Optimization of Cutting Parameters & Nanoparticle Concentration in CNC Turning of EN8 Steel using Al_2O_3 Nanofluids as Coolant

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Abstract *—In this study, an attempt has been made to investigate the machining characteristics on EN8 steel using Al_2O_3 nanofluids as coolant. EN8, which are commonly used in the automobile applications has been found to have high roughness value generated on the machined surface. A CNC turning operation was performed on the EN8 steel using HSS tool. Al nanoparticle with high thermal conductivity has been used with water as basefluids to form Al_2O_3 nanofluids to reduce the heat formation. The results obtained showed a better surface finish on the machined surface indicating considerably reduced surface roughness. By using ANOVA, the optimum condition for surface finish and MRR was found out*

Keywords — *EN8 steel, Al_2O_3 nanofluids, cutting speed, feed rate, depth of cut, nanoparticle concentration, surface roughness, MRR, ANOVA*

I. INTRODUCTION

Turning is one of the most basic machining processes. In turning process, parameters such as cutting tool geometry and materials, number of passes, depth of cut for each pass, the depth of cut, feed rates, cutting speeds as well as the use of cutting fluids will impact the production costs, MRRs, tool lives, cutting forces, and the machining qualities like the surface roughness, the roundness of circular and dimensional deviations of the product. Cooling becomes one of the top technical challenges facing high-tech industries such as microelectronics, transportation, manufacturing, and metrology. The selection of the best cutting fluid for a particular operation will rely on several parameters such as cutting speed, feed rate and depth of cut, workpiece and tool materials, required tolerances and surface integrity of the machined component. It has been reported that the application of cutting fluid is unable to prevent high temperatures at a tool/chip interface due to the fact that it cannot access the flow zone where a considerable amount of heat is generated.

Nanofluids are used nowadays as coolants in machining due to higher thermal conductivity and better heat transfer rate compared to conventional cutting fluids. Nanofluids are primarily used as coolant in heat transfer equipment such as heat exchangers, electronic cooling system (such as flat plate) and radiators. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer.

EN8 is a very popular grade of through-hardening medium carbon steel, which is readily machinable in any condition. EN8 steel is suitable for the manufacture of parts such as general-purpose axles and shafts, gears, bolts and studs. During the CNC turning of components like shafts, the EN8 material may be subjected to high loads. Under these machining conditions, EN8 material may be subjected to high heat generation. This can create thermal cracks on the shafts, which will affect the quality of aeronautical and automobile components. Nanofluids are considered as potential heat transfer fluids because of their superior thermal properties. So nanofluids will carry away heat generated in tool and work piece more efficiently. Hence nanofluids can be applied as coolants in machining operations which can reduce the heat generated on the tool and workpiece. This will also improve the machining rate and surface parameters.

II. LITERATURE REVIEW

R.F.Avila, A.M Abrao (2001), in his work, the performance of cutting fluids were compared to dry machining processes, when continuous turned hardened AISI 4340 steel using mixed alumina inserts. Conventional turning tests were conducted on a CNC lathe. The different cutting fluids used were: fluid A (emulsion without mineral oil), fluid B (synthetic), fluid C (emulsion containing mineral oil). The tests were repeated under conditions of dry machining also. The results observed that the machining done using fluid A gave better tool life when compared to dry cutting. For a cutting speed of 200m/min, fluid C obtained lowest roughness value. With regard to chip control, use of cutting fluids has a positive influence.

Daungthongsuk, Somchai Wongwises (2005), found cutting fluids can be synthesized by mixing metallic, non-metallic, ceramics, or carbon nanoparticles in a conventional cutting fluid because as compared with suspended milli- or micro-sized particles, nanofluids show better stability, rheological properties, extremely good thermal conductivity, and no negative effect on pressure drop. Many types of particle, such as metallic, non-metallic and polymeric, can be added into fluids to form slurries. Compared with suspended particles of millimeter-or-micrometer dimensions, nanofluids show better stability and rheological properties, dramatically higher thermal conductivities, and no penalty in pressure drop. The main reasons for the heat transfer enhancement of the nanofluids are the suspended nanoparticles increase the thermal conductivity of the fluids, and the movement of ultrafine particles increases fluctuation and turbulence of the fluids which accelerates the energy exchange process.

Dongsheng Wen, Guiping Lin, Saeid Vafaei, Kai Zhang (2009), proposed inclusion of nanoparticles of metal oxides into any base fluid enhances its thermal conductivity. Two step method and one step method has been adopted for nanofluid formulation. For the two-step method, dried nanoparticles have to be either synthesized or purchased in the form of dry powders. Certain stabilizers are generally used during the formulation of nanofluids to establish steric barriers among nanoparticles, in order to stabilize the nanofluids. Gold nanofluids having higher thermal conductivity is been investigated by a limited number of studies due to the high cost.

