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Comparing Machinability Performance in CNC Turning of Inconel 718 Using Aluminum Oxide Nanofluid with Conventional Coolant

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Abstract

Wet machining of Inconel 718 using standard coolant and aluminum oxide (Al_2O_3) nanofluid application to increase machining rate are compared in this work. Various parameters are adjusted during computer numeric control (CNC) turning of Inconel 718, and measurements are taken to determine the material removal rate (MRR). Al_2O_3 nanofluid was used as a novel flood coolant while cutting at varying speeds, feed rates, and depths. Samples machined using nanofluid (Group A) and samples machined using conventional coolant (Group B) made up the two groups. Samples machined using nanofluid (Group A) and samples machined using conventional coolant (Group B) made up the two groups. The sample size was calculated 16 per group and used Taguchi standard Design of Experiments L16. The volume of material removed per minute is calculated using weight loss due to machining, machining time, and material density data. The key parameters of depth of cut, adjusting the input variables of work angular velocity (speed) and rate of tool feeding resulted in 16 different permutations of weight loss and machining time. The machining rate (MRR) that was observed was compared. The application Al_2O_3 nanofluid significantly raised the mean MRR to 1110.8376 mm^3/min than the use of conventional coolant (795.76 mm^3/min). Sig. value was 0.02 and it is less than 0.05, so statistically significant difference between the observed results of two groups. This suggests that there is a discernible divide between the two sets of people. In CNC turning of Inconel 718, it was discovered that the unique use of Al_2O_3 nanofluid gave greater MRR than conventional coolant.

Keywords

Computer numeric control, Turning, Conventional coolant, Inconel 718, Aluminum oxide, Nanofluid, Material removal rate, Machining, Economy

Introduction

Inconel 718 is used in this study to investigate and analyze how various machining independent variables, such as the rotational speed of a multipoint cutting tool, its feed rate for machining, depth of cut, machining environment and others affect the MRR [1]. This research is being carried out for the precise and quick machining of expansion joints in aerospace applications, which snugly fix components and prevent the held component from expanding and absorbing temperature changes. Precision machining is essential for achieving a flawless fit. The MRR is affected by the multipoint cutting tool's rotating speed, machining feed rate, depth of cut, machining environment, and this investigation for Inconel 718 for gas turbine [2].

For over five years, there have been around 39 articles published in the Science Direct database and around 1023 articles published in the Google Scholar database. The [3] recommended that a unique set of physical and mechanical properties that make it valuable for a variety of applications. [4] recommends wet machining of AISI 202 austenitic stainless steel with nanofluids in minimum quantity lubrication form at CNC machine. Inconel 718 is valued for its distinctive and specialized uses because of its unique and exceptional physical and mechanical qualities [5]. Although the work material is stainless steel, it has a higher corrosion resistance and is naturally harder. Inconel 718 is employed in the medical, aerospace, chemical and automobile industries due to its unique features.

Previous research on the use of nanofluid in the flood coolant in CNC turning operations is lack in not reported. It is considered here for economy and best performance in Inconel 718 machining. This research focusses to explore the possibilities of using Al_2O_3 nanofluid to increase the machinability with economy and support for green machining.

Methodology

YCM – EV 1020A turning center in-house research facility at Saveetha University (Figure 1). This experiment uses metallic materials and synthetic nanoparticles that are biodegradable and environmentally benign. In group A, CNC turning of Inconel 718 is done with conventional cooling fluid. However, the samples in group B were machined using an application of Al_2O_3 nanofluid. The first group, known as group A, is an experimental group, while group B is the intervention group. The sample size of 16 per group was calculated using expected (86.17%) and historical (62.41%). For the prediction, the sample size calculator (ClinCalc open-source software) was used. The G-power, mean, standard deviation was used for this investigation are 80%, 2.666 mm/min and 0.34056, respectively.

Figure 1: The CNC turning center at Saveetha University.

The work material in sample group A (Conventional coolant) is Inconel 718 machined using conventional coolant (Mix Max ST 2020). The work material constitutions furnished in table 1. In the 16 trials, the independent variables were modified at four levels to explore machinability. Sample size for the experiment was 16 and MRR is a response.

The workpiece is purchased and finished by cutting Inconel 718 into a cube of 50 mm side in the wire electric discharge machine. A single point cutter used to perform turning.

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

Al_2O_3 nanofluid is used to process the samples in group B (Al_2O_3 nanofluid). Al_2O_3 nanoparticles with a diameter of less than 5 nm are used in a ratio of 40 g per 1000 g of Mix Max ST 2020. The magnetic stirrer was employed for 9 h to ensure proper mixing, allowing Al_2O_3 nanoparticles to suspend on the coolant and preventing settlement during turning. Table 2 lists the input parameters and application level. The change in viscosity is ignored in this experiment because the particles are suspended and nanosize.

