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Original scientific paper

Reduction of Cutting Temperature Effect and Surface Deficiencies on CNC Turned AZ91 Mg Alloy with Fluidized Nano Oxide Coolants

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Abstract: Tool wear is a natural phenomenon in machining process and it leads to get damage to tool. According to more demand in the market, the selection of high speed, feed rate and depth of cut of machining process are latest trends in all industry. Such machining process creates high cutting temperature, which not only reduces tool life but also induces the product quality. Cutting fluids are used to maintain the tool life and to preserve the workpiece surface properties without damages. To avoid this imperfection, it is necessary to use standard coolants during machining operations. The temperature and surface finish play a vital role in a machining process. In this work, three different nano fluids, like aluminium oxide, copper oxide and titanium oxide,are introduced, and used as a coolant in CNC lathe for turning operation. The output responses of temperature and surface roughness of the workpieces are analyzed with the help of Design of Experiment (DOE) by using L9 orthogonal array of each nano coolant. The result of output responses like temperature and surface roughness are compared with three nano fluids. The copper oxide nano fluid gives a better surface finish as compared to aluminium oxides and titanium oxide.

Keywords: CNC turning; DOE; nano fluid; surface roughness; temperature; tool life

1 INTRODUCTION

High production machining process of metals generates high temperature in cutting zone [1]. Such high temperature affects dimensional deviation and untimely failure of cutting tools [2-4]. The important parameter of surface and subsurface gets micro crack and also rapid oxidation and corrosion are created using high production of machining process. In high speed machining, the cutting fluid used before failed to enter the chip-tool boundary and it cannot take out heat successfully. Several companies are spending large amounts of money for the cutting fluid and the cost of cutting fluid is higher than the cutting tool for peculiar machining processes. In this situation, it is necessary to have better lubricants to eliminate the temperature in cutting tool during rapid machining process. The researchers analyzed various cutting fluids and some important research articles have been discussed in this paper. Huaiyuan Wang et al. [5] investigated the process of PSPC with the vacuum suction technologies. A load of 250 N and a sliding speed of 0.69 ms^{-1} are used to determine its tribological properties. The error values should be < 10% to determine accuracy of simulation result. When the porosity was 16.8% the PSPC showed excellent tribological properties. Hui Yang et al. [6] analyzed the reverse fluid model of V-groove. FLUENT finite element is used to determine various arrangements. V-shaped texture is scanned using Femtosecond laser processing technology. A friction and wear experiment help in understanding tribological properties. The gradient of 7° is most ideal for hydrodynamic lubrication effect. Ho Chang et al. [7] by analyzing found that the nanoparticles are manufactured by the vacuum submerged arc machining. NTUT's Nano Laboratory plays a vital role in development of nanoparticles. The insulating liquid is developed by melting of Titanium bar and vaporizing it in distilled water. Nano crystalline particles are formed by rapid quenching. The above process helps in determining pulse duration, peak current and dielectric liquid temperature on TiO_2 nanoparticles suspension. In R. Dharmalingam et al. [8] the environmental friendly fluid is referred to as nanofluid which is a colloidal mixture of nano sized particles. It helps in determining the heat transfer in nanofluid and some of their physical and chemical properties are determined in this technology. Abu Raihan Ibna Ali et al. [9] found that the nano fluid is a heat transfer fluid with superior thermal conductivity and rheological properties. In this process heat transfer characteristics of nano fluid and the factors including particle size, shape, surfactant and the temperature, will be presented. It has wide range of applications such as heat exchanger, transportation cooling, refrigeration, electronic equipment cooling, transformer oil, industrial cooling, nuclear system, machining operation, solar energy etc.

