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Research Article

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Comparing Material Removal Rate in CNC Turning of Inconel 718 Using Silicon Dioxide Nanofluid with Conventional Coolant

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Abstract

In this study, the results of computer numerical control (CNC) turning operations on Inconel 718 are compared utilizing both conventional coolant and a silicon dioxide (SiO_2) nanofluid for flood cooling. CNC turning of the Inconel 718 was done with different settings of parameters and the observations made for calculating the material removal rate (MRR). The inputs parameters of speed, tool feed and depth of cut, were varied and machined with the flood coolant of SiO_2 nanofluid. Machining samples with use of nanofluid was group 1 and machined with conventional coolant was group 2. There were16 samples per group total 32 samples were tested. Pre-test G-power 80% was used in sample size prediction. Both groups are compared for finding the best coolant to improve machining performance in terms of MRR. The MRR of the SiO_2 nanofluid (group 1) was 1285.146 mm^3/min, whereas the mean MRR of machining the material of Inconel 718 with conventional coolant (group 2) was 795.763 mm^3/min. The significance p-value of this research study was 0.016 and it is less than 0.05. So statistically significant difference between the observed results of two groups. After conducting an experimental study, Machining with SiO_2 nanofluid resulted in higher MRR than the practice of machining with the conventional coolant in CNC.

Keywords

Turning, Coolant, Inconel 718, Silicon dioxide, Nanofluid, Material removal rate, Machining, Material removal rate, Computer numerical control, Economy

Introduction

In order to machine materials that are notoriously tough to cut and generate high temperatures, flood cooling is often used. There are a variety of health and environmental risks associated with the cutting fluids used in this technique. During turning, the area of contact between the tool and the workpiece generates the most heat. This is because shear cutting plane friction is considerable when removing hard and brittle materials, leading to subpar machining. This research aims to determine the impact of key machining factors on MRR and other performance metrics in CNC turning of Inconel 718. MRR and machining performance were used as performance metrics, with spindle speed, feed, and depth of cut serving as control variables [1]. Increased heat conduction is due in part to nanofluids' high thermal conductivity.

There has been a lot of published work in this field in recent years. About 375 publications may be found in the Google Scholar database, while another 260 can be found in the Science Direct database. According to the majority of the publications included in this analysis, cutting fluid's crucial functions in metal cutting are the maintenance of a cool cutting zone and tool, the removal of chips from the cutting zone, and the lubrication of the tool-workpiece interface. Machining efficiency is obviously affected by cooling procedures and fluid types [2-4]. Analysis, modeling, and optimization of turning Inconel 718 using nano-additives-based minimal amount lubrication are presented and discussed in this paper [5, 6]. The cutting zone may be cooled using a variety of liquid media that each have their own special additions in the form of nanoparticles. The study claims that compared to traditional cutting fluids, nanofluids provide better lubrication and cooling, however the exact degree of improvement varies depending on a variety of parameters [7]. A study with use of nanofluid with minimum quantity lubrication type lubrication investigation is most relevant to chosen investigation and considered as the be experiments on the use of SiO_2 nanofluid as a flood coolant in CNC turning operations have been lacking in prior studies [8, 9]. As a result, this research addresses not only process parameter optimization, but also heat conduction of the job and tool with nanofluid in flood coolant to boost MRR.

Methodology

This investigation is facilitated with inhouse research facilities, which have all of the necessary tools and machines to undertake the tests. Green manufacturing methods are employed in this project, including careful milling of metallic components with a highly secure CNC machine, biodegradable synthetic nanoparticles, and ecologically friendly coolants.

This experimental investigation divided participants into two groups: Group 1 used SiO_2 nanofluid coolant, whereas group 2 used conventional coolant while CNC turning. The number of samples 16 per group which is 32 samples in total was obtained from ClinCalc.com with the setting of 80% G-power. The utilized mean MRR was 2.666 for this investigation and the standard deviation of MRR was 0.34056 for production.

SiO_2 nanofluid is used as a coolant in group 1 for 16 samples. Each sample is clamped to the CNC chuck and the program is set to run. The program consists of various input parameters such as depth of cut (mm), feed (mm/rev), and spindle speed (m/min). These parameters are included in the program. The machining operation is done and closely observed with the SiO_2 nanofluid as a coolant. The same process is set to run each time for all the 16 samples of the (Group 1).

Conventional coolant is used as a coolant in flood cooling for the samples from group 2. The samples are in cylindrical shaped Inconel 718 material rod, cut equally into 16 samples for separate machining. Each sample is set in the CNC chuck and the same program is set to run. One sample at a time is machined for better observation, the values and behavior are recorded for further study. Every sample in (Group 2) is machined in the same procedure followed. Inconel 718's chemical composition and its 1285.146 mm^3/min physical composition are both included in table 1.