Before and after machining, the sample's mass was determined using a precise weight balance. The time taken per sample length of machine (25 mm). the observed data utilized to calculate the MRR. Hence the 32 values of MRR are calculated from the observations obtained from experiments of the 'Conventional' group and 'Al_2O_3' group. The time spent cutting each sample length (25 mm). The data that was used to calculate the MRR as a result, the 32 MRR values are derived using observations from the conventional and Al_2O_3 groups' studies.

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

Using IBM SPSS software version 26, we determined the minimum required sample size using the ClinCalc sample size calculator, assuming a margin of error of 5%. The cutting speed (in meters per minute), tool depth of cut (in millimeters), tool feed (in millimeters per revolution), and machining zone cooling method are the experimental factors.

Results

Figure 2 shows the average MRR for both the 'Conventional' group and 'Al_2O_3' group. The proposed method of machining greatly enhanced the MRR over the conventional method. The optimization strategy is larger the better. The 0.05 mm per revolution feed rate, 0.7 mm cut depth, 150 m/min speed, and for maximum MRR is recommended. Table 3 shows the calculated MRR based on the experimental observations.

Table 4 displays the t-test data obtained using SPSS software to obtain the standard error (SE), standard deviation

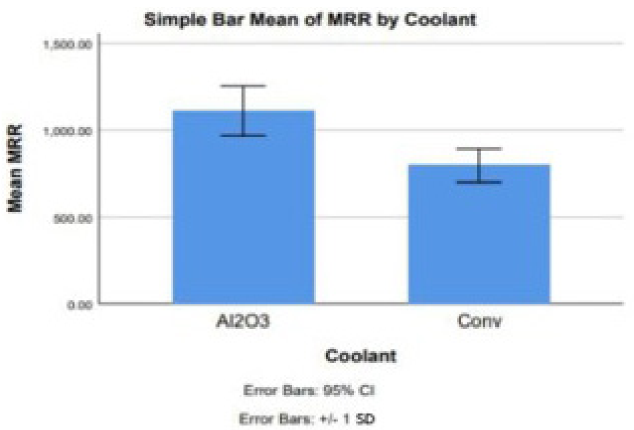

Figure 2: MRR during CNC turning of Inconel 718 was compared using conventional coolant vs a Al_2O_3 nanofluid. When comparing Al_2O_3 group with conventional group, Al_2O_3 group has a much higher mean MRR than conventional group. Mean accuracy of detection ± 1 SD. The groups are shown on the X-axis and mean MRR yielded by respective group in Y-axis.

(SD) and the mean. The MRR of conventional group, at which employed conventional coolant, was recorded as 795.76 mm^3/min, with a SD of 382.151 and a SE of mean of 95.537 mm^3/min. The Al_2O_3 group, which used Al_2O_3 nanofluid as a coolant, had a mean of 1110.83 mm^3/min, a SD of 572.7, and a SE of mean of 143.175.

Figure 1 shows the in-house research facility for this study YCM – EV 1020A CNC turning center. In figure 2, the X-axis shows the class of groups, i.e., 'Conventional' group and 'Al_2O_3' group and the Y-axis reflects the average MRR.

Table 4: Group statistics for MRR responses.

Group	Al_2O_3 group	Conventional group
Samples	16	16
Mean MRR	1110.8376	795.763
SD of MRR	572.700	382.1512
SE mean for MRR observations	143.1752	95.537

Table 5 resembles the results of t-test, which shows a significance value of $p < 0.02$ and also it is less than 0.05, there is a statistical significance between the control group and experimental group observations and the observed results did not violate statistical assumptions. The findings did not contradict statistical assumptions.

Discussion

Reduced cutting zone temperature, tool wear, surface roughness, chip removal, and machining lubrication to lessen frictional losses were all aided by the novel use of high-discharge Al_2O_3 nanofluid. When compared to machining with conventional coolant, the combined benefits enhance productivity by 65.1%. The optimal process parameters for cutting include a cutting speed of 150 m/min, a cut depth of 0.7 mm, and a feed rate of 0.05. The depth of the cut is secondary to the cutting speed.