Jahar Sarkar [10] studied the heat transfer medium used for the sustainable future generation using nano fluids which are formulated by nanoparticles. Its heat transfer coefficient is higher than its thermal conductivity effect. The pressure drop is predicted using conventional friction factor correlation. The particle properties and nano fluid composition on flow and heat transfer characteristics lead to deviation in predicted values due to lack of understanding. William Andrew [11] has discussed the colloidal systems introductions. Chapter 2 involves preparation methods of nano fluid. Chapter 3 involves techniques of stability measurement. Thermo physical properties are discussed in chapter 4. Chapter 5 and 6 comprise rheological behaviours and optical properties. Chapter 7 includes correlations used for nano fluid property. Hwang, et al [12] found that the nano fluid consists of nanometer-sized particles. Nano fluids are produced by multi-walled carbon nanotube (MWCNT), fullerene, copper oxide, silicon dioxide and silver. DI water, ethylene glycol are used as base fluids. UV-vis spectrophotometer determines stability. FALEX EP tester determines extreme pressure. The pressure increases up to 225% due to addition of fullerene in oil.

M. Sheikholeslami et al. [13] analyzed a clean energy storage unit designed to reduce energy consumption. The air passage utilized sinusoidal channels. Porous media and nanoparticles were used to enhance heat transfer. After comparing the output, the experimental data showed a maximum deviation of 9.3%. The porous foam solidifies 21.4% faster than the base case. Second case slope of profile is higher than first case with t = 33 h. PCM temperature reduces when porous foam is used. Mehdi Shanbedi et al. [14] explored how highly-dispersed MWNT-based water nano fluids are generated by adding Aspartic acid to the primary structure. TGA, FTIR, and Raman spectroscopes aid in functionalization. Thermophysical characteristics and heat transmission rates are calculated. The weight of nano fluids is evaluated at flow rates ranging from 2.86 to 8.85 ml/s.

Eric C. Okonkwo et al. [15] discovered that nanoscale particles were vanishing into fluids in the late twentieth century. Because of their heat exchanger properties, nano fluids play an important role. The preparation of nanofluids and numerous heat transfer applications were discussed in 2019. The assessment helps to update its heat transfer fluids. Hilmy Eltoum1 et al. [16] examined how nanofluids may help prevent oil from being trapped in hydrocarbon reserves. This study examines and summarizes the influence of nano fluids on wettability. This paper discusses possible opportunities for wettability alteration using nanofluids. Hamideh Sardarabadi et al. [17] found that a two-phase closed thermosiphon is an effective heat transfer device. In this study, the thermal performance of multi-walled carbon nanotubes was evaluated using an evaporator with a square frustum shape and a condenser made of two connected tubes. Oxidant agents such as potassium per sulphate and sodiumsulphate are used to prepare nano fluids. Fourier transform infrared spectroscopy helps in determining prepared nano fluids. Amin A. Sadi et al. [18] examined the thermal characteristics and impacts of different ultrasonication settings on stability. Increasing the ultrasonication period produces stable nano fluids. It also improves heat transmission and has a reduced viscosity. Ultrasonic bath devices are more efficient than ultrasonic horn/probe devices. Lowering the ultrasonication time yields better outcomes.

Laura Fedele et al. [19] investigated the fact that in the development of new fluids the dispersion process is found to be critical. Nanoparticles such as single wall carbon nanohorns (SWCNHs), titanium dioxide (TiO_2) and copper oxide (CuO) are used to determine stability of water in this study. Stability of nanofluids and enhancing thermal characteristics is a major aim of this study. The stability of nanofluids is increased by adding n-dodecyl sulphate and polyethylene glycol as dispersants to SWCNHs-water and TiO_2-water nano fluids. Jayant K. Kittur et al. (2014) employed the desirability function to find the best process parameters, including the fast shot velocity injection pressure holding duration and phase change-over point. The composite and Box-Behnken designs are tested for prediction accuracy and statistical adequacy using ANOVA. The numerical values from the experiment were compared to the theoretical values, and optimum values were discovered. Sushil Kumar et al. (2010) used Taguchi parameter design for optimization of green sand casting. The parameters considered here are green strength, pouring temperature, mold hardness vertical and horizontal and moisture content. The selected process parameters and casting defects level are controlled by using analysis of variance and signal-to-noise ratio. A modal run was made which gave a good result and showed that it is a more efficient way of finding the casting parameters in easy manner.

