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Prabu.L[1], Saravanakumar.N[2]

1. Department of Mechanical Engineering, Sri Shanmugha College of Engineering and Technology, India
2. Department of Mechanical Engineering,PSG institute of Technology and Applied Research, India

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Abstract:

Metal working fluids play a prominent role in the machining operation, to provide better lubrication and surface finish of the machined products. The deprived heat transfer and lubricating property of these conventional fluids causes severe problems to meet the demands of the industry. In recent years, nano-size solid particles have received considerable attention and widely used as additives to improve the thermal and lubricating properties of the cutting fluids. In the current study, nano-metalworking fluids were formulated by dispersing copper and aluminium oxide nanoparticles in the mineral oil based water soluble metal working fluid, in different volume fractions. The tribological characteristics of the synthesized nano-cutting fluids were assessed through the anti-wear and extreme-pressure (EP) tests carried out in Four-ball tester as per ASTM standards. The enrichment in the anti-corrosive properties of the nano-metal working fluids was investigated with the aid of standard iron-chip corrosion test. The cutting fluid containing copper nanoparticles and aluminium oxide nanoparticles shows, considerable reduction in the wear rate and coefficient of friction. The load carrying capacity was enhanced maximum by 5% for the fluid sample containing aluminium oxide nanoparticles rather than base fluid. The coefficient of friction was gently reduced by 15% for the aluminium oxide based cutting fluid sample. From the tribological test results it was observed that the aluminium oxide based nano-cutting fluid shows superior resistance towards wear rate and friction than the copper based cutting fluid. The modified nano-cutting fluids with nanoparticles show signs of a better resistance towards corrosion.

1. Introduction

During machining operation, cutting tool has to endure the elevated temperature and pressure imposed on it by the moving work piece and chip. Tool life is a significant factor in the evaluation of machining process because it directly influences machine set-up time, down time and tool cost. To mitigate and diminish the tool wear and friction in the metal cutting process many techniques such as tool coatings and lubricant usage being adopted in the industries [1]. Among the available options, Water soluble metal working fluids were widely employed to decrease the tool-tip temperature, tool wear and corrosion rate.

In the past decade, various researchers formulated and investigated new age metal working fluids with the dispersion of various nanoparticles to improve its performance connected with heat transfer, anti-wear, anti-corrosion and anti-microbial properties. Thermal conductivity is the most significant physical property responsible for superior heat transfer for any cooling application. Several experimental works have been reported on this characteristic. Eastman et al. [2] dispersed Cu, CuO and Al_2O_3 in the two various base fluids HE 200 oil and water. The thermal conductivity measurement of nanofluids reported 60% enhancement in the thermal conductivity value of formulated nanofluids for the volume fraction of 5 % of nanoparticles rather than the consequent base fluids. Lee et al. [3] examined the thermal conductivity enhancement of the two different based fluids ethylene glycol EG and water dispersed with CuO and Al_2O_3 in four combinations. Results reveal that the size of nanoparticles is considered to be key factor in improving the thermal conductivity of nanofluids in addition to the particle shape. Eastman et al. [4] investigated that the enrichment in the thermal conductivity of the base fluid ethylene glycol dispersed with approximately 0.3 vol % of Cu nanoparticles. From the experimental data it was observed that the thermal conductivity of the nanofluids containing Cu nanoparticles was increased by up to 40% than pure ethylene glycol and ethylene glycol dispersed with similar volume fraction of oxide nanoparticles.

Many researchers investigated the influence of nanoparticles in the metal working fluids in different machining operations. Bin shen et al. [5] investigated the influence of water-based diamond and Al_2O_3 nanofluids while grinding the cast iron using various lubrication environments. Experimental results showed that high-concentration of nanofluids improved the G-ratio. The grinding temperature during machining was greatly reduced.

Alberts et al. [6] evaluated the performance of nano graphite platelets as additive for the coolants used in surface grinding of tool steel. The result specifies that graphite nanoplatelets appreciably decreased the grinding forces, specific energy, and enhances surface finish of the work piece. Lee et al. [7] conducted experiments to examine the performance of paraffin oil containing diamond particles through MQL. The magnitude of surface roughness and grinding forces were greatly reduced in case of nanofluids rather than dry grinding process.S.N.Rao et al. [8]formulated CNT based cutting fluids in varying proportion and conducted to measure the change in the magnitude of cutting forces, tool-tip temperatures, surface finish and tool wear. The results depicts that tool wear decreases rapidly up to 2% inclusion of CNT and rate of change remains constant at higher percentages. Zhang et al. [9] investigated the feasibility of nanoparticles based lubrication for diamond turning of RB-Sic. Four various nanoparticles namely Graphite Fiber (GF), copper (Cu), molybdenum disulfide (MoS_2), and copper oxide (CuO) in different concentrations were dispersed in the grease lubricant and experimented in turning operation. From the experimental results it was found that the particle size and concentration of nanoparticles influences the surface finish and wear rate of tool. Superior surface quality and less tool wear was acquired for the grease containing 10% wt of copper (Cu) nanoparticles. Samuel et al. [10] conducted micro turning experiments in the presence of cutting fluids containing Graphene platelets in varying concentrations. Based on the experimental results it was observed that the kinematic viscosity and thermal conductivity of the graphene based cutting fluids increases with the increase in volume fraction of nanoparticles. Khandekar et al. [11]