R R Srikant, D.N.Rao, M S Subramanyam, P. Vamsi Krishna (2009) found that the addition of nanoparticles in cutting fluids improved their coolant properties. Cutting fluids with inclusion of nanoparticles have enhanced heat transfer capacity up to 6 percent. Heat liberated and the friction associated with the cutting process ever pose a problem in terms of tool life. Nanofluids, with their cooling and lubricating properties, have emerged as a promising solution. A facing operation is conducted on AISI 1040 (EN 8) steel which is used as the workpiece material. It may be observed that temperatures are significantly low for fluid with nanoparticles inclusion. The results clearly show that temperatures decrease from 0.5 to 6 percent inclusion of nanoparticles, beyond which the temperatures increase. Up to 1 percent, the decrease in temperatures is more drastic compared to concentrations beyond 1 percent.

P.Krajnik, F.Pusavec, A.Rashid (2011), nanofluids have higher potential efficiency than conventional cutting fluids. Hence he proposed in the future, nanofluid properties should be tested under real machining conditions. Most nanofluids contain less than 1% by volume of nanoparticles. One of the biggest problems refers to the scale of fabrication. As the volume increases, the way the constituents of a nanofluid mix and react changes drastically . The higher the wetting the higher is the heat transfer hence, nanoparticles increase the wettability of a base fluid.

Akshaya T Poojary, Rajesh Nayak (2014), conducted an experimental study to determine the machinability on AISI 1040 steel on PSG A141 lathe. The conventional cutting fluids fail to achieve the desired cutting temperature and also have techno-environmental problems along with the possibility of corroding the workpiece and machine tool parts. AISI steel was machined using High Speed Steel cutting tool at different feed, speed and depth of cut. Different feed rate was given at low, medium and high conditions at 0.1, 0.13 and 0.18 mm/rev. correspondingly at different cutting speeds of 27.14, 33.92 and 43.73 m/min etc. and different depth of cut of 0.25, 0.5 and 0.75 mm repectively.

III EXPERIMENTS AND METHODOLOGY

The main objective of this work is that to reduce the roughness on the EN8 material by using nanofluids as coolant. The various cutting parameters and nanoparticle concentration are varied in order to identify the surface finish obtained on the EN8 material which is used in automobile applications. This experimental investigation was conducted on CNC lathe by varying the different factors to find these effects on the material. In order to achieve the objectives, the experiments were designed based on Taguchi's design of experiments.

A. Design of Experiments

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. The Taguchi method tests for pairs of combinations which allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. For the turning process of EN8 material, 4 different factors are selected at 3 different levels. The factors selected for the process are

i) Cutting speed
ii) Cutting feed,
iii) Depth of cut and
iv) Concentration of nanoparticle in basefluid.

The parameters selected are tested at three different levels of operation. For 4 different factors selected at 3 different levels, an L9 orthogonal array is to be selected.

B. Methodology

Selection of proper nanoparticle is the prime step to be carried out in the process. Al_2O_3 nanoparticle are selected based on the thermal conductivity of the material. Nanoparticle with higher thermal conductivity has higher heat transfer rate. Al_2O_3 Nanoparticle selected is to be mixed with the base fluid (water) at a proper concentration ratio. The Al_2O_3 nanofluid thus obtained can be used for the machining operation. CNC turning operation is to be performed on EN8 mild steel material. Experiments have to be conducted by varying machining parameters such as cutting speed, feed, depth of cut etc. at low, medium and high conditions, along with the varying concentration of nanoparticle in water ratio. Depending on the change in the input conditions, the variations in surface finish and the material removal rate (MRR rate) are to be investigated. A profilometer can be used for the measurement of surface finish of the material surface.

C. Scheme of experiment

The cutting experiments is to be carried out on a CNC Lathe under different cutting conditions. Machining tests are performed on an EN8 bar having diameter Φ40mm. Tool material for this study is High Speed Steel. The cutting fluid selected for machining is Al_2O_3 nanofluids. Each experiment has to be repeated twice for more reliable data and results are recorded for surface finish and MRR rate. Taguchi parameter optimization method is used to evaluate the best possible combination for surface finish during turning operation. The scheme of experiment is as shown in table 1.

Experiment	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Nanoparticle concentration (wt%)
1	500	0.05	0.1	0.1
2	500	0.10	0.2	0.5
3	500	0.15	0.3	1
4	650	0.05	0.2	1
5	650	0.10	0.3	0.1
6	650	0.15	0.1	0.5
7	850	0.05	0.3	0.5
8	850	0.10	0.1	1
9	850	0.15	0.2	0.1

Table 1. Scheme of experiment

IV RESULTS AND DISCUSSION

This chapter deals with the results obtained and the discussions based on the machining operation carried out on EN8 steel. Results are obtained for surface roughness and material removal rate. MINITAB 17 software is used to perform Taguchi design of experiment and ANOVA.