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 group	Al_2O_3 group
1	L	90	L	0.1	L	0.05	202.23	210.5852
2	L	90	B	0.3	B	0.1	353.90	447.2734
3	L	90	A	0.5	A	0.15	471.90	670.4523
4	L	90	H	0.7	H	0.2	505.59	719.2408
5	B	110	L	0.1	B	0.1	336.93	405.9026
6	B	110	B	0.3	L	0.05	606.53	819.412
7	B	110	A	0.5	H	0.2	749.83	977.5153
8	B	110	H	0.7	A	0.15	943.80	1336.22
9	A	130	L	0.1	A	0.15	674.14	921.0675
10	A	130	B	0.3	H	0.2	808.96	1130.67
11	A	130	A	0.5	L	0.05	1011.20	1440.155
12	A	130	H	0.7	B	0.1	1179.73	1683.833
13	H	150	L	0.1	H	0.2	842.66	1184.919
14	H	150	B	0.3	A	0.15	1179.73	1680.537
15	H	150	A	0.5	B	0.1	1348.29	1943.724
16	H	150	H	0.7	L	0.05	1516.80	2194.525

Table 5: T-test results are displayed below after the statistical analysis is done for the obtained MRR data. The observations are statistically significant as significance value is shown below as 0.02 and less than 0.05.

Equal variances in MRR observations	F	Sig.	t	df	Sig. (2- tailed)	Mean difference	SE difference	95% confidence interval of the difference	
								Lower	Upper
Assumed	2.713	0.039	1.828	30	< 0.02	314.613	172.123	-36.91059	666.1369
Not assumed	-	-	1.828	26.14	< 0.02	314.613	172.123	-36.91059	666.1369

The machining is economical as it is reusable. As a result, the findings are acceptable, and the proposed intervention could be used in routine practices. Since the t-test's two-tailed significance value is less than 0.02, indicating a statistically significant difference between the groups, we may conclude that the observations are also significant.

Turning Inconel 718 material because of its fine grain structure, dry machining exposes the cutting zone to high temperatures, and the subsequent cooling to room temperature by air reveals a significant increase in microhardness. Tool monitoring was included to provide consistent machining quality and throughput. Dry turning of AISI 321 looked at aspects such surface roughness, force of cut, and tool wear but not MRR because of the material's difficulty to machine. This research suggests a novel use of Al_2O_3 nanofluid as a flood coolant for Inconel 718 turning. Because of this application, the cutting zone temperature was reduced, and the tool's sharpness was maintained for a long time. The high flow rate prevents cutting fluid evaporation and producing fumes while turning. This meant that CNC turning of Inconel 718 resulted in a greater MRR than traditional machining [6]. The suggested method enhanced machining rate (MRR) by an average of 65.1% as measured by the difference between the Al_2O_3 group and the conventional group in terms of mean MRR. Several parameters, cutting chief among them, affect surface quality. These include feed rate and depth of cut. However, Al_2O_3 nanofluid aids in reaching a higher machining rate (MRR) while maintaining good surface quality.

With respect to fundamental input values, the regression equation is supplied for forecasting the MRR. This reduced time and trail waste while machined at the appropriate MRR. As a result, this experiment was organized and carried out on the Inconel 718 machine while taking into account personnel and environmental engineering concerns, particularly the selection of a biodegradable, environmentally friendly coolant for processing samples on both groups [7]. The statistical investigation confirmed the Al_2O_3 nanofluid samples outperformed significantly. The Al_2O_3 nanofluid samples outperformed significantly, according to the statistical analysis. Surface roughness, tool wear, pressures needed, tool life, surface integrity, and productivity are all factors affected by the cutting zone temperature, which was drastically reduced by the Al_2O_3 nanofluid in addition to the MRR reaction.

Because of the high flow rate, odors were not generated by evaporation while heat was absorbed, and multiple recirculation provided long-term use and cost savings. There is no need for any major modifications or additional setup/attachment/auxiliary power/power driven equipment. The removal of chips from the cutting zone and the lubrication of the contact between the tool and the workpiece are two essential aspects of high-quality machining. Our team is committed to generating reliable studies, and we have found success in many sectors. This study, we hope, will contribute to that illustrious past.

The nanoparticle size stayed consistent for all machining combinations, the nanopowder concentration in the fluid remained constant, and the tool material remained constant throughout the experiment. Despite these caveats, it is evident from the foregoing that MRR in CNC turning of Inconel 718 may be improved by considering and optimizing Al_2O_3 nanoparticle size, concentration, and tool material.

Conclusion

Within the restrictions of this investigation, the acquired results and findings suggest that the unique application of Al_2O_3 nanofluid in flood cooling method outperformed by recording the mean MRR of 1110.83 mm^3/min and enhanced the machinability of Inconel 718 CNC turning over machining with the conventional coolant (MRR was 795.76 mm^3/min). As this coolant is reusable the machining will be economical. A statistically significant difference exists between the groups, or the observations are significant, if the two-tailed significance value ($p < 0.02$) is less than 0.05, as shown by the t-test.

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None.

Conflict of Interest

None.

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