examined the change in lubricating properties, wettability and conductive heat transfer coefficient of nano-cutting fluids containing Al_2O_3 nanoparticles. The magnitude of cutting force, work piece, surface roughness, tools wear and chip thicknesses were reduced with the application of nano-cutting fluid. Mao et al. [12] examined the suitability of Al_2O_3 nanoparticles as additive for water based coolant while grinding hardened AISI 52100 steel. The experimental outcomes demonstrate that water based Al_2O_3 nanofluids based MQL grinding extensively reduced the grinding temperature, grinding forces; and enhances the ground surface morphology rather than pure water lubrication.Saravanakumar et al. [13] has examined the influence of silver nanoparticles on the enrichment of cooling and lubricating capacity of the mineral oil based metal working fluid for hard turning operation. The magnitude of the surface roughness of the work piece ,cutting forces, and tool-tip temperature was found to be reduced considerably due to change in the properties of the base fluid.Rahman et al. [14] evaluated the performance of water-based nanocoolant containing zinc oxide nanoparticles while grinding ductile cast iron. It was found that the depth of cut(s) and table speed were the key influencing factors of the surface quality in the grinding process. Hegab et al. [15] synthesized nano-cutting fluids dispersed with MWCNT and aluminiumoxide nanoparticles and conducted machining experiments to assess the improvement in the machining performance. In this investigation, it has been found that both nano-cutting fluids showed superior results rather than fluids without nano-additives. John S. Agapiou [16] developed the Carbon Nano-Onions for water-based MWF as lubricant additives and investigated the influence of nanoparticles in the enhancement of machining performance. The experimental results exhibit the significant improvement in the lubricating properties of the nano-MWF. Gajrani et al. [17] carried out experiments to analyze the performance of the developed nano-green cutting fluids containing calcium fluoride (CaF_2) and molybdenum disulphide (MoS_2) nanoparticles at various concentrations. The empirical results shows that cutting fluids containing 0.3% concentration of molybdenum disulphide (MoS_2) performs better concerning tool-work piece interface friction, surface roughness, cutting force, and feed force when compared to other cutting fluids samples. Madanchi et al. [18] formulated the nano cutting fluids containing nanoparticles and micro particles which includes Aluminium oxide and Zirconium dioxide, as well as silica and conducted experiments to assay the effect of particle size, and concentration of nanoparticles. The data shows that the most of the test samples achieved improved lubrication. Sharma et al. [19] assessed the improvement in the tribological and thermal properties of the cutting fluids dispersed with hybrid lubricant additives which includes MWCNT and alumina nanoparticles. The studies illustrate that friction coefficient and wear reduction increases with increase in nanoparticles concentration. Also the synthesized hybrid nanolubricant considerably reduced the nodal temperature and tool wear and by 27.36% and 11% respectively, rather than other lubricants.

Kotnarowski et al. [20] conducted experiments to investigate the anti-wear properties of the three different base fluids with the inclusions of copper nano powders by 0.25 % wt concentrations. During the wear test frictional force, coefficient of friction and morphology of the worn surface were measured. The experimental result reveals that the copper nanopowders effectively influence on the uniqueness of the modified lubricants. Huang et al. [21] evaluated the lubricating properties of nanoscale graphite added in the base paraffin oil. It was found that the anti-wear, EP properties and load wear index of the nanolubricant was greatly enhanced with the nano additive when compared with plain paraffin oil. Pei et al. [22] investigated the chemical and tribological properties of the water soluble polyacrylamide grafted multi-walled carbon nanotubes with the aid of four ball tester. The experimental result describes that due to the bearing effect of tiny nanometer size composites formed, significantly reduced the friction and enhances the load wear index and anti-wear property and of the nanolubricant. Kao et al. [23] examined the suitability of spherical shaped TiO_2 nanoparticles for the enrichment in the tribological properties of base paraffin oil. The experimental results show that the lower friction coefficient attained with nano-oil rather than the plain paraffin oil, due to the rolling function and surface repair by spherical nanoparticles and increased viscosity.Cursaru et al. [24] conducted the experiments to evaluate the (EP) properties of the mineral base oil dispersed with (AW) additives and (SWNTs). It was observed that the combination of wear additive and SWNTs exhibits a synergistic effect in reducing the wear rate and coefficient of friction. Laura et al. [25] investigated the reduction in COF and wear of metalworking fluids with the inclusion of MWCNT, TiO_2, CuO and Al_2O_3 nanoparticles. The results shows that with small concentrations of nanofillers the significantly reduced the wear and friction. CuO reduced the wear by 86% for 0.01 % wt when compared to base metal working fluid. Yu Su et al. [26] studied the tribological properties of vegetable oil dispersed with graphite nanoparticles. The outcomes of the experiment reveals remarkable reduction in friction and wear, increase in the volume fraction graphite concentration increases the friction and wear reduction. Tao et al. [27] utilized GO/SiO_2 hybrid nanoparticles as additives for water-based lubricants, and its machining and tribological characteristics were comparatively analyzed using milling and four-ball testing setup. The results reveal that the worn scar diameter and coefficient of friction appreciably reduced for the GO/SiO_2 water-based lubricant. Prabu et al. [28] examined the effect of silver nanoparticles in the development of lubricating properties of the water soluble metal working fluid. The empirical data reveals that the load-wear index of the modified fluid was increased. Tao Lv et al. [29] employed Graphene nanoplatelets as additives to improve the machining and tribological characteristics of the nano-lubricants. The results demonstrate that nano-lubricant reduced wear scar diameter and coefficient of friction, as well as improved machining performance. Several researchers examined the performance of the nano-metalworking fluids in various machining operation and parameters such as metal cutting temperature, cutting force, surface finish, tool wear rate etc were investigated. However the research work contributing to assess the tribological properties of mineral oil based metal working fluids dispersed with copper nanoparticles and Aluminium oxide nanoparticles have not conducted so far. In this present study, nanoscale copper and aluminium oxide has considered as an additive for the mineral oil based water soluble metal working fluid and its extreme pressure property, wear preventive characteristics and anti corrosive property were evaluated as per ASTM standard.

2. EXPERIMENTAL PROCEDURES

2.1 Preparation of nano-metal working fluid

In this present work, to enhance the tribological and anti-corrosive properties of the base fluid, superior quality copper and aluminimum oxide nanoparticles was procured from commercial supplier, named Nanolabs India. The morphology of the nanoparticles was studied with TEM images. The properties of the base fluid and procured nanoparticles are given in Table 2.1.The water soluble mineral oil base metal working fluid was prepared by mixing 95% water and 5% concentrated soluble oil comprising fatty acid based emulsifier, mineral oil and other additives.

Table 2.1 Material Properties

Properties of Nanoparticles		
Properties/ Particles	**Cu nanoparticles**	**Al_2O_3 nanoparticles**
Average Size	30-50 nm	20-40 nm
Shape	Nearly spherical	Nearly spherical
Purity	99.0%	99.0%
Bulk Density	0.21 g/cm^3	3.5-3.9 g/cm^3
pH	4-5	4-5
Properties of base fluid		
Fluid type	Mineral oil based	
Colour	Brown	
Emulsifier type	Fatty acid containing alkanolamines (6%)	
Mineral oil content	58%	
Density at 20^{0}C	0.96 g/cm^3	

The selected nanoparticles were added in the ratio of 0.5%, 1% and 2% volume concentration to the base fluid. After which the complete mixture was stirred for duration of 30 minutes using magnetic stirrer uniformly at a speed of 600 rpm. Later, the prepared fluid was placed in ultrasonic bath for 60 minutes, to avoid the agglomeration of nanoparticles in the base fluid.

