COMPARISON AND OPTIMIZATION OF CUTTING PARAMETERS IN CNC TURNING OF EN8 STEEL USING VEGETABLE OIL AND AL_2O_3 NANOCOOLANT AS CUTTING FLUID

Phati P. Sawant[1], Abhay S. Naik[2], Gaurav A. Desai[3], Abhijit R. Bhagat[4], Khandekar S. B.[5]

[1,2,3,4]Students of B.E., Mechanical Engineering, Rajendra Mane College of Engineering & Technology, Ambav, Devrukh, Maharashtra, India

[5]Assistant Professor, Mechanical Engineering, Rajendra Mane College of Engineering and Technology, Ambav, Devrukh, Maharashtra, India.

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Abstract - *In this study, an attempt has been made to compare machining parameters in CNC turning of EN8 steel using vegetable oil and AL_2O_3 nanocoolant as cutting fluid and to suggest the optimum machining parameters and process. Experiments were designed using Taguchi method and were carried out on CNC lathe using Tungsten Carbide inserts as cutting tool. The results obtained showed better surface finish and reduced tool wear using nanocoolant as cutting fluids. By using ANOVA, the optimum machining condition for tool life, surface roughness was found out.*

Key Words: EN8 Steel, vegetable oil (High Cut 150), depth of cut, feed rate, Spindle speed, surface roughness, tool wear, nanoparticle concentration, DOE.

1. INTRODUCTION

In machining process, turning is the most basic and widely used operation. Turning operation includes parameters such as, feed rate, spindle speed, depth of cut, cutting fluids, tool geometry, which have major impact on surface finish, tool wear, cutting temperature, material removal rate and dimensional stability of workpiece material and this in turn affects the manufacturing cost. The selection of optimum cutting parameters is essential to obtain better product quality and to minimize the overall cost of production.

Nanoparticles, because of their high thermal conductivity and better heat removal rate are mixed with vegetable oils as base fluids and used as cutting fluids.

EN8 carbon steel is medium carbon and medium tensile steel with improved strength over mild steel through hardening. EN8 is readily machinable in any condition. EN8 is suitable for all general engineering applications requiring a high strength than mild steel such as shafts, gears, bolts, studs, axles etc. In case of precision parts of aerospace and automobile industries, close dimensional tolerances has to be obtained while machining so with the use of nanocoolant this risk can be reduced by carrying away the heat generated at the tool-workpiece interface. This will improve the response variables such as surface roughness, tool wear etc.

With the continuous improvement in manufacturing industry there is a need to reduce the tooling costs, which would in turn reduce the cost of the product machined. In conventional machining HSS was used as cutting tool material. Nowadays use of tungsten carbide is becoming more prominent in industries. Tungsten carbide is a type of steel. It is comprised of mainly tungsten carbide and cobalt. The cobalt acts as a binder and improves shock resistance. As the percentage of cobalt in the mix rises, so does the shock resistance. Tungsten carbide is known for its ability to retain an extremely sharp edge for an extended amount of time under certain cutting applications.

2. LITERATURE REVIEW

[1] N. K. Chavda, Jay R. Patel, Hardik H. Patel, Atul P. Parmar, (2014) carried out an experimental investigation to determine the effect of various concentration of Al2O3 nano-dispersion mixed in water as base fluid on heat transfer characteristics of double pipe heat exchanger for parallel flow and counter flow arrangement. The conclusion derived for the study is that overall heat transfer coefficient increases with increase in volume concentration of Al2O3 nano-dispersion compared to water up to volume concentration of 0.008 % and then decreases.

[2] Nithin K Mani, Prof. Cijo Mathew, Prof. Prakash M Kallanickal (2015), found that the addition of nanoparticles to vegetable oil improved the properties of workpiece material. 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. Based on ANOVA, 0.5 wt. % Al2O3 nanoparticle concentration is found to be the most optimum parameter obtaining minimum surface roughness. Feed rate with the level of 0.15mm/rev was found as an important factor in identifying the surface roughness.