A. **Analysis of experiment data**

Analysis of variance (ANOVA) is done to investigate which design parameter has major influence on surface roughness and the material removal rate (MRR). Based on ANOVA, the importance of machining parameters and nanoparticle concentration with respect to surface roughness and material removal rate (MRR) was investigated to determine the optimum combination of the machining parameters. All analysis are carried out with a significance level of $\propto = 0.5$, i.e with a confidence level of 95%. The percentage of contribution of each source to the total variation indicates the degree of influence on the result by each source.
Taguchi's method of analyzing means of the S/N ratio using conceptual approach involves graphical method in studying the effects and to identify the significant factors. The rank indicates the dominant machining parameter.

A) Surface Roughness

In the experiment, the desired characteristic for surface roughness is lower the better. The signal to noise ratio for lower the better is given as :

$$S/N = -10\log [1/n \sum_{i=1}^{n} (y_i^2)]$$

Exp. No.	Speed (rpm)	Feed (mm /rev)	Depth of cut (mm)	Nanoparticle concentration (wt%)	Surface roughness (μm)	S/N ratio
1	500	0.05	0.1	0.1	1.687	-4.54
2	500	0.10	0.2	0.5	1.929	-5.71
3	500	0.15	0.3	1	1.691	-4.56
4	650	0.05	0.2	1	1.855	-5.37
5	650	0.10	0.3	0.1	1.890	-5.53
6	650	0.15	0.1	0.5	0.998	0.02
7	850	0.05	0.3	0.5	0.897	0.944
8	850	0.10	0.1	1	1.866	-5.42
9	850	0.15	0.2	0.1	1.375	-2.77

Table 2 Signal to noise ratio of surface roughness

The table 2 summarizes the surface roughness obtained on the machined surface of EN8 steel and their corresponding signal to noise ratios. The surface roughness on the EN8 steel varies from 0.897 to 1.929 μm. The main effects plot for S/N ratio is as shown in figure 1.

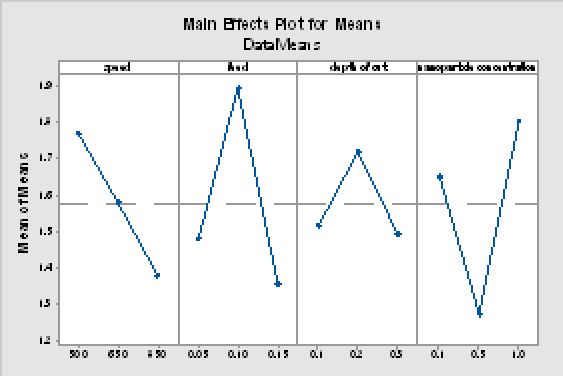

Figure 1 Main effects plot for surface roughness

Table 3 Response table for surface roughness

Level	Speed	Feed	Depth of cut	Nanoparticle concentration
1	1.769	1.479	1.517	1.651
2	1.581	1.895	1.719	1.275
3	1.379	1.355	1.493	1.804
Delta	0.39	0.54	0.226	0.53
Rank	3	1	2	4

Table 3 shows the response table of Signal to Noise ratios for surface roughness. Based on the analysis, low surface roughness is obtained at speed (850 rpm), feed (0.15mm/rev), depth of cut (0.3mm) and nanoparticle concentration (0.5 wt%). In the analysis, nanoparticle concentration is shown as the most influencing parameter which determines the surface finish followed by feed, speed and depth of cut.

Table 4 Analysis of Variance for surface roughness

Source	Degrees of freedom	Sum of squares	Mean of squares	% of contribution
Speed	2	0.228	0.114	18.29
Feed	2	0.480	0.240	38.52
Depth of cut	2	0.093	0.046	7.46
Nanoparticle concentration	2	0.445	0.223	35.71
Error	0			
Total	8	1.246		100

Table 4.3 shows the ANOVA results for the surface roughness. The percentage contribution of each factors to surface roughness is obtained as shown in the table. The analysis has shown that the feed rate is the maximum percentage contribution factor comprising 38.52%. Hence the feed rate is identified as the most influencing factor, followed by the nanoparticle concentration with 35.71%. Speed (18.29%) and depth of cut (7.46%) are found as the least influencing parameters.