2.2 Physical properties measurement

In the present work, few essential properties were evaluated for the nano metal working fluids through a series of standard tests. The density of the base fluid and the nano-cutting fluid was measured with the aid of hydrometer. The optimum pH range influences the performance of the cutting fluid. The pH values of the base cutting fluid and nano-cutting fluids were measured by HQ40D digital pH meter. The redwood viscometer was utilized to determine the kinematic viscosity of the synthesized fluid samples, as per ASTM D445 [35] standard.

2.3 Dispersion stability measurement

The dispersion stability of the nanoparticles has a great influence on the performance of the nanofluids. The zeta potential value of the nanofluids can be used to assess the stability level of the nanoparticles in the dispersed medium. The zeta potential values of the formulated nano-cutting fluids were measured by using Zetasizer instrument. The specification of the Zetasizer was given below in the table 2.2.

Table 2.2 Specification of Zetasizer

Description	Range
Measurement range	3.8nm-100microns
Zeta potential range	> +/-500mV
Sensitivity	10mg/mL 66kDa protein
Mobility range	> +/- 20 µ.cm/V.s
Light source	He-Ne laser 633nm, Max 4mW
Temperature control range	0°C - 90°C +/-0.1

2.4 Tribological characteristics measurement

To evaluate the improvement in the tribological properties such as extreme pressure EP and anti wear properties of the nano cutting fluids experiments were conducted as per ASTM D2783 [32] and ASTM D4172 [33] respectively in four ball tester. The specification of the four-ball tester was summarized in the table 2.3. The optical microscope was utilized to compute the wear scar diameters (WSD) in the stationary balls. The transformations in the worn surface of the hardened steel balls collected were analyzed by using scanning electron microscope (SEM).The EDS analysis was carried out to trace the metallic elements which might formed on the worn surfaces of the test balls, during the wear test.

Table 2.3 Specification of Four-ball tester

Description	Range
Collet diameter	12.7 mm
Load range	60N – 9999N
Max axial load	10,000 N
Loading arm ratio	1:15
Loading arm length	1305 mm
Spindle speed	300 - 3000 rpm
Operating Temperature	Up to 100^0 C

2.5 Corrosion test

To evaluate the anti-corrosive property of the synthesized nano-cutting fluids, standard test ASTM D4627 [34] was carried out. Cast iron chips are placed in a Petri dish comprising a filter paper and diluted metalworking fluid (nano-cutting fluid) shown in fig. 2.1. The dish is enclosed and permitted to stand overnight. The quantity of rust stain on the filter paper and breakpoint are sign of the corrosion control given by the nano-cutting fluid.

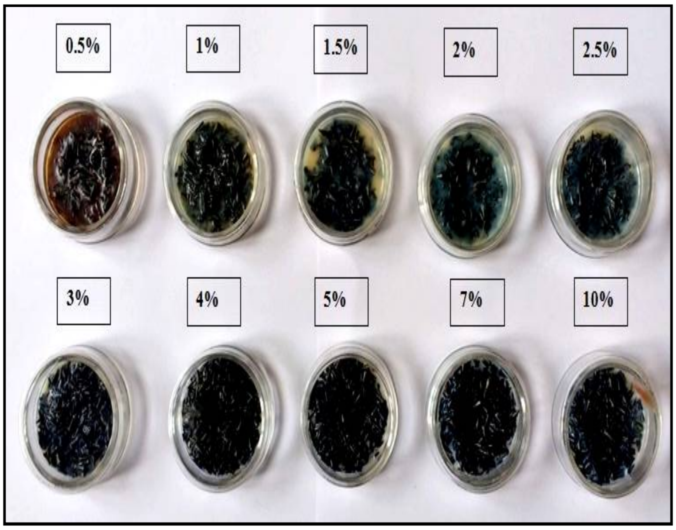

Figure 2.1 Iron-chip corrosion test arrangement

3. RESULTS AND DISCUSSION

3.1 Influence on physical properties

3.1.1 Density

For all the concentrations of nanoparticles in the base fluid shows an improvement in the density when compared to the base state. It can be seen from the Table 3.1.that the density of the cutting fluids increases with the increase in volume fraction of nanoparticles. The base fluid with 2% Cu nanoparticles shows maximum density value of 997.55Kg/m^3, whereas the density of base fluid was found to be 996Kg/m^3.

3.1.1 pH

pH is the indicator of hydrogen ion concentration in the liquid medium. In general, pH value of 7 is considered as neutral state. A higher value in pH represents alkaline solution and the pH value below 7 indicates acidic solution. The optimum range of pH for water soluble cutting fluids should be maintained between 8.6-9.3[30]. The bacterial growth occurs when the pH value falls lower than 8.5 and when the pH value is greater than 9.3, it causes dermatitis and corrosion on non-ferrous metals. Hence, too low or too high values of pH cause a difficulty in handling and disposal of the cutting fluids. From the table 3.1, it was observed that the pH values decreases with the raise in volume fraction of nanoparticles in the base fluid. The fall in pH value is characterized by decrease in alkalinity of the cutting fluid. From the results it was found that the pH value of all the cutting fluid samples lies in the optimum range. Thus, it is evident that the growth of biological activities is limited.

3.1.2 Viscosity

The viscosity is one of the significant properties of fluid, which indicates the fluid friction. Higher the viscosity value of lubricating oil provides better lubrication. Table 3.1 shows the measured values of the cutting fluids. From the results it was found that the viscosity of cutting fluids increases with the increase in volume fraction of nanoparticles. The viscosity improved to a maximum extent by 11.03% for cutting fluids containing 2% Al_2O_3 nanoparticles, rather than the base fluid. For 2% of Cu nanoparticles in the base fluid, the viscosity value enhanced by 9.65%.From the Figure 3.1, it was observed that the viscosities of all the cutting fluid samples decreases with increase in temperature. Thus the improvement in the viscosities of the base cutting fluid with the inclusion of nanoparticles shows the feasibility of enhanced lubrication effect during the machining operation.