[3] V Sridhara, Lakshmi Narayan Satapathy (2015) reported that in a study by Kole and Dey 82 Al2O3 nanoparticles (<50 nm) were dispersed in a car EC and measured thermal

conductivity by THW technique. The result indicated 10.41% enhancement in thermal conductivity at 30oC for the nanofluids containing 0.035 volume fraction of Al2O3 and a maximum of approx. 11.25% at 80oC. For Al2O3-based nanofluids, nanoparticle of size ranges from 13–80 nm in base oil by different research groups were studied resulting in 5–40% enhancement in thermal conductivity. The temperature varied between 10oC–80oC for Al2O3-based nanofluids and reported 2.6–40.8% enhancement in thermal conductivity.

[4] Shrikant Borade. Dr. M. S. Kadam, (2016) studied and compared the effect of vegetable oil and al2o3 nanofluids used with mql on surface roughness and temperature. The surface roughness (Ra) and Temperature (T) were measured under different cutting conditions for different combinations of machining parameters. These experiments show that Surface Roughness and Temperature reduced significantly by machining EN353 steel using nanofluid (i.e. 3 Vol. % of Al2O3 Nanofluid) as compared to MQL Vegetable oil.

3. MATERIAL SPECIFICATIONS

3.1 Work Material: EN8

Table -1: EN8 properties

Chemical composition	
Carbon	0.36-0.44%
Silicon	0.10-0.40%
Manganese	0.60-1.00%
Sulphur	0.050 Max
Phosphorus	0.050 Max
Chromium	-
Molybdenum	-

3.2 Cutting tool: Tungsten Carbide

Table -2: Tool specifications

Insert style	CNMG
Insert size	432
Manufacturers grade	IC907
coating	TiAlN
shape	Diamond
Chip breaker	TF
Coating process	PVD
Length (mm)	12.9
Thickness (inch)	0.1874
Included angle (degree)	80

4. EXPERIMENTS AND METHODOLOGY

The main objective of this work is to study and compare the effect of vegetable oil and nanocoolant on turning operation and to determine the optimum machining parameters of turning. The cutting parameters and nanoparticle concentration were varied to identify the best values of the response variables. The experiments were designed using Taguchi method and were performed on CNC lathe machine.

4.1 Design of Experiments

Taguchi factorial design was used to determine the machining conditions for various experiments required to be carried out for optimization of cutting parameters. It uses orthogonal arrays such as L9, L16, and L27 etc. to organize the process parameters at different levels. It is commonly used in improving industrial product quality due to the proven success. With the use of Taguchi method we can significantly reduce the number of experiments.

The experiments were designed using L9 orthogonal array on Minitab 17. A 3^3 Taguchi factorial design was obtained for machining with vegetable oil. It contains 3 factors (Speed, feed and depth of cut) each at 3 different levels.

3^4 Taguchi factorial design was obtained for machining with nanocoolant. It contains 4 factors (Speed, feed, depth of cut and nanoparticle concentration) each at 3 different levels.

Table -3: Machining parameters and levels

Sr. no	Factor	Levels		
		1	2	3
1	Speed (RPM)	1200	1400	1600

2	Feed (mm/rev)	0.1	0.12	01.5
3	Depth of cut (mm)	0.5	1	1.5
4	Nanoparticle concentration (wt. %)	0.06	0.08	1

4.2 Methodology

All the experiments were performed on CNC lathe machine using tungsten carbide tool inserts. First, machining using vegetable oil (High Cut 150) was carried out according to Taguchi design. Cutting temperature was recorded for each experiment using an Infrared Temperature Sensor.

Fig -1: Experimental setup

Then, machining using nanocoolant with different Al2O3 concentrations was conducted. Al2O3 nanoparticles were mixed with vegetable oil as base fluid, which increased the heat carrying capacity of vegetable oil. The experiments were conducted by varying the process parameters according to the Taguchi design and the cutting temperatures were recorded. For each experiment the response variables were to be investigated.