To observe weight loss by machine at certain sample lengths, the predefined values of input parameters in different combinations of low, below medium, above medium, and high ranges were used. Precision weight balance is used to measure weight loss. When each of the individual combinations was executed, the machining time recorded by using a timer. Table 2 lists the input parameters, which are then loaded into the CNC program for machining.

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 to 21
Si	0.35
S	0.015 max
Ni	50 to 55

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

Physical property	Quantity
Density	8192 mg/cc
Specific gravity	8.19
Melting range	1370 - 1430 °C

A precision weight balance was used to determine the mass of the sample before and after turning. The amount of time it takes to machine one sample length (25 mm). As a result, MRR for the 32 observations from both group experiments from the SiO_2 nanofluid and conventional coolant groups' studies were studied. In order to lessen the inaccuracy, the experiment's repetitions were incorporated, and their averages were considered. This research study's ultimate result is the calculated MRR.

Statistical analysis

IBM SPSS software was utilized for statistical analysis, as well as ClinCalc sample size estimator employed to determine required minimum samples per group with a 5% error. Spindle speed of cutting (m/min), depth of cut (mm), feed (mm/rev), and machining zone cooling method all serve as independent factors in this study. The MRR in cubic feet per minute is the dependent variable. Machining time, metal block weight, and MRR.

Results

Saveetha University's horizontal machining center is home to this CNC turning machine (Figure 1). The photo clearly shows the workpiece installed in the machine spindle and securely fastened. The 3-pointed tool is used for cutting the edges and machining in the turning process depicted in figure 1. For each sample, we meticulously record its MRR. The MRR information is then sent into the SPSS program for additional analysis. Both the input parameters (spindle speed, feed, and depth of cut) and the resulting MRR are shown in table 3. The cutting zone temperature, tool wear, surface roughness, chip removal, and machining lubrication were all improved by using SiO_2 nanofluid as the coolant. When compared to traditional coolant, the SiO_2 nanofluid dramatically increases the rate of machining performance. The


Figure 1: CNC turning center.

more comprehensive the optimization plan, the better. Speed of 150 m/min, 0.5 mm cut depth, and 0.1 mm/rev the feed rate should be optimized so that the material is removed as quickly as possible. The optimal process parameters for cutting include a cutting speed of 150 m/min, a cut depth of 0.5 mm, and a feed rate of 0.1.

The reported results are statistically computed using SPSS software. Table 4 displays the calculated group data, where we see that group 1's mean MRR for Inconel 718 using SiO_2 nanofluid as coolant is close to 1285.146 mm^3/min, with a standard deviation of 668.457. As can be shown in table 4, the average rate at which traditional coolant removes material from a workpiece is 795.763 mm^3/min, with a standard deviation of 382.1512. Results from the SPSS independent sample t-test and Levene's test for equality of means are shown in (Table 5). The 5% level of significance is lower than the achieved significance value of 0.016 from this investigation. Mean MRR of CNC turning of Inconel 718 in the presence of conventional coolant and SiO_2 nanofluid is shown in figure 2. When comparing group 2 (SiO_2 nanofluid) with group 1 (conventional coolant), group 2 has a much higher mean MRR. Detection efficiency on average 1 standard deviation. Group 1 (conventional coolant) on the X-axis, group 2 (SiO_2 nanofluid) on the Y-axis.

Table 4: Group statistics for MRR responses.

Group	SiO_2 nanofluid	Conventional coolant
Samples	16	16
Mean MRR	1285.146	795.763
Std. dev. of MRR	668.457	382.1512
Std. error mean for MRR observations	167.114	95.537

Discussion

There was a mean MRR of 795.763 mm^3/min, a standard deviation of 382.1512 mm^3/min, and a standard error of 95.537 mm^3/min for the conventional coolant group. Using SiO_2