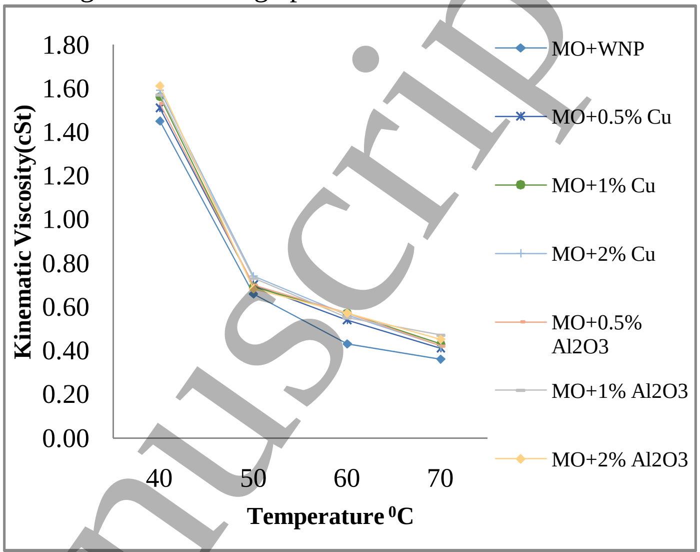

Figure 3.1 Kinematic Viscosity of cutting fluids

3.2 Dispersion stability of nanoparticles

The functional properties of the nanofluids depend upon the dispersion stability of the nanoparticles. The zeta potential measurement technique is widely used to investigate the stability of the nanoparticles in the base fluids. Particles with zeta potentials more than +30mV or -30mV are normally considered stable.

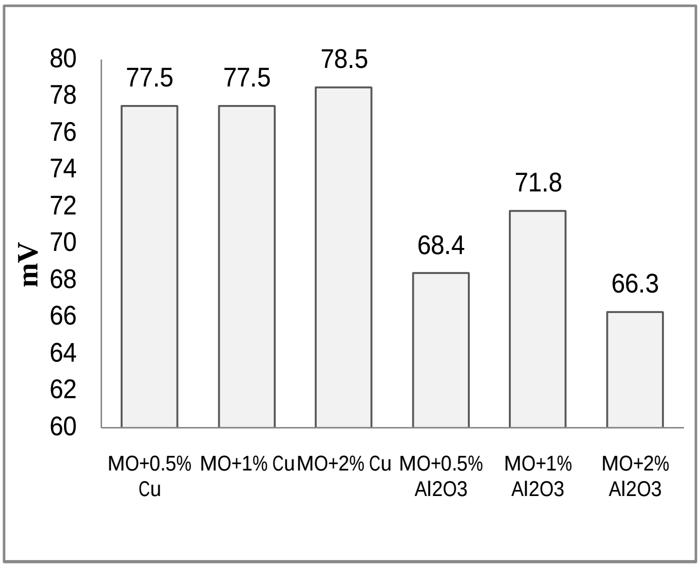

Figure 3.2 Zeta potential values of cutting fluid samples

Table 3.1 Physical properties of the cutting fluid samples

Cutting Fluid Samples	Density (Kg/m^3)	pH	Kinematic Viscosity(cSt)			
			40^0C	50^0C	60^0C	70^0C
MO+WNP	996	8.96	1.45	0.66	0.43	0.36
MO+0.5% Cu	996	8.92	1.51	0.70	0.54	0.41
MO+1% Cu	996.65	8.88	1.56	0.69	0.57	0.43
MO+2% Cu	997.55	8.87	1.59	0.74	0.56	0.42
MO+0.5% Al_2O_3	996.25	8.90	1.53	0.70	0.57	0.42
MO+1% Al_2O_3	996.55	8.86	1.57	0.73	0.55	0.47
MO+2% Al_2O_3	997	8.84	1.61	0.68	0.57	0.45

From the measured values, it was found that all the nano-cutting fluid samples possessed the zeta potential values more than 30 mV, shown in figure 3.2.The maximum zeta potential value of 78.5mv was observed for the cutting fluid sample containing 2%Cu nanoparticles, when compared to other samples. In case of Al_2O_3 nanoparticles, the magnitude of zeta potential is higher for 1% volume fraction, reported as 71.8 mV.Hence, the nanoparticles dispersed in the mineral oil based cutting fluid, shows a better stability. This possible characteristic of nano-cutting fluids is due to the influence of pH values of the fluid medium and ultrasonication effect.

3.3 Tribological characteristics of nano-cutting fluids

To assess the anti-wear properties of the formulated cutting fluid samples, the extreme-pressure property test (EP) and (WCT) wear preventive characteristics test were performed in four ball tester.

3.3.1 Influence on Extreme-Pressure (EP) property

Table 3.2 narrates the empirical data acquired through the EP test conducted in four ball tester. From the data it can be understood that the nanoparticles inclusion in the base fluid has greatly influence in reducing the wear rate from LNSL to ISL. From the experimental results it was observed

Table 3.2 Tribology test results

Cutting Fluid Samples	ASTM D2783						ASTM D4172	
	LNSL (N)	WSD (LNSL) (mm)	ISL (N)	WSD (ISL) (mm)	Weld load (N)	LWI (N)	WSD (mm)	Coefficient of Friction
MO+WNP	618	0.415	981	1.015	1236	689.48	0.640	0.38
MO+0.5% Cu	618	0.406	981	0.971	1236	698.17	0.634	0.37
MO+1% Cu	618	0.398	981	0.957	1236	707.53	0.621	0.36
MO+2% Cu	618	0.408	981	0.963	1236	703.25	0.625	0.36
MO+0.5% Al_2O_3	618	0.384	981	0.932	1236	715.65	0.572	0.35
MO+1% Al_2O_3	618	0.372	981	0.901	1236	724.84	0.537	0.32
MO+2% Al_2O_3	618	0.378	981	0.910	1236	717.01	0.556	0.33

that, for all the cutting fluid samples the weld point occurs at a load 1236N. Figure 3.3-3.4 shows the changes in the magnitude of wear scar for various load regions. The wear scar diameter at LNSL for the base fluid without nanoparticles is observed to be 0.415mm, whereas at ISL the wear scar diameter is 1.015mm. The reduction in wear scar diameter for cutting fluids with cu nanoparticles was found to be 0.957 mm and 0.398 mm at ISL and LNSL respectively, for volume fraction of 1%. The wear scar has been greatly reduced by 11.23% at ISL and 10.36% at LNSL for the cutting fluids with 1% Al_2O_3 nanoparticles, corresponding wear scar diameter are 0.901mm and 0.372mm. The enrichment in the LWI (load wear index) shows the effectiveness of the nanoparticles in the base fluid that can be seen in Figure 3.5. The LWI for the fluids sample dispersed with Cu and Al_2O_3 nanoparticles enhanced to a maximum extent by 3% and 5% respectively for 1%volume fraction, rather than the base fluid. The overall results depicts that the tribological characteristic improved for the