Surface roughness was measured using Surface Roughness Tester, tool wear was measured using Tool Maker's Microscope and hardness was measured using Brinell Hardness Tester.

The results obtained were analyzed using ANOVA to find optimum machining parameters and nanocoolant concentration.

5. RESULT

Analysis of Taguchi design was performed using the software, Minitab 17. SN ratios were calculated for each experiment. SN ratio is the conversion of the loss function. The output characteristics contains a desirable value, termed as 'signal' which is the result of controllable factors and an undesirable value called 'noise', which is due to the uncontrollable factors. So if the effect of the uncontrollable factors is negligible then, it would give best response. The SN ratio analysis is categorized into three types that are the higher the better, nominal the better and the lower the better. The SN ratio for each experiment is calculated based on SN ratio analysis. The experiment having the highest SN ratio gives the optimum conditions of machining for that particular response.

All the responses i.e. surface roughness, tool wear and cutting temperature were analyzed for SN ratios using lower the better performance characteristics.

SN ratio for lower the better:

$$S / N = -10\log_{10}\left(\frac{1}{r}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right)$$

The response table for each response was also obtained. It gives rank to each factor which helps to determine the most significant factors that affect the process the most.

Fig -2: Machined components

5.1. Taguchi Analysis for machining using Vegetable oil

A. Cutting temperature

Table -4: SN ratio for Cutting temperature

Exp. No	Speed (RPM)	Feed (mm/ rev)	Depth of cut (mm)	Cutting Temperature (°C)	SN Ratio
1	1200	0.10	0.5	29.330	-29.3462
2	1200	0.12	1.0	28.900	-29.2180
3	1200	0.15	1.5	29.600	-29.4258
4	1400	0.10	1.0	29.833	-29.4939
5	1400	0.12	1.5	29.060	-29.2659
6	1400	0.15	0.5	29.300	-29.3374
7	1600	0.10	1.5	29.330	-29.3462
8	1600	0.12	0.5	29.400	-29.3669
9	1600	0.15	1.0	29.150	-29.2928

The table 4 shows the cutting temperature measured on the EN8 steel machined surface and their corresponding signal to noise ratios. The cutting temperature varies from 28.9°C to 29.83°C. The main effects plot for S/N ratio is as shown in figure 1.

Table -5: Response Table for Cutting temperature

Level	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)
1	-29.08	-29.12	-29.06
2	-29.15	-29.08	-29.11
3	-29.09	-29.12	-29.15
Delta	0.07	0.04	0.09
Rank	2	3	1

Table 5 is the response table of Signal to Noise ratios for cutting temperature. It can be seen that lowest cutting temperature of 28.9°C was obtained at feed (0.12 mm/rev), speed (1200 rpm), Depth of cut (1 mm). Depth of cut is the most influencing parameter on Cutting temperature followed by speed and feed.

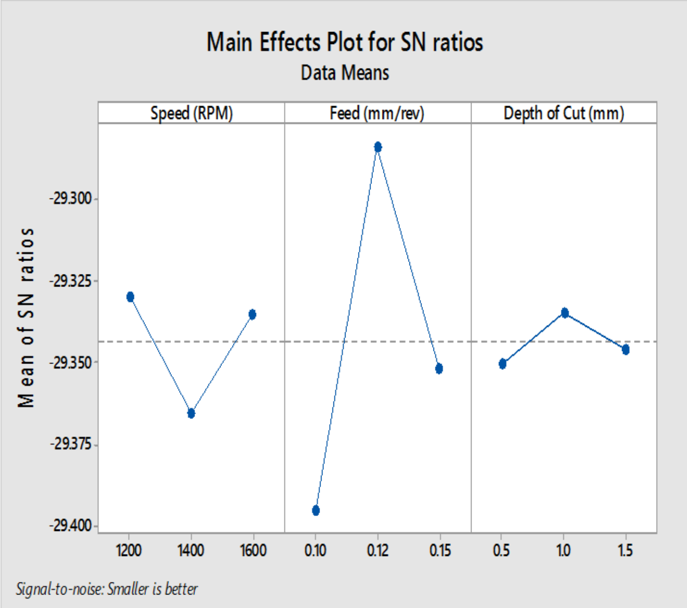

Chart -1: Main effects plot for cutting temperature

Optimal machining condition for low Cutting temperature:
Speed= 1400 rpm
Feed= 0.15 mm/rev
Depth of cut= 0.5 mm