Based on the literature review, a variety of cutting fluids are introduced for various machining operations. Convectional cutting fluids are not used for some cutting conditions. The nano fluids are used as a coolant for machining operation and it can reduce the temperature of the tool and work piece for high speed machining operations. In this study, three nano fluids are introduced: silicon carbide, copper oxide, and titanium oxide. They have been chosen with varying percentages of nano fluids and combined with lubricant. The ratio of nano fluids and lubricant is discussed in succeeding chapter

2 MATERIALS AND METHODS

Magnesium alloy is one of the important materials for automobile and power plant accessories. The high speed turning operation is very difficult for this material. There are several operations available in CNC lathe. But the finishing on surface is done by turning operation only. In this work, magnesium alloy is selected as a workpiece; the turning operation is selected in CNC lathe machine. The composition of magnesium alloy is shown in Tab. 1.

Table 1 Composition of magnesium alloy

Mn	Al	Fe	Zn	Cu	Mg
0.18%	8.21%	0.02%	0.6%	0.004	Balance

For this experimental effort, nano fluids with high thermal conductivities, such as silicon carbide, titanium oxide, and aluminum oxide, were used. Nanoparticles have accumulated on the work piece's surface and the tool's tip during the machining process. So, it is very easy to extract heat from the tool and workpiece in high speed turning operation. The thermal properties of three nano fluids are shown in Tab. 2.

Table 2 Thermal properties of nano fluids

Name of the Nano Fluids	Molar mass / g/mol	Density / g/cm^3	Melting point / °C	Thermal Conductivity / W/mK
Silicon Carbide (SiC)	40.10	3.21	2730ºC	249
Copper oxide (CuO)	79.545	6.315	1326	400
Titanium oxide (TiO_2)	70.545	5.316	1623ºC	159

The high thermal conductivity of copper, silicon and titanium oxide was prepared by nano particles. The nano particle proportions such as 1%, 3% and 5% are added with synthetic coolant. The preparations of three nano fluids are shown in Fig. 1.

(a) (b) (c)

Figure 1 a) SiC nano fluid; b) CuO nano fluid; c) TiO_2 nano fluid

Today's industrial scenario: 70% of industry transformed from convectional lathe to Computer Numerical Control (CNC) lathe. It is achieving high accuracy for any operation in workpiece with minimum production time. It is possible to do various numbers of operations in a single workpiece. In this work, the CNC lathe is selected for this turning operation with nano lubricants,as shown in Fig. 2.

Figure 2 Sinumerik CNC lathe (820D)

In today's industrial scenario, 70% of industry transformed from convectional lathe to Computer Numerical Control (CNC) lathe. It is achieving high accuracy for any operation in workpiece with minimum production time. It is possible to do various numbers of operations in a single workpiece. In this work, the CNC lathe Sinumerik CNC lathe (820D), Turning diameter 200 mm, Turning length 300 mm, Circumference diameter over bed 445 mm, x-way 200 mm, Z-way 345 mm, Main spindle bore 53 mm, Main spindle speed 50-6000 rpm, Main spindle drive 19 kW, Spindle head DIN 55026 Gr. 5 and Torque 120 Nm,are selected for this turning operation with nano lubricants as shown in Fig. 2.

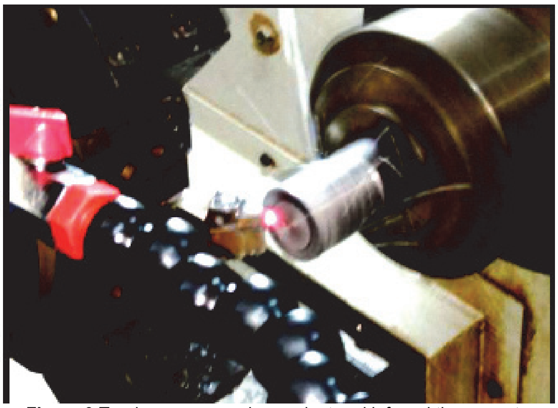

Figure 3 Turning process using coolant and infrared thermometer

The turning operation can be done in 820D CNC lathe with standard parameters of feed and depth of cut. The spindle speed of 1500rpm, 2000 rpm and 2500 rpm are selected in this experiment. The feed rate of 0.1 mm / rev and depth of cut of 1.5mm have been selected for all nine experiments of each lubricant. The infrared thermo meter point and turning operation of the tool and work piece interactive point are shown in Fig. 3.