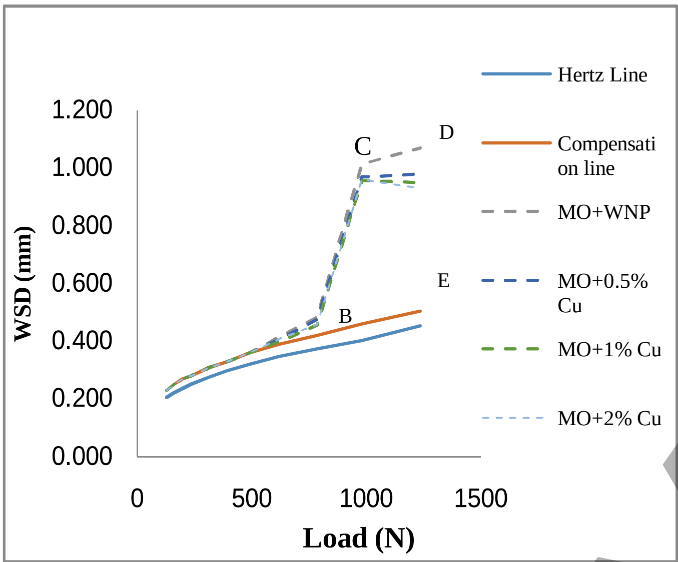

Figure 3.3 Wear-Load curve of copper nanoparticles based cutting fluids

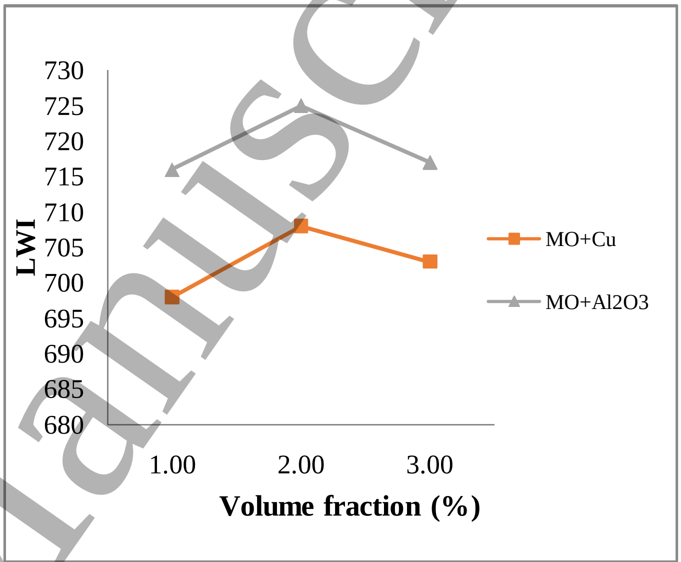

Figure 3.5 Load wear index of nano- cutting fluids

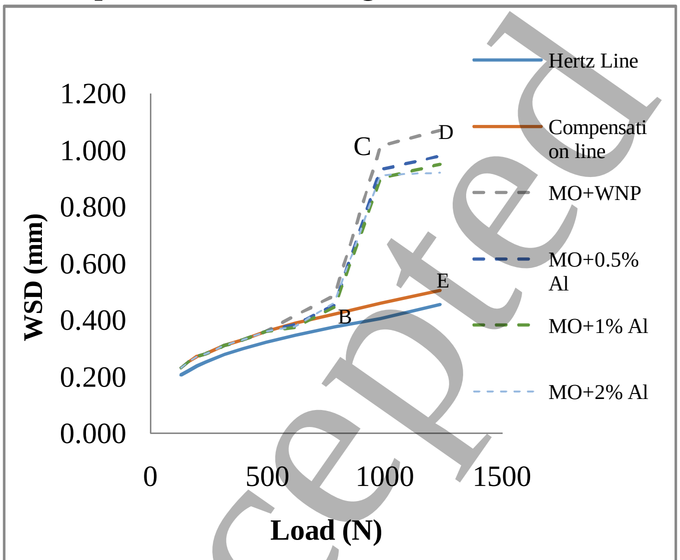

Figure 3.4 Wear-Load curve of aluminiumoxide nanoparticles based cutting fluids

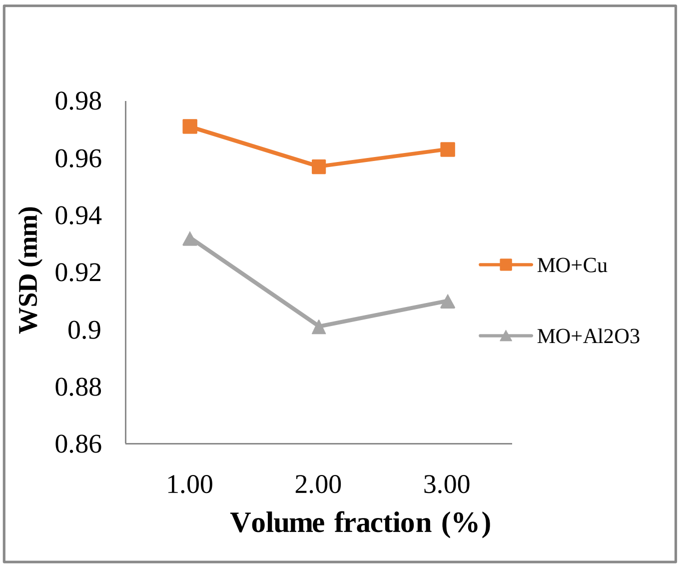

Figure 3.6 Wear scar diameter for nano- cutting fluids (EP test)

cutting fluids dispersed with copper and aluminium oxide nanoparticles.

3.2 Influence on anti-wear characteristics

Table 3.2 presents the experimental results of wear preventive characteristics test. From the results, it was observed that the wear rate and friction fluctuates with respect to the dispersed nanoparticles and its concentration. The magnitude of the scar diameter for the base fluid is 0.64 mm, whereas for the fluid sample containing copper nanoparticles, the value reduced to 0.621mm. The inclusion of aluminium oxide nanoparticles in the cutting fluids reduced the wear scar to a maximum by 16%, for a volume fraction of 1% shown in Figure 3.7.The coefficient of friction is an exhibition of energy loss caused by friction. The minimum value of friction coefficient of the cutting fluids containing 1%Al_2O_3 nanoparticles reaches 0.32 can be seen in Figure 3.8.This shows the resistance level of the selected nanoparticles towards wear and friction. The reduction in the magnitude of wear and friction by the nano-metal working fluids could be due to the formation of thin tribo-film between the contacting surfaces.