B. Surface roughness

Table -6: SN ratio for Surface roughness

Exp. No	Speed (RPM)	Feed (mm/ rev)	Depth of cut (mm)	Surface Roughness (µm)	SN Ratio
1	1200	0.10	0.5	1.513	-3.59678
2	1200	0.12	1.0	2.033	-6.16275
3	1200	0.15	1.5	1.350	-2.60668
4	1400	0.10	1.0	1.630	-4.24375
5	1400	0.12	1.5	2.737	-8.74550
6	1400	0.15	0.5	1.070	-0.58768
7	1600	0.10	1.5	1.637	-4.28097
8	1600	0.12	0.5	2.837	-9.05719
9	1600	0.15	1.0	2.190	-6.80888

The surface roughness for each experiment are shown in table 6. Surface roughness varies from 1.07 µm to2.837 µm

Table -7: Response Table for Surface roughness

Level	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)
1	9.213	14.571	10.261
2	7.823	6.455	10.227
3	12.578	8.588	9.127
Delta	4.756	8.117	1.134
Rank	2	1	3

It can be seen from the ranks obtained from the response table 7 that feed is the most influencing parameter for surface roughness followed by speed and depth of cut.

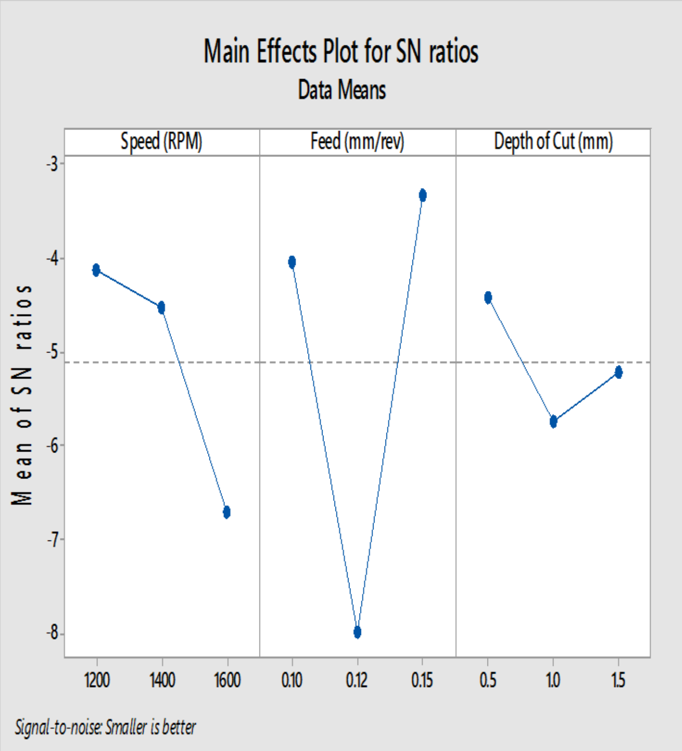

Chart -2: Main effects plot for Surface roughness

Optimal machining condition for surface roughness:
Speed= 1200 rpm
Feed= 0.12 mm/rev
Depth of cut= 1 mm

C. Tool wear

Table -8: SN ratio for Tool wear

Exp. No	Speed (RPM)	Feed (mm/rev)	Depth of cut (mm)	Tool Wear (mm)	SN Ratio
1	1200	0.10	0.5	0.210	13.5556
2	1200	0.12	1.0	0.760	2.3837
3	1200	0.15	1.5	0.260	11.7005
4	1400	0.10	1.0	0.135	17.3933
5	1400	0.12	1.5	0.715	2.9139
6	1400	0.15	0.5	0.695	3.1603
7	1600	0.10	1.5	0.230	12.7654
8	1600	0.12	0.5	0.198	14.0667
9	1600	0.15	1.0	0.285	10.9031

The tool wear for each experiment are shown in table 6 and it varies from 0.135 mm to 0.760 mm.