2.1 Design of Experiment

There are three varieties of nano fluids lubricants, and magnesium alloy material is used as a workpiece in this investigation. Three types of nano oxide such as Silicon Carbide (SiC), Copper oxide (CuO) and Titanium oxide (TiO_2) are used for this investigation. The various factors and levels are mentioned in Tab. 3. Determining design of experiments (DOE) parameters requires many steps. First, determine the experiment's hypothesis. Following that, response variables and their quantities are determined. Each factor's variation range has minimum and maximum values. For accurate results, randomization and replication are utilized. Literature reviews help choose parameters based on time and money. Expert feedback and pilot studies enhance parameters. Optimization can discover the best parameter combination and assess implementation feasibility. This extensive method allows reasonable DOE parameter selection.

Table 3 Process parameters of nano fluid and spindle speed

S. No.	Input Parameters	Units	Levels		
			1	2	3
1.	Spindle Speed	rpm	1500	2000	2500
2.	Nano Proportion	%	1	3	5

Design of Experiment (DOE) is the important tool to obtain the best parameter values [20-23]. This experimental work has selected L9 orthogonal array of three levels of two input parameters and two output responses through design of experiment (DOE). The nano fluids and lubricant oil are mixed by using stirrer instrument and three different proportions, 1%, 3% & 5%,are selected The L9 orthogonal array is implemented in this experiment for the parameters of spindle speed and percentage of nano oxide added in the lubricant as shown in Tab. 4.

Table 4 Input parameters of L9 orthogonal Array

Runs	Input Levels / %	
	Spindle Speed / rpm	Nano Proportion / %
1	1500	1
2	1500	3
3	1500	5
4	2000	1
5	2000	3
6	2000	5
7	2500	1
8	2500	3
9	2500	5

The spindle speed of 1500 rpm, 2000 rpm and 2500 rpm is selected in this experiment. The feed rate of 0.1 mm/rev and depth of cut of 1.5 mm have been selected constantly for all nine experiments of each lubricant. Totally three L9 orthogonal experiments were conducted for this investigation. Three nano lubricants are used as coolant in 9 experiments each in CNC lathe and the output parameters of temperature and surface roughness are discussed in results and discussion chapter.

3 RESULTS AND DISCUSSION

The experimental works have been carried out from DOE data of inputs and output response. The work pieces of AZ91 magnesium are used for this investigation. The work piece of length of 100 mm and diameter of 25 mm is used for this experimental work and the 9 work pieces of each nano fluid used as a coolant in CNC lathe. Totally 27 work pieces can be done in turning operation and it is shown in Fig. 4.

Figure 4 Work piece materials

Turning process plays most significant role for machining of metals, plastics and composites. Spindle speed, depth of cut, feed rate and percentage of nano particles are the important process parameters for this experimental work. Based on the research, 9 experiments were conducted on various nano fluids like aluminium oxides, copper oxides and titanium oxide to calculate the optimal level of process parameters as presented in Tab. 5.

Table 5 Experimental results of L9 orthogonal array

Titanium Oxide Nano Coolant				
Runs	Spindle Speed / rpm	% of Nano Oxide	Temperature / ºC	Surface Roughness / µm
1	1500	1	42	2.213
2	1500	3	40	2.135
3	1500	5	40	2.015
4	2000	1	45	2.655
5	2000	3	44	2.525
6	2000	5	42	2.321
7	2500	1	45	2.561
8	2500	3	44	2.562
9	2500	5	41	2.423
Silicon Oxide Nano Coolant				
Runs	Spindle Speed / rpm	% of Nano Oxide	Temperature / ºC	Surface Roughness / µm
1	1500	1	36	2.135
2	1500	3	35	2.085
3	1500	5	33	1.962
4	2000	1	31	2.235
5	2000	3	37	2.215
6	2000	5	38	2.013
7	2500	1	33	2.151
8	2500	3	41	2.1
9	2500	5	35	1.888
Copper Oxide Nano Coolant				
Runs	Spindle Speed / rpm	% of Nano Oxide	Temperature / ºC	Surface Roughness / µm
1	1500	1	36	2.015
2	1500	3	34	2.003
3	1500	5	30	1.985
4	2000	1	38	2.013
5	2000	3	38	2.001
6	2000	5	33	1.838
7	2500	1	42	2.135
8	2500	3	40	2.185
9	2500	5	34	1.981