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

Exp. No.	Spindle angular velocity (m/min)		Tool working depth (mm)		Longitudinal feed rate of tool (mm/rev)		MRR (mm^3/min)	
	Description of level	Quantity of level set	Description of level	Quantity of level set	Description of level	Quantity of level set	Conventional coolant	SiO_2 nanofluid
1	L	90	L	0.1	L	0.05	202.23	240.05
2	L	90	B	0.3	B	0.1	353.90	512.29
3	L	90	A	0.5	A	0.15	471.90	769.51
4	L	90	H	0.7	H	0.2	505.59	826.44
5	B	110	L	0.1	B	0.1	336.93	466.10
6	B	110	B	0.3	L	0.05	606.53	943.61
7	B	110	A	0.5	H	0.2	749.83	1127.11
8	B	110	H	0.7	A	0.15	943.80	1542.85
9	A	130	L	0.1	A	0.15	674.14	1064.00
10	A	130	B	0.3	H	0.2	808.96	1307.80
11	A	130	A	0.5	L	0.05	1011.20	1667.88
12	A	130	H	0.7	B	0.1	1179.73	1952.29
13	H	150	L	0.1	H	0.2	842.66	1374.66
14	H	150	B	0.3	A	0.15	1179.73	1952.29
15	H	150	A	0.5	B	0.1	1348.29	2260.53
16	H	150	H	0.7	L	0.05	1516.80	2554.94

Table 5: T-test results including Levene's test for equality of means are displayed below after the statistical analysis is done for the obtained MRR data. Significance of this research study is shown below as 0.35 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	4.873	0.035	-2.54	30	<0.016	489.38	192.495	96.2541	882.512
Not assumed	-	-	-2.54	23.85	<0.016	489.38	192.495	91.9666	886.799

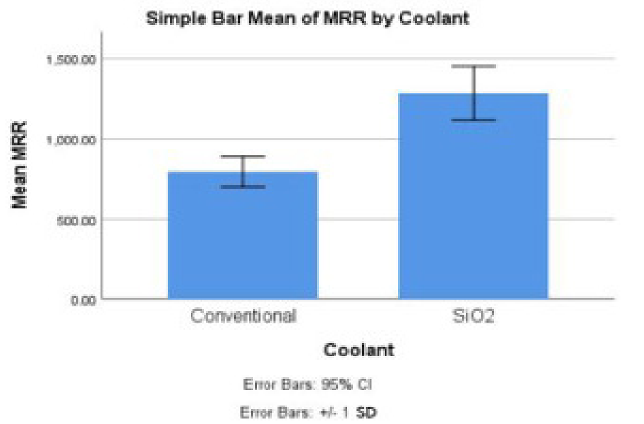

Figure 2: MRR during CNC turning of Inconel 718 was compared using conventional coolant vs a novel SiO_2 nanofluid. When comparing group 2 (SiO_2 nanofluid) with group 1 (conventional coolant), group 2 has a much higher mean MRR. Detection efficiency on ± 1 standard deviation. Group 1 (conventional coolant) and group 2 (SiO_2 nanofluid) are shown on the X-axis, while the mean of the MRR is shown on the Y-axis.

nanofluid as a coolant, the SiO_2 nanofluid group raised MRR by 1285.146 mm^3/min (167.114 mm^3/min on average, with a standard deviation of 668.457). The results of the independent sample test are shown in table 5; this test utilized Levene's test for equality of variances and a 0.035 level of significance. The level of significance is less than 5% since the significance value is less than 0.05. There is no indication that the observed findings violate the statistical assumptions. The depth of the cut is secondary to the cutting speed. The data did not challenge the standard statistical model. The use of coolant was essential in accelerating the MRR and smoothing out the surface. The results are so convincing, and the suggested intervention is feasible for implementation in everyday settings.

Inconel 718 is a nickel-based super alloy often used in high-temperature applications because to its remarkable high temperature strength and corrosion resistance [10]. SiO_2 nanofluid applied to the top of the tool increased heat dissipation, reducing the chance of chip welding. As feed and cutting speed rise, the chip reduction coefficient falls. As of SiO_2 nanofluid samples showed high dispersion stability. The thermal conductivity of nano-coolant improved with both concentration and temperature. Nanofluid, defined as a liquid with a colloidal dispersion of particles on the nanoscale scale, is known to have superior quenching heat transfer capabilities because to modifications to the surface properties brought about by the deposition of nanoparticles.

This research is cost-effective and showed respectable outcomes. However, it has several restrictions, such as requiring a consistent nanoparticle size throughout all machining combinations, a constant nanopowder concentration in the fluid, and a constant tool material. However, the aforementioned features and limitations of the experiment SiO_2 nanoparticle size, concentration, and tool material may all be optimized to increase the MRR in CNC turning of Inconel 718 in the future.

Conclusion

Within the restrictions of this investigation, the obtained results and findings suggest that the new application of SiO_2 nanofluid in flood cooling method outperformed and enhanced the machinability on CNC turning of Inconel 718 material over traditional coolant by 61.64% that is from 795.763 mm^3/min to 1285.146 mm^3/min. The significance of this research study is 0.016 which is less than 5%.

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None.

Conflict of Interest

None.

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