Table -9: Response Table for Tool wear

Level	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)
1	-4.122	-4.041	-4.414
2	-4.526	-7.988	-5.738
3	-6.716	-3.334	-5.211
Delta	2.594	4.654	1.325
Rank	2	1	3

It can be seen from the ranks obtained from the response table (table 9) that feed is the most influencing parameter for tool wear followed by speed and depth of cut.

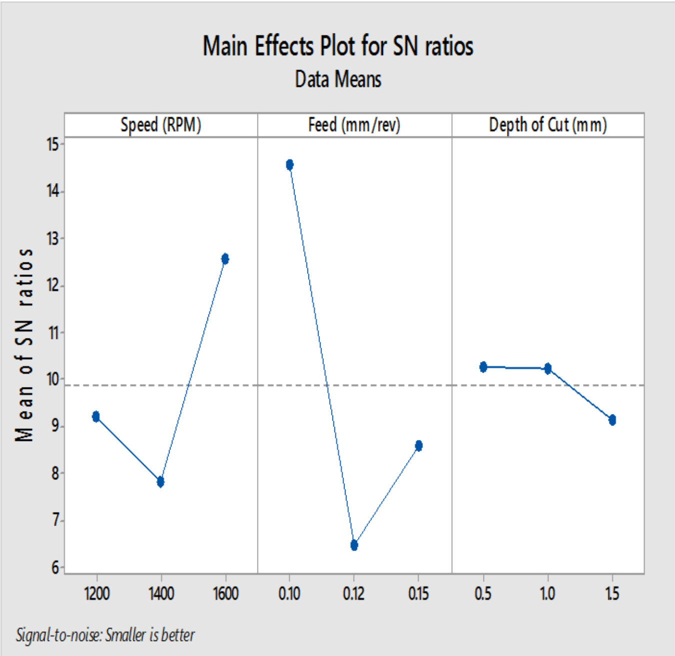

Chart -3: Main effects plot for Tool wear

Optimal machining condition for tool wear:
Speed= 1400 rpm
Feed= 0.1 mm/rev
Depth of cut= 1 mm

5.2 Taguchi Analysis for machining using Nanocoolant

A. Cutting temperature

Table -10: SN ratio for Cutting temperature

Exp. No	Speed (RPM)	Feed (mm/rev)	Depth of cut (mm)	Al_2O_3 concentration (gm/litre)	Cutting Temperature (°C)	SN Ratio
1	1200	0.10	0.5	0.6	28.4	-29.07
2	1200	0.12	1.0	0.8	28.3	-29.04
3	1200	0.15	1.5	1.0	28.6	-29.13
4	1400	0.10	1.0	1.0	28.7	-29.16
5	1400	0.12	1.5	0.6	28.8	-29.19
6	1400	0.15	0.5	0.8	28.5	-29.1
7	1600	0.10	1.5	0.8	28.6	-29.13
8	1600	0.12	0.5	1.0	28.2	-29.00
9	1600	0.15	1.0	0.6	28.6	-29.13

The table 10 shows the cutting temperature measured on the EN8 steel machined surface and their corresponding signal to noise ratios. The cutting temperature varies from 28.2°C to 28.8°C. The main effects plot for S/N ratio is as shown in figure 1.

Table -11: Response Table for Cutting temperature

Level	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Al_2O_3 concentration (gm/litre)
1	-29.08	-29.12	-29.06	-29.13
2	-29.15	-29.08	-29.11	-29.09
3	-29.09	-29.12	-29.15	-29.10
Delta	0.07	0.04	0.09	0.04
Rank	2	3	1	4

It can be seen from the ranks obtained from the response table that depth of cut is the most influencing parameter for cutting temperature followed by speed feed and Al_2O_3 concentration.