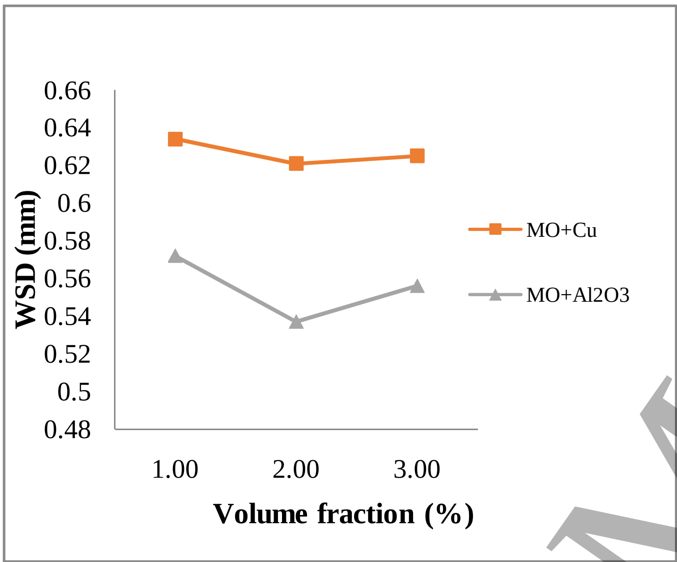

Figure 3.7 Wear scar diameter for nano- cutting fluids (WCT)

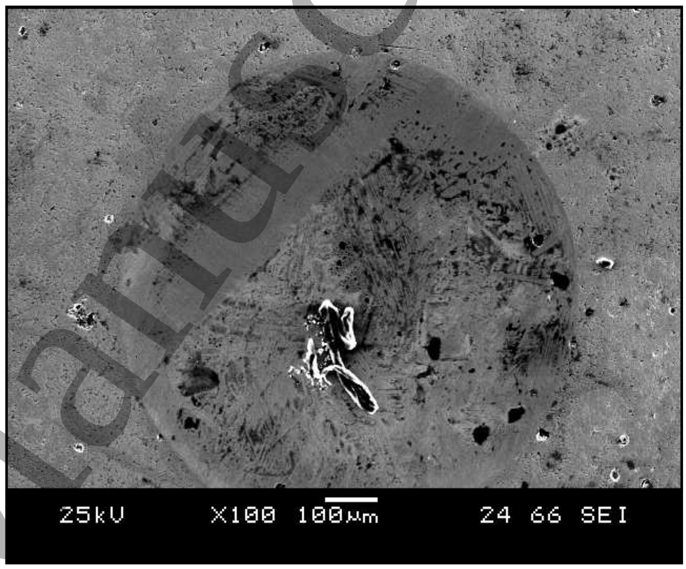

Figure 3.9(a)

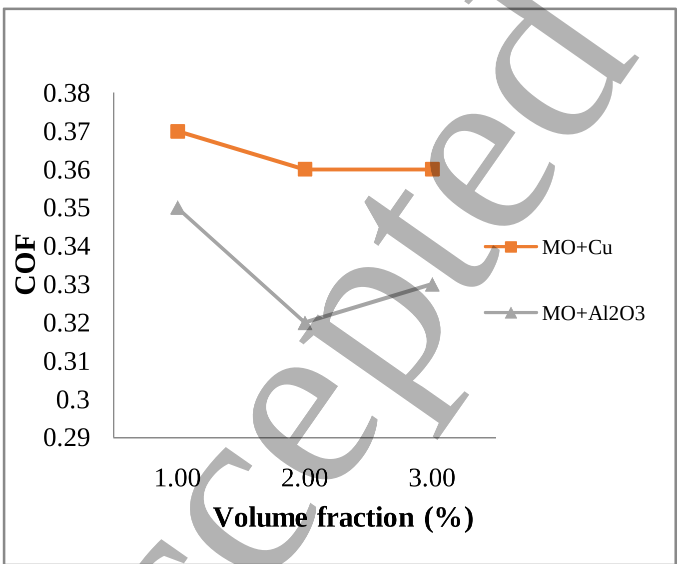

Figure 3.8 Coefficient of friction for nano-cutting fluids (WCT)

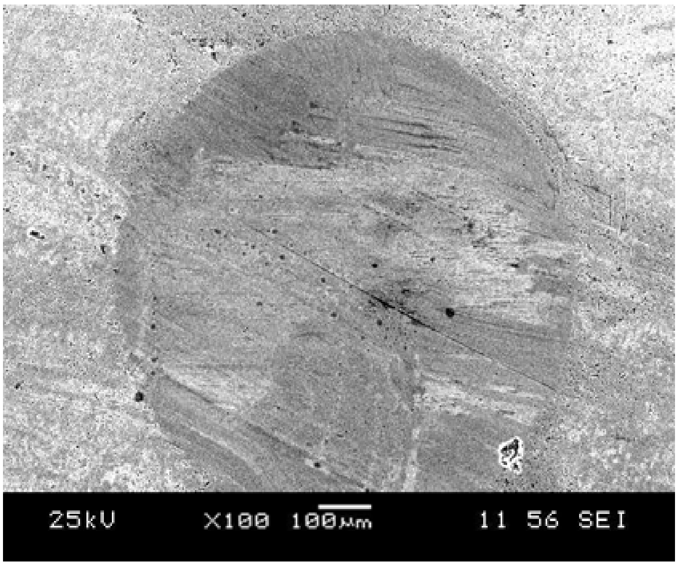

Figure 3.9 (b)

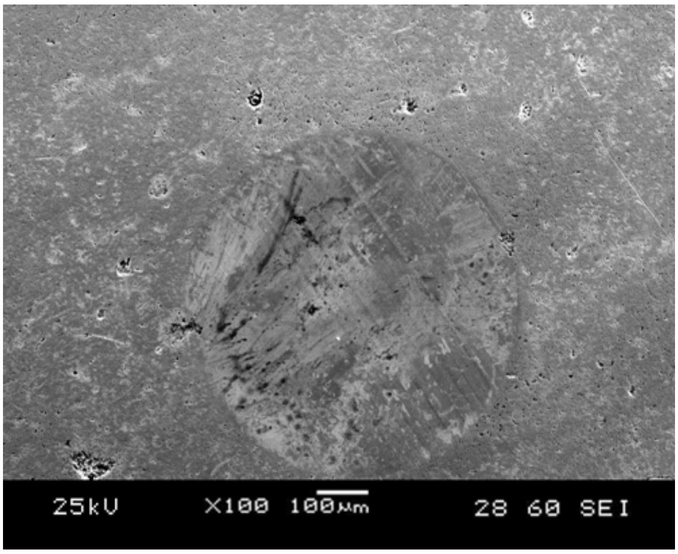

Figure 3.9 (c)