3.1 Regression Equation

The Design of experiment (DOE) analyzed by various nano fluids regression equation is mentioned below

a) Copper Nano Fluid

- Temperature (°C) = 35.889 + 3.33% of Nano + Spindle Speed 2000 rpm
- Surface Roughness (µm) = 2.0380 + 5% of blending Nano + Spindle Speed 2000 rpm

b) Silicon Nano fluid

- Surface Roughness (µm) = 2.1472 + 2.787% of Nano + Spindle Speed 1500 rpm
- Temperature (°C) = 32.56 + 4.33% of Nano +Spindle Speed 1500 rpm

c) Titanium Nano fluid

- Temperature (°C) = 42.111 + 0.333% of Nano + Spindle Speed 1500 rpm
- Surface Roughness (µm) = 2.2184 + 3% of Nano + Spindle Speed 1500 rpm.

Based on the regression equation by Design of Experiment (DOE), the best input and output parameters are shown in Tab. 6. The titanium oxide has achieved the best value of 41 °C temperature and 2.015 micron of surface roughness and the Silicon oxide gives 32 °C temperature and 1.922 micron of surface roughness. It is clear that the titanium and silicon oxide nano coolants are induced to increase the hardness of workpiece during turning operation in CNC lathe. The copper oxide nano fluid as a coolant achieved the best value of input parameters in turning operation and it achieved good output responses.

Table 6 Best input and output parameters of various nano fluids by design of experiment (DOE)

Name of the Coolant	Spindle Speed / rpm	% of Nano Oxide	Temperature / ºC	Surface Roughness / µm
Titanium Oxide Nano Coolant	1495	4.55	40	2.015
Silicon Oxide Nano Coolant	2035	4.82	34	1.922
Copper Oxide Nano Coolant	1895	4.83	30	1.861

3.2 Main Effect Plots

The effect of input process parameters on the Spindle Speed of AZ91 Magnesium alloy material is shown in Fig. 5. The main effect plot is used to signify the optimal level of input process parameters for this investigation.

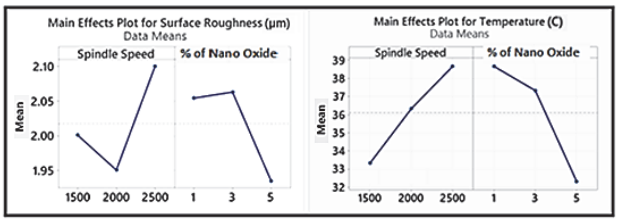

Figure 5 SN ratios for copper oxide with spindle speed

From this Fig. 5, it is shown that the effect of input process parameters of spindle speed and % of nano oxide increase with an increase in the level that is selected for this analysis work. The optimum levels for this investigation are 1500 rpm of spindle speed and 5% mm nano oxide achieves better surface finish with minimum temperature of tool tip and work piece in Fig. 5.

From Fig. 6, the input parameters and output responses of Silicon oxide as a coolant in CNC lathe show that 5% of Silicon oxide nano fluids achieve better surface finish of 2.05 micron. The lowest temperature of 34 °C is achieved by the spindle speed of 1500 rpm with 5% of silicon oxide nano fluid.