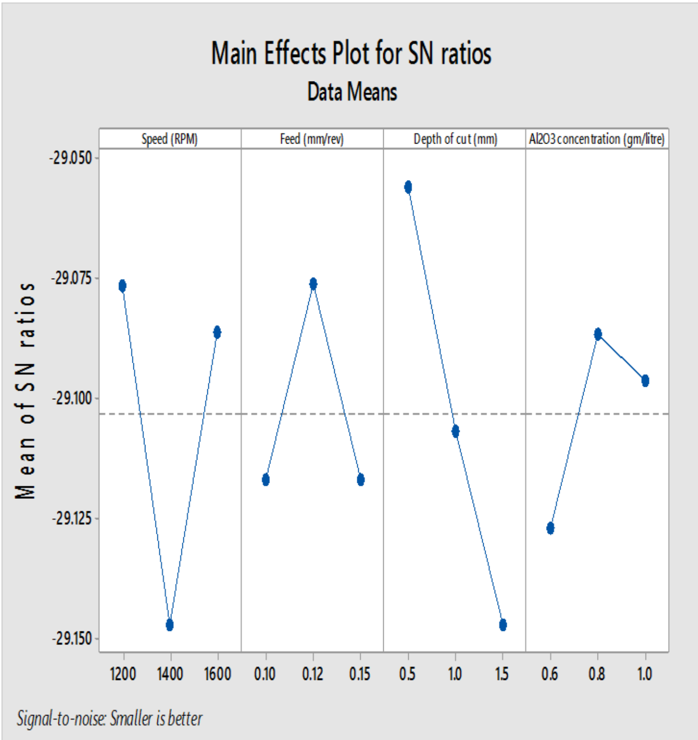

Chart -4: Main effects plot for Cutting temperature

Optimal machining condition for cutting temperature:
Speed= 1600 rpm
Feed= 0.12 mm/rev
Depth of cut= 0.5 mm
Al_2O_3 Concentration: 1 gm/litre (0.1 wt. %)

B. Surface roughness

Table -12: SN ratio for Surface roughness

Exp. No	Speed (RPM)	Feed (mm/rev)	Depth of cut (mm)	Al_2O_3 concentration (gm/litre)	Surface Roughness (µm)	SN Ratio
1	1200	0.10	0.5	0.6	1.480	-3.406
2	1200	0.12	1.0	0.8	2.147	-6.637
3	1200	0.15	1.5	1.0	1.336	-2.516
4	1400	0.10	1.0	1.0	0.840	1.514
5	1400	0.12	1.5	0.6	0.950	0.446
6	1400	0.15	0.5	0.8	0.933	0.602
7	1600	0.10	1.5	0.8	0.900	0.915
8	1600	0.12	0.5	1.0	0.867	1.24
9	1600	0.15	1.0	0.6	1.313	-2.362

The surface roughness and SN ratios for each experiment are shown in table 6. Surface roughness varies from 0.84 µm to 2.147 µm.

Table -13: Response Table for Surface roughness

Level	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Al_2O_3 concentration (gm/litre)
1	-4.18600	-0.32522	-0.52108	-1.77500
2	0.85410	-1.65050	-2.49584	-1.70637
3	-0.07018	-1.42635	-0.38515	0.07930
Delta	5.04010	1.32527	2.11069	1.85430
Rank	1	4	2	3

The ranks obtained from the response table show that speed is the most influencing parameter for surface roughness followed by depth of cut, Al2O3 concentration and feed.