The optimal combination of surface finish is:
Speed = 850 rpm
Feed rate = 0.15 mm/rev
Depth of cut = 0.3mm
Nanoparticle concentration = 0.5 wt%

B) Material Removal Rate (MRR)

In the experiment, the desired characteristic for material removal rate is larger the better. The signal to noise ratio for larger the better is given as :

S/N = -10log[1/n $\sum_{i=1}^{n}(1/y_i^2)$]

Table 5 Signal to noise ratio for material removal rate

Exp No.	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Nanoparticle concentration (wt%)	MRR mm^3/rev	S/N ratio
1	500	0.05	0.1	0.1	314.15	49.94
2	500	0.10	0.2	0.5	1256.6	61.98
3	500	0.15	0.3	1	2857.3	69.12
4	650	0.05	0.2	1	1633.6	64.26
5	650	0.10	0.3	0.1	2450.4	67.78
6	650	0.15	0.1	0.5	1225.2	61.76
7	850	0.05	0.3	0.5	1602.1	64.09
8	850	0.10	0.1	1	1068.1	60.57
9	850	0.15	0.2	0.1	3204.3	70.11

Table above shows the material removal rate (MRR) and its corresponding signal to noise (S/N) ratios. Material removal rate varies from 314.15 mm/rev to 3204.3 mm/rev at 3 different levels of operations. The main effects plot for means is as shown the figure 2.

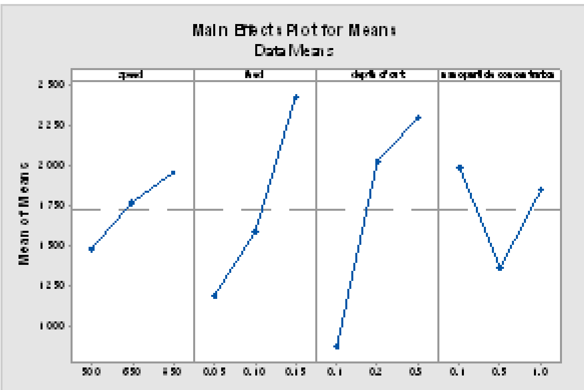

Figure 2 Main effects plot for material removal rate

Level	Speed	Feed	Depth of cut	Nanoparticle concentration
1	1476.02	1183.28	869.15	1989.62
2	1769.8	1591.7	2031.5	1361.3
3	1958.17	2428.93	2303.26	1853
Delta	482.15	1245.65	1434.11	628.32
Rank	4	2	1	3

Table 6 Response table for MRR

Table 6 shows the response table for Signal to Noise ratios for material removal rate. From the table, high MRR is obtained for cutting speed (850rpm), feed rate (0.15mm/rev), depth of cut (0.3mm) and nanoparticle concentration (1wt%). Depth of cut is obtained as the most influencing factor in material removal rate followed by feed rate, nanoparticle concentration and cutting speed.

Table 7 Analysis of variance for MRR

Source	Degrees of freedom	Sum of squares	Mean of squares	% of contribution
Speed	2	354258.56	177129.28	5.13
Feed	2	2420331.41	1210165.71	35.02
Depth of cut	2	3482361.52	1741180.76	50.38
Nanoparticle concentration	2	655219.93	327609.97	9.48
Error	0			
Total	8	6912171.42		100

ANOVA results for material removal rate (MRR) as shown the table gives the percentage contribution of speed, feed, depth of cut and nanoparticle concentration to MRR. The depth of cut is found to have major percentage of contribution with 50.38%, followed by feed rate (35.02%), nanoparticle concentration (9.48%) and cutting speed (5.13%).

The optimal combination of MRR is :
Cutting speed =850 rpm
Feed rate = 0.15 mm/rev
Depth of cut = 0.3 mm
Nanoparticle concentration = 1 wt%

V CONCLUSION

Cutting fluids are used in the machining operation as it cools the workpiece surface and the cutting tool. The turning operation conducted at different input conditions indicated results in high heat generation which causes thermal cracks on the cutting tool and the workpiece surface. Hence nanofluids (Aluminium nanoparticle in water) can be used in turning operation as it carries high thermal conductivity and reduces the friction between the workpiece surface and the tool. The cutting parameters selected for machining are speed of cut, feed rate, depth of cut and nanoparticle concentration in water. The cutting parameters were tested under 3 different levels of operation.

The experiments conducted in machining found that the nanoparticle concentration & feed rate are the main factor that determines the surface finish on the EN8 steel. The optimum parameters are obtained from Taguchi analysis using signal to noise ratio. Based on ANOVA, the nanoparticle concentration with 0.5 wt% in Al_2O_3 nanofluid is found to be the most optimum parameter in determining the minimum surface roughness. It has been found that the nanofluids when used as a coolant will improve the surface finish on the metal surface. Feed rate is also found as an important factor in identifying the surface quality with 0.15mm/rev. Cutting speed and depth of cut are found least influencing factors in determining the surface finish.

The material removal rate obtained on the EN8 steel was found to be depending on the depth of cut on the material with 0.3mm. It contributes a total of 50.38% when compared to other factors. Feed rate is also found to be an important factor with optimum value of 0.15mm/rev. Cutting speed and nanoparticle concentration are found very less influencing parameters in the material removal rate.

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