat dissipation and rendered chip welding impossible, chip welding was minimized. The chip reduction coefficient decreases with increasing feed and cutting speeds [32]. The samples of the novel ZnO nanofluid exhibited good dispersion stability. As concentration and temperature increased, the thermal conductivity of nano coolant increased [22]. It is well known that modifications to surface characteristics brought about by nanoparticle deposition enhance the ability of nanofluid, a liquid containing colloidal dispersion of nanometer-sized particles, to transfer heat during quenching [33]. The optimum MRR was calculated using high-efficiency range analysis with a traditional flood method and novel ZnO nanofluid coolant, then employed in minimum quantity lubrication studies, with the results compared and assessed [34].

Though the proposed process exhibits economy and best performance in machining, there are some limitations. The nanoparticle size must be consistent for all machining combinations, the nano powder concentration in the fluid must remain constant, and the tool material must remain constant throughout the experiment [35]. Based on the traits and experimental constraints, it is possible to increase the future scope of MRR by investigating and improving ZnO nanoparticle size, concentration, and tool material in CNC turning of Inconel 718 material.

Conclusion

The collected results and findings imply that the new application of novel ZnO nanofluid in flood cooling method outperformed and boosted the machinability on CNC turning of Inconel 718 material over traditional coolant within the constraints of this investigation. The proposed method is economy and the average MRR improved by 36.48% that is MRR improved to 1085.86 mm^3/min from 795.76 mm^3/min. The t-test result, which shows the 2-tailed significance value p as less than 0.001 which is also less than 0.05, implies that there is a significant difference between the groups or that the observations are statistically significant.

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Conflict of Interest

None.

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