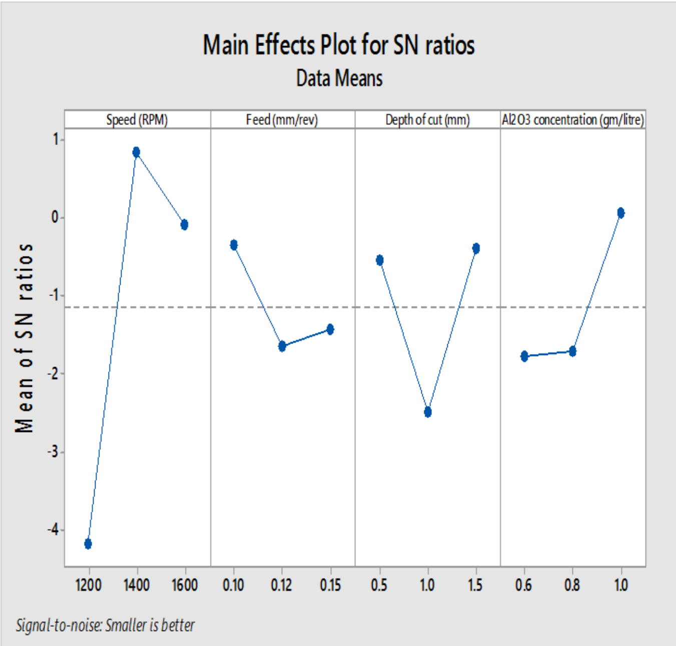

Chart -5: Main effects plot for Surface roughness

Optimal machining condition for Surface roughness:
Speed= 1400 rpm
Feed= 0.1 mm/rev
Depth of cut= 1 mm
Al_2O_3 Concentration: 1 gm/litre (0.1 wt. %)

C. Tool wear

Table -14: SN ratio for Tool wear

Exp. No	Speed (RPM)	Feed (mm/rev)	Depth of cut (mm)	Al_2O_3 concentration (gm/litre)	Tool wear	SN Ratio
1	1200	0.10	0.5	0.6	0.085	21.4116
2	1200	0.12	1.0	0.8	0.675	3.4139
3	1200	0.15	1.5	1.0	0.115	18.7860
4	1400	0.10	1.0	1.0	0.390	8.1787
5	1400	0.12	1.5	0.6	0.545	5.2721
6	1400	0.15	0.5	0.8	0.075	22.4988
7	1600	0.10	1.5	0.8	0.110	19.1721
8	1600	0.12	0.5	1.0	0.080	21.9382
9	1600	0.15	1.0	0.6	0.125	18.0618

The tool wear for each experiment are shown in table 6 and it varies from 0.075 mm to 0.675 mm.

Table -15: Response Table for Tool wear

Level	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm	Al_2O_3 concentration (gm/litre)
1	14.537	16.254	21.950	14.915
2	11.983	10.208	9.885	15.028
3	19.724	19.782	14.410	16.301
Delta	7.741	9.574	12.065	1.386
Rank	3	2	1	4

The ranks obtained from the response table show that depth of cut speed is the most influencing parameter for tool wear followed by feed, speed and Al_2O_3 concentration.

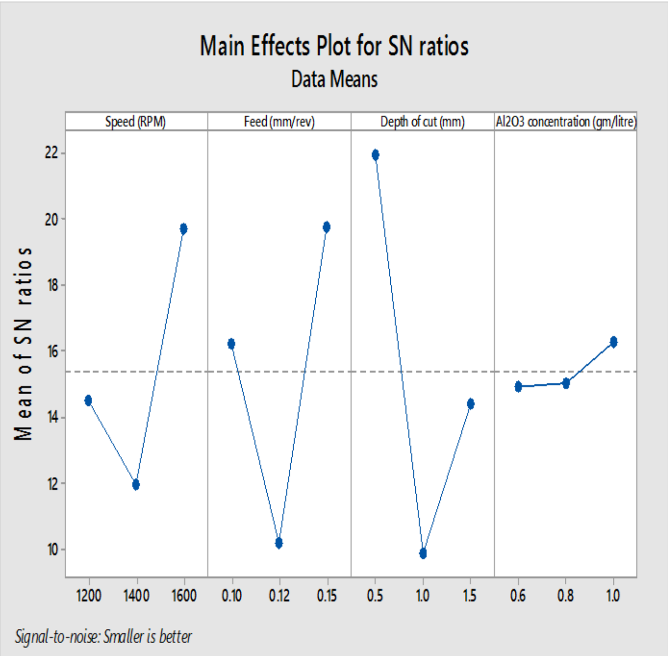

Chart -6: Main effects plot for Tool wear

Optimal machining condition for Tool wear:
Speed= 1400 rpm
Feed= 0.15 mm/rev
Depth of cut= 0.5 mm
Al2O3 Concentration: 0.8 gm/litre (0.08 wt. %)