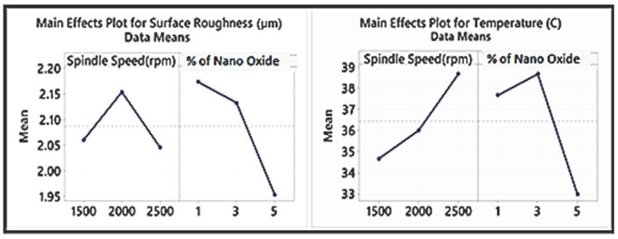

Figure6 SN ratios for silicon oxide with spindle speed

Main effect plot for the surface roughness in Fig. 7 shows that the minimum surface roughness of 2.1 microns is achieved at 1500 rpm of spindle speed and 5% of Titanium oxide nano fluid. The minimum temperature of 40.5 °C is achieved by 5% of Titanium oxide nano fluid. Based on the main effects plots, it is confirmed that both silicon and titanium oxide nano fluids at 5% concentration and a spindle speed of 1500 rpm yield the best outcomes in terms of surface finish and temperature reduction in the turning operation of CNC lathe.

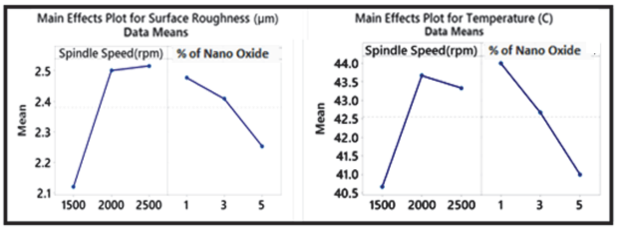

Figure 7 SN ratios for titanium oxide with spindle speed

3.3 3D Plots for Surface Roughness and Temperature of Various Nano Fluids

The output response of surface roughness is varying from 1.9 micron to 2.2 micron for copper oxide nano fluid. The variation of surface roughness by the input parameters of spindle speed and % of copper oxide nano fluid is shown in Fig. 8. The temperature ranges from 30 °C to 41 °C varying by the input parameters of spindle speed and % of copper oxide nano fluid. From Fig. 8, it is clear that the temperature range between 35 °C to 40 °C is achieved in turning operation.

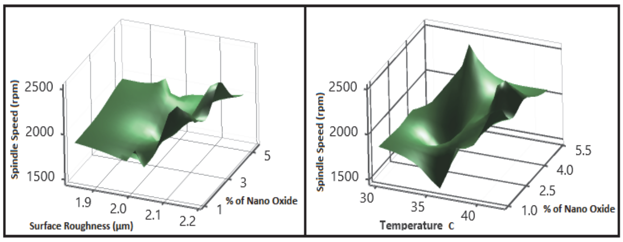

Figure 8 3D plot for copper oxide nano fluid

From Fig. 9, the lowest surface roughness from 2.1 micron to 2.2 micron is achieved for the input parameters of spindle speed and the % of silicon oxide nano fluid. Similarly the same input parameters achieved the minimum temperature range from 30 °C to 40 °C for turning operation in CNC lathe.

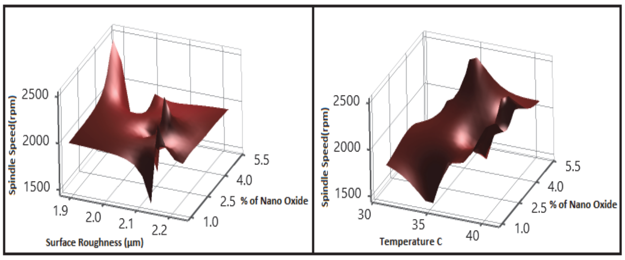

Figure 9 3D plot for silicon oxide nano fluid

The lowest surface roughness from 2.2 micron to 2.4 micron is achieved for the input parameters of spindle speed and the percentage of silicon oxide nano fluid are shown in Fig. 10. Similarly the same input parameters achieved the minimum temperature range from 40 °C to 44 °C for turning operation in CNC lathe.