Figure 3.9 SEM images of worn surfaces - Wear preventive characteristics test- (a) MO+WNP (b) MO+0.5%Cu (c) MO+1%Cu (d)MO+2%Cu (e) EDS analysis of worn surfaces of test specimen MO+2%Cu

Due to the constant shear movement, the nanoparticles might deform and amalgamated on the worn surface which leads to the progress of slender tribo-film.The deposited thin film between the contacting surface, reduces the friction and keeps wear surface smoother, which can been in SEM images of the test specimens shown in figure 3.9. The presence of tribo- film was witnessed by the EDS analysis results, which shows the traces of

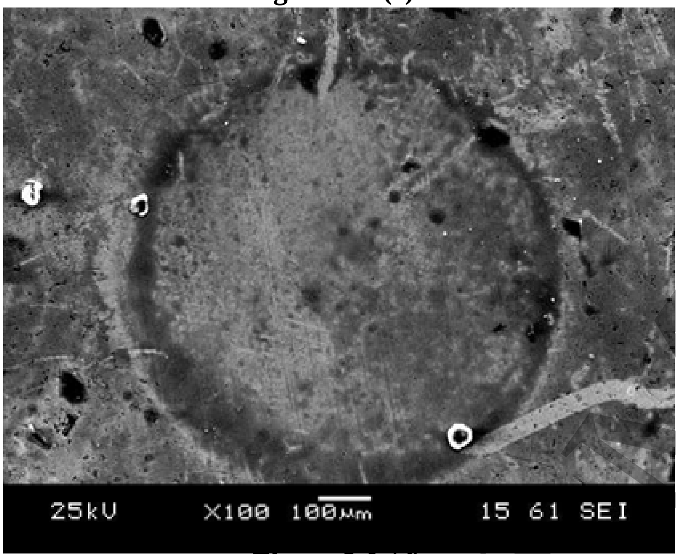

Figure 3.9 (d)

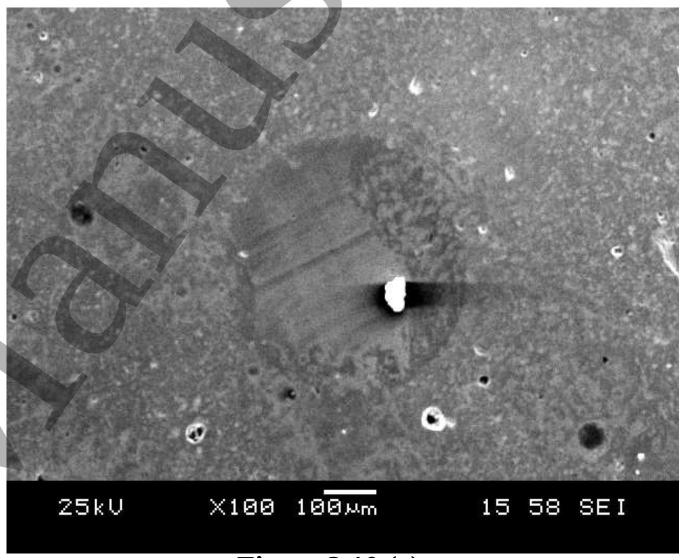

Figure 3.10 (a)

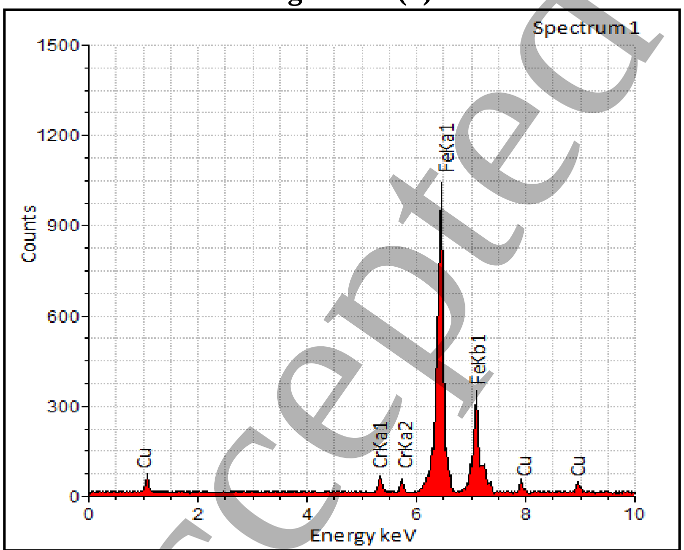

Figure 3.9 (e)

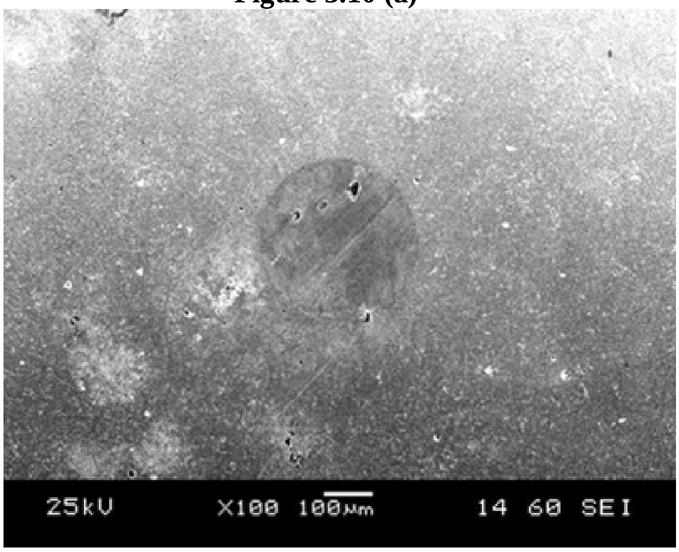

Figure 3.10 (b)

respective chemical elements of the nano-cutting fluids can be seen in figure 3.9(e) and figure 3.10(d).