6. CONCLUSIONS

In machining operations, high amount of heat energy is developed at tool-workpiece interface which results in thermal crack. This eventually reduces the life of cutting tool and also affects the surface roughness of workpiece. Cutting fluids are introduced in machining in order to cool the tool and workpiece at their interface. Thermal conductivity plays an important role in enhancing the heat transfer performance of a base fluid (vegetable oil). Since the thermal conductivity of solid metals and metal oxides is higher than that of base fluids, the suspended particles increase the thermal conductivity and heat transfer performance of base fluid. Cutting fluids also act as lubricant and reduces the cutting forces exerted by tool on workpiece.

Feed, speed and depth of cut are the three cutting parameters selected for machining and were tested for three different levels of operation. The experiments were designed by using Taguchi Factorial Design using Minitab 17 software.

Machining was carried out using two different coolants i.e.
1. Water based vegetable oil (high cut 150)
2. Nanofluids (Al_2O_3 mixed with base fluid)

And their results were compared to find optimum machining parameters and Al_2O_3 concentration from Taguchi analysis using signal to noise ratio.

A significant temperature drop was observed when nanocoolant was used as cutting fluid which ranged from 28.2^0C to 28.8^0C whereas with the use of vegetable oil it ranged from 28.9^0C to 29.83^0C.
Optimal machining condition for cutting temperature:
Speed= 1600 rpm
Feed= 0.12 mm/rev
Depth of cut= 0.5 mm
Al_2O_3 Concentration: 1 gm/litre (0.1 wt. %)

Considering the surface roughness nanocoolant delivered better surface finish as compared to vegetable oil. Optimal machining condition for Surface roughness:
Speed= 1400 rpm
Feed= 0.1 mm/rev
Depth of cut= 1 mm
Al_2O_3 Concentration: 1 gm/litre (0.1 wt. %)

Nanocoolant also influences the tool wear rate. The temperatures obtained using nanocoolant shows that heat carrying capacity was increased and thus reducing the tool wear. Optimal machining condition for Tool wear:
Speed= 1400 rpm
Feed= 0.15 mm/rev
Depth of cut= 0.5 mm
Al_2O_3 Concentration: 0.8 gm/litre (0.08 wt. %)

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BIOGRAPHIES

Phati Prabhakar Sawant, student of B.E (Mechanical Engineering) and working on project of "Experimental Investigation and Optimization of Machining Parameters for Cryogenically Treated Tool and Nanocoolant" under the guidance of prof. S. B. Khandekar.

Abhay Shivdas Naik, student of B.E (Mechanical Engineering) and working on project of "Experimental Investigation and Optimization of Machining Parameters for Cryogenically Treated Tool and Nanocoolant" under the guidance of prof. S.B. Khandekar.

Gaurav Appa Desai, student of B.E (Mechanical Engineering) and working on project of "Experimental Investigation and Optimization of Machining Parameters for Cryogenically Treated Tool and Nanocoolant" under the guidance of prof. S.B. Khandekar.

Abhijit Rambhau Bhagat, student of B.E (Mechanical Engineering) and working on project of "Experimental Investigation and Optimization of Machining Parameters for Cryogenically Treated Tool and Nanocoolant" under the guidance of prof. S.B. Khandekar.

Prof. Khandekar Shailesh B. M.E. (Mechanical Engineering) working as assistant professor in department of Mechanical Engineering at Rajendra Mane College of Engineering and Technology, Devrukh, (University of Mumbai)