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Research Article

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Comparing Machinability in CNC Turning of Inconel 718 Using Copper Oxide Nanofluid and Conventional Coolant for Flood Cooling

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Abstract

The machining performance is compared when using copper oxide (CuO) nanofluid and conventional coolant for flood cooling while machining Inconel 718 material in computer numerical control (CNC) turning operation is focused in this research. CNC turning of Inconel 718 is performed with several parameter settings, and the resulting data is used to determine the material removal rate (MRR). Flood coolant of CuO nanofluid was used to machine at varying inputs of speed, tool feed, and depth of cut. Group 1 consisted of samples machined using nanofluid, while group 2 consisted of samples machined using conventional coolant. Each group consists of 16 samples and a total sample size of 32. Pre-1test G-power used was 80%. Both groups are compared for finding the best coolant to improve the MRR. The MRR of the CuO nanofluid (group 1) was 1032.710 mm^3/min, whereas the mean MRR of Inconel 718 using conventional coolant (group 2) was 795 mm^3/min. The significance value (p) obtained for the results was 0.0199 and it is less than 0.05, the observations are statistically significant between groups. After conducting an experimental study, CuO nanofluid supported well for machining and improve the MRR significantly.

Keywords

Turning, Coolant, Inconel 718, Copper oxide, Nanofluid, Material removal rate, Machining, Material, Economy

Introduction

For machining tough-to-cut materials that produce high temperatures, flood cooling is a frequent technique. The cutting fluids used in this process pose a variety of threats to human health and the environment. Wherever the turning tool contacts the workpiece is where the most heat is generated. Significant friction at the shear cutting plane while removing hard and brittle materials is the root cause of subpar machining results. The purpose of this research is to determine how important machining parameters affect MRR and other performance indicators during CNC turning of Inconel 718. MRR and machining performance were used as performance indicators, whereas spindle speed, feed rate, and depth of cut were used as controlling factors. One reason for the enhanced heat transmission is the high thermal conductivity of nanofluids.

Several articles pertinent to this investigation have appeared in recent years. About 375 papers may be found in Google Scholar, whereas about 260 can be found in the Science Direct database. Machining efficiency is obviously affected by cooling techniques and fluid types [1, 2]. Analysis, modelling, and optimization of turning Inconel 718 using nano-additives-based minimal quantity lubrication are presented and discussed in this paper. Several types of coolants are explored, each of which employs a liquid medium to transport nanoparticle-based additives to the cutting zone. The study claims that the use of nanofluids as cutting fluids improves lubrication and cooling in comparison to traditional cutting fluids, however the extent of the benefit depends on a variety of circumstances.

There hasn't been enough research done on the effectiveness of CuO nanofluid as a flood coolant for CNC turning operations for experiments to be conducted. Our group has a rich history of experience across many different types of research initiatives. Due to the increasing interest in this area, we have chosen to investigate this subject further. As a consequence, this study considers not only the optimization of process parameters and the reduction of machining costs, but also the enhancement of MRR through heat conduction of the job and tools using nanofluid in flood coolant.

Methodology

This investigation is carried out at the university premisses. This project uses green manufacturing techniques, such as economy and carefully machining metallic components with a highly safe CNC machine, synthetic nanoparticles that are biodegradable, and environmentally friendly coolants. Experimental group samples are to be machined by using CuO nanofluid coolant and control group samples are to be machined by using usual coolant in the CNC turning operation. Each group has 16 samples of Inconel 718 specimens for CNC turning operation to the specimens. For the prediction, a sample size calculator (ClinCalc - an open-source software) was used. 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. Table 1 shows the chemical constituents of Inconel 718 along with its 1032.710 mm^3/min physical constitution.

CuO 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, feed, and spindle speed. These parameters are included in the program. The Machining operation is done and closely observed with the CuO 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.

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

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 was recorded using a timer. Table 2 lists the input parameters, which are then loaded into the CNC program for machining.