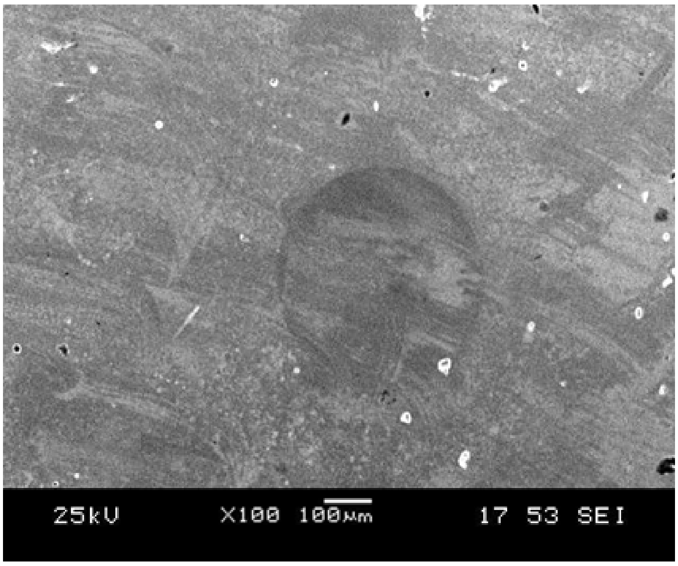

Figure 3.10 (c)

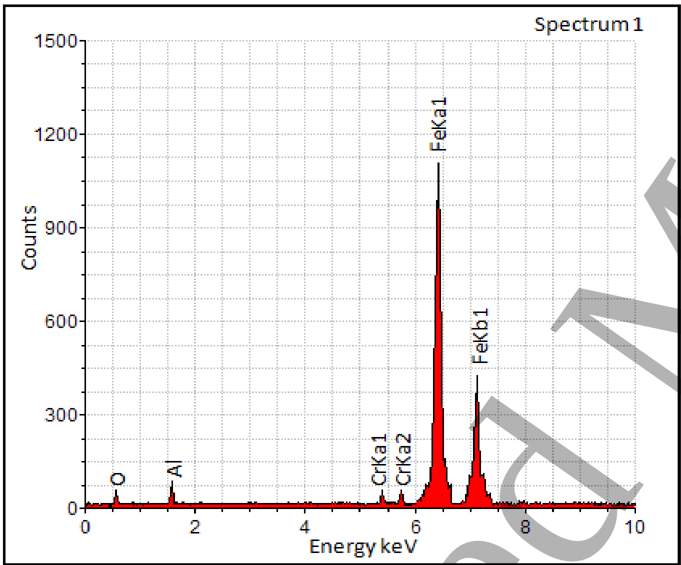

Figure 3.10 (d)

Figure 3.10 SEM images of worn surfaces - Wear preventive characteristics test, (a) MO+0.5%Al_2O_3,(b)MO+1% Al_2O_3,(c)MO+2% Al_2O_3,(d) EDS analysis of worn surfaces of test specimen MO+2% Al_2O_3

3.3 Influence on anti-corrosive property

To assess the anti-corrosive property of the developed nano-cutting fluids, iron-chip corrosion test was conducted as per ASTM D 4627 standard.

Through the experiment, the break points of corrosion for the cutting fluid samples were determined. The weakest concentration identified that left no rust stain on the filter paper is called as breakpoint. Table 6.7 depicts the break point of corrosion for the formulated cutting fluid samples. From the standard test results it was found that the inclusion of nanoparticles shows a good sign in resisting the corrosion.

Figure 3.11 Iron chip corrosion test result-MO+WNP

Figure 3.12 Iron chip corrosion test result-MO+2%Cu

The breakpoint of corrosion for the cutting fluid without nanoparticles was found to be 4% cutting fluid concentration. In case of nano-cutting fluids for all the selected nanoparticles the break point was identified as 3% fluid concentration. From the Figure 6.19, it can be seen that all the nanoparticles dispersed with 1% and 2% volume fraction shows a

Table 6.7 Break point of corrosion for cutting fluid samples

Cutting fluid	Concentration of Cutting fluid									
	0.5%	1%	1.5%	2%	2.5%	3%	4%	5%	7%	10%
MO+WNP	1	1	1	1	1	1	0	0	0	0
MO+0.5% Cu	1	1	1	1	1	1	0	0	0	0
MO+1% Cu	1	1	1	1	1	0	0	0	0	0
MO+2% Cu	1	1	1	1	1	0	0	0	0	0
MO+0.5% Al_2O_3	1	1	1	1	1	1	0	0	0	0
MO+1% Al_2O_3	1	1	1	1	1	0	0	0	0	0
MO+2% Al_2O_3	1	1	1	1	1	0	0	0	0	0

0-No Stain formed 1-Stain formed

Figure 3.13 Iron chip corrosion test result- MO+2% Al_2O_3

better resistance towards the corrosion, rather than 0.5%. The reduction in the stain level is the evident for the enhancement in the anti-corrosive property of nano-cutting fluid, which can be seen in Figure 3.11-3.13. The reduction in the stain could be due to the formation of protective layer of nanoparticles on the metal surface based on the chemisorptions phenomenon [31].

4. CONCLUSIONS

In the current study, nano-cutting fluids was synthesized by dispersing copper and aluminium oxide nanoparticles in the mineral oil based water soluble oil. The experiments were conducted on the developed nano-cutting fluids to evaluate the enhancement in the thermo-physical properties, tribological properties and anti-corrosive properties. as per ASTM standard. The research findings based on the experimental investigations were summarized below.

1. The density of all the nano-cutting samples were measured, it was observed that increase in nanoparticles concentration increases density in all cases.
2. The pH values of all the nano-cutting fluids falls in the optimum range 8.6 – 9.3, as recommended for water miscible metal working fluids.
3. From the experimental results, it was observed that the maximum kinematic viscosity value of 1.61 cSt was acquired for cutting fluid dispersed with 2% Al_2O_3 nanoparticles.
4. The zeta potential values of all cutting fluid samples has values more than 30mV.The higher zeta potential value of 78.5mV was attained for cutting fluid containing 2% copper nanoparticles.
5. A higher LWI of 724.84 was observed for cutting fluid with the 1% Al_2O_3 nanoparticles, corresponding wear scar diameter of the test specimen at LNSL and ISL found to be 0.372mm and 0.901mm respectively.
6. In wear preventive characteristics test, the maximum reduction in wear scar diameter (WSD) and coefficient of friction was found to be 0.537mm and 0.32 respectively for the cutting fluid dispersed with 1% Aluminium oxide nanoparticles.

7. Through Iron-chip corrosion test results, it was found that the nano-cutting fluids exhibit a better resistance towards corrosion. The break point of corrosion for all the nano-cutting fluids in both 1% and 2% volume fraction was preceded, when compared with the base fluid.

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Nomenclature

MO-Mineral Oil based cutting fluid
WNP-Without nanoparticles
Cu-Copper nanoparticles
Al_2O_3- Aluminium oxide nanoparticles
COF-Coefficient of Friction
WSD-Wear Scar Diameter in mm
LWI-Load wear index in N
LNSL -Last Non Seizure Load
ISL -Initial Seizure Load

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