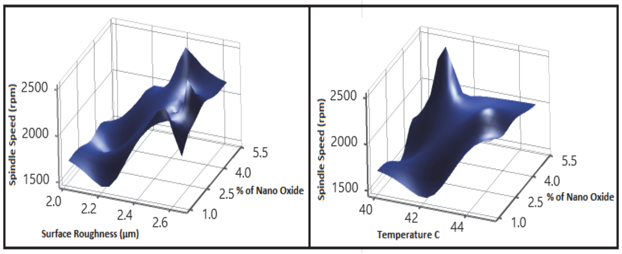

Figure 10 3D plot for titanium oxide nano fluid

3.4 Validation

The best output value of Design of Experiment (DOE) and corresponding experimental results are analyzed. The output parameters such as temperature and surface roughness are discussed with various nano fluids. The comparison result of temperature in theoretical and experimental result is shown in Fig. 11. The temperature of workpiece zone is conducted experimentally and it coincided at about 90% and above. The lowest temperature of 30 °C is achieved in Copper oxide nano fluid as a coolant for turning operation in CNC lathe.

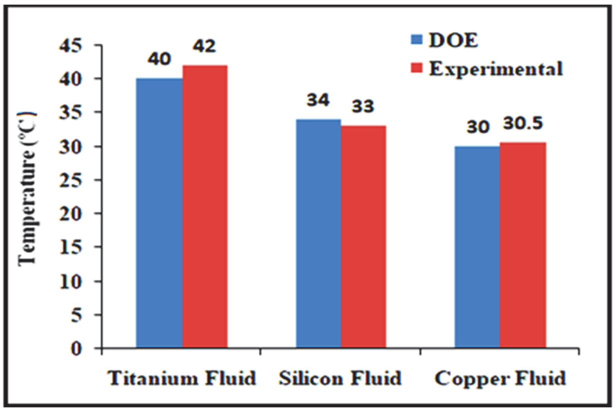

Figure 11 Comparsion results of temperature in various nano fluids

The surface roughness of the various nano fluids is obtained from Design of Experiment (DOE) and the experimental work results of surface rougnesss are shown in Fig. 12. The highest suraface rougness of 2.015 is achieved in titanium oxide nano fluid and the lowest surface roughness of 1.755 micron is achieved in copper oxide nano fluid as a coolant. It is clear that the minimum surface roughness is achieved for copper oxide nano fluid as coolant of turning operation in CNC lathe.

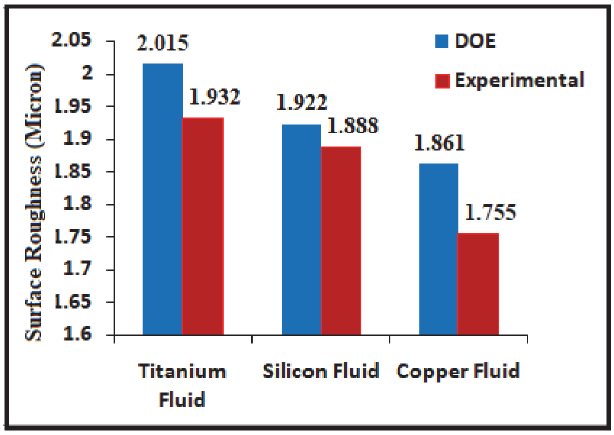

Figure 12 Comparsion results of surface roughness in various nano fluids

4 CONCLUSION

The various nano fluids are introduced for turning operation with high spindle speed of 1500, 2000 and 2500 in CNC lathe. The results of mechanical properties such as work piece temperature and surface roughness are varied by using these nano fluids. The various results are mentioned as follows:

- Use of titanium oxide of 1% gives very low finish in all testing.
- Machining of AZ91 Magnesium Alloy Material has improved mechanical properties.
- Production rate and excellence of the surface finish are enhanced.
- Use of copper oxide nano fluid gives standard low surface roughness of 1.755 micron.
- Copper oxide nano fluid is significantly decreasing the temperature of 30 °C.

Based on the experimental work, it is found that surface finish and production rate are improved at the optimal conditions. This study is supportive for the researchers to build up the knowledge on turning of AZ91 Magnesium Alloy material. It is strongly recommended that the 4.83 % of copper nano fluid and 4.82 % of silicon oxide are very suitable for the turning operation in CNC lathe.

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