The sample's mass was measured both before and after turning using a high-precision weight balance. The amount of time it takes to machine one sample length (25 mm). The MRR was calculated from the observed data. Hence, the 32 MRR is derived from observations gathered from the CuO nanofluid and conventional coolant groups' studies. In order to lessen the inaccuracy, the experiment's repetitions were incorporated, and their averages were taken into account. This research study's ultimate result is the calculated MRR to do matching in an economic way.

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

Statistical analysis

Clinically relevant sample sizes were determined using Clincalc, and IBM SPSS statistics v26 was used for statistical analysis. Feed rate, depth of cut, and spindle speed coolant used for machining zone cooling method are the experimental factors to be controlled. MRR is the response under consideration [3].

Results

Cutting zone temperature, tool wear, surface roughness, chip removal, and machining lubrication to decrease frictional loss economically were all improved by using CuO nanofluid as a coolant. The CuO nanofluid booms up the machining performance rate significantly higher than conventional coolant. The bigger the optimization strategy, the better. The feed rate of 0.1 mm per revolution, cutting depth of 0.5 mm, and speed of 150 m/min When it comes to maximizing the MRR, the feed rate is ideal.

Figure 1 exhibits the CNC turning venter, Saveetha University. As shown in the picture (Figure 1) the workpiece is set up in the machine spindle and rigidly clamped. The single point tool is used for cutting the edges and machining in the turning operation. The MRR is noted for each of the samples carefully. As a next step, the MRR data is sent into SPSS for statistical analysis. In table 2, we see the relationship between the input parameters (such as spindle speed, feed, and depth of cut) and the resultant MRR.

The MRR data for both groups are shown in table 3. The statistical computation of the results is performed using SPSS

Figure 1: CNC turning center.

software. Table 4 displays the calculated group data; the mean MRR for Inconel 718 in group 1, using CuO nanofluid as coolant, is around 1032.710 mm^3/min with a standard deviation of 668.457. In table 4, we can see that the conventional coolant has a mean MRR of 795.763 mm^3/min and a standard deviation of 382.1512. Levene's test for equality of means is included in the SPSS-run independent sample t-test findings that are shown in table 5. The obtained significance value of 0.019 from this investigation is below than the 5% level of significance, which is defined as p 0.0199. Figure 2 shows the mean MRR of CNC turning of Inconel 718 when using either conventional coolant or the CuO nanofluid. Group 2 (CuO nanofluid) showed a considerably higher mean MRR than group 1 (conventional coolant) during machining. Detection efficiency, on average, is within one standard deviation. Mean MRR on the Y-axis, group 1 being the conventional coolant and group 2 being the CuO nanofluid.

Table 4: Group statistics for MRR responses.

Group	CuO nanofluid	Conventional coolant
Samples	16	16
Mean MRR	1032.710	795.763
Std. dev. of MRR	612.482	382.1512
Std. error mean for MRR observations	153.120	95.537

Discussion

Standard error mean of 95.537, standard deviation of 382.1512, and mean of observed MRR of 795.763 mm^3/min were calculated for the conventional coolant group. With a mean of 167.114 and a standard deviation of 668.457, the CuO nanofluid group saw an increase in MRR of 1032.710 when they switched to CuO nanofluid as a coolant. Independent sample test results using Levene's test for equality of variances at a 0.0199 significance level are shown in table 5. The observations show substantial differences between groups, as shown by a p-value of less than 0.05. No violation of the statistical hypotheses can be inferred from the observed data.

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)		Longitudinal feed rate of tool (mm/rev)	
	Description of level	Quantity of level set	Description of level	Quantity of level set	Description of level	Quantity of level set	Description of level	Quantity of level set
1	L	90	L	0.1	L	0.05	L	0.05
2	L	90	B	0.3	B	0.1	B	0.1
3	L	90	A	0.5	A	0.15	A	0.15
4	L	90	H	0.7	H	0.2	H	0.2
5	B	110	L	0.1	B	0.1	B	0.1
6	B	110	B	0.3	L	0.05	L	0.05
7	B	110	A	0.5	H	0.2	H	0.2
8	B	110	H	0.7	A	0.15	A	0.15
9	A	130	L	0.1	A	0.15	A	0.15
10	A	130	B	0.3	H	0.2	H	0.2
11	A	130	A	0.5	L	0.05	L	0.05
12	A	130	H	0.7	B	0.1	B	0.1
13	H	150	L	0.1	H	0.2	H	0.2
14	H	150	B	0.3	A	0.15	A	0.15
15	H	150	A	0.5	B	0.1	B	0.1
16	H	150	H	0.7	L	0.05	L	0.05

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 0.0199 which is less than (5%).

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	4.525	0.042	-1.31	30	< 0.02	-236.946	180.48	-605.538	131.644
Not assumed	-	-	-1.31	25.14	< 0.02	-236.946	180.48	-608.547	134.654

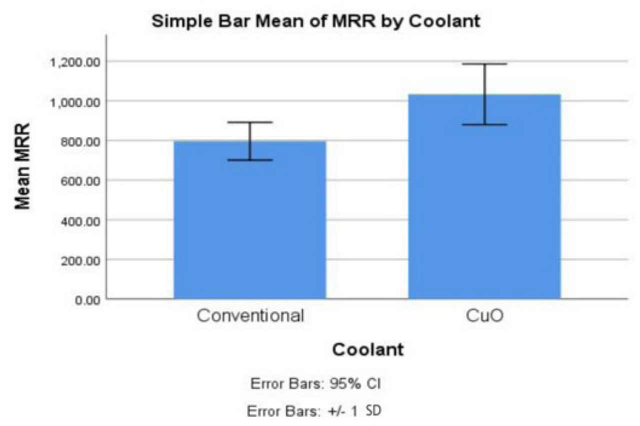

Figure 2: Comparison of MRR in presence of conventional coolant and CuO nanofluid in terms of mean MRR of CNC turning of Inconel 718. The mean MRR of machining with CuO nanofluid (Group 2) is significantly greater than machining with conventional coolant (Group 1). Mean accuracy of detection ± 1 standard deviation. X-axis: Group 1 (Conventional coolant) vs group 2 (CuO nanofluid) and Y-axis: Mean MRR.

One must priority cutting speed over cutting depth. The findings did not contradict statistical assumptions. Coolant economy was crucial in increasing the rate of material removal and reducing surface roughness. As a consequence, the findings are acceptable, and the proposed intervention could be used in routine practices.

Inconel 718, a nickel-based super alloy, is widely used in high-temperature applications because to its remarkable high temperature strength and corrosion resistance. The use of CuO nanofluid on the tool's top surface decreased chip welding by increasing heat dissipation and therefore eliminating the likelihood for chip welding. Cutting faster and with a higher feed rate results in a lower chip reduction coefficient [4]. CuO nanofluid sample dispersion stability was satisfactory. A nano-coolant's thermal conductivity improved with both concentration and temperature [5]. It is widely known that modifications to the surface characteristics caused by the deposition of nanoparticles increase the quenching heat transfer capabilities of nanofluid, a liquid comprising a colloidal dispersion of nanometer-sized particles. High-efficiency range study was performed using the conventional flood technique and CuO nanofluid coolant to determine the optimal MRR, which was then employed in minimal amount lubrication tests with the results of each approach compared and analyzed [6].

This study has some limitations, such as the nanoparticle size remaining constant for all machining combinations, the nanopowder concentration in the fluid remaining constant, and the tool material remaining constant throughout the experiment. After reviewing the experiment's features and limits, it's evident that novel CuO nanoparticle size, concentration, and tool material may 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 CuO nanofluid in flood cooling method outperformed and enhanced the machinability on CNC turning of Inconel 718 material over conventional coolant. The proposed coolant improved the MRR from 795.763 mm^3/min to 1032.710 mm^3/min. Since the p-value is less than 0.05 ($p = 0.0199$), a statistically significant split may be drawn between the groups.

Acknowledgements

None.

Conflict of Interest

None.

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