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RESEARCH

Influence of Ag Nanoparticles for the Anti-wear and Extreme Pressure Properties of the Mineral Oil Based Nano-cutting Fluid

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A B S T R A C T

The cutting fluids are widely used to reduce the temperature and friction between the tool and work piece in the metal cutting processes. This work investigates the enhancement in the tribological properties of the mineral oil (MO) based cutting fluid with the inclusion of silver nanoparticles. The nano-cutting fluid was prepared by adding various proportions of silver nanoparticles in the mineral oil based cutting fluids. The extreme pressure properties and wear preventive characteristics of the nano-cutting fluid were assessed as per ASTM standard. The wear surfaces were analyzed using scanning electron microscopy and energy- dispersive spectroscopy. The inclusion of silver nanoparticles in the base fluid as additive shows a gradual reduction in the friction and wear. The influence of silver nanoparticles improved the load-wear index of the cutting fluid by 8 % and reduced the wear scar diameter by 13% .With reference to the empirical data, all the concentration of nanoparticles exhibit the improvement in the extreme pressure and anti-wear properties of the nano-cutting fluid. The formation of thin tribofilm containing silver nanoparticles at the wear surface is most likely mechanism behind the improvement in tribological behavior of mineral oil-based nano-cutting fluid.

1. INTRODUCTION

During machining operation, cutting tools are subjected to intense plastic deformation at high strain rate; this leads to friction between cutting tool and work piece materials results in progressive loss of materials in cutting tool. Hence the role of cutting fluids is prominent to reduce the friction and temperature [1]. The basic function of cutting fluids is to provide adequate lubrication and cooling between tool and work piece. By adding appropriate additives in the conventional cutting fluids, the thermal and tribological properties of the cutting fluid could be enhanced. Nanomaterials have attracted great attention in various research fields as additives during the last few years due their tremendous improvement in the basic properties. Nanofluids are engineered colloidal suspensions of nanoparticles (1-100 nm) in a base fluid. The improvement in the essential properties of the working fluid with the inclusion of metallic nanoparticles stems from the research work of Choi et al. [2] and Eastman et al. [3] which resulted in the larger enhancements in the thermal conductivity of common heat transfer fluids. Rabesh Kumar Singh et al. [4]assessed the thermal conductivity and specific heat of the nano fluids has suspension of Titanium dioxide (TiO_2), Silicon oxide (SiO_2) and Aluminum oxide (Al_2O_3) nano particles in vegetable oil water emulsion at different temperatures for different Nano particle volumetric concentrations of , it has been found that increase of Nano particles concentration in base fluid enhanced its thermal conductivity and decreases its specific heat. Saravanakumar et al. [5] has investigated the effect of silver nanoparticles as additives in the mineral oil based cutting fluid for turning operation. The experimental data shows the improved lubricating and thermal properties of the nano-cutting fluid have reduced the cutting forces, cutting temperature and surface roughness of the machined work piece.Yanbin Zhang et al.[6]found the effects of the hybrid nanofluids on grinding force, coefficient of friction, and work piece surface quality for Ni-based alloy grinding. The Results show that the MoS2/CNT hybrid nanoparticles achieve better lubrication effect than single nanoparticles. Yaogang Wang et al.[7] experimented with different Nanofluids namely MoS_2, SiO_2, diamond, carbon nanotubes (CNTs), Al_2O_3, and ZrO_2, to select the kind of nanoparticles with optimum lubrication performance in grinding nickel alloy GH4169. Rabesh Kumar Singh et al.[8]developed a hybrid nanofluids by mixing alumina-based nanofluids with graphene nanoplatelets (GnP) in the volumetric concentrations for hard turning operation. The study reveals that blending of GnP with alumina enhances the performance of hybrid nanofluids.

Sudeep et al. [9] examined the effect of TiO_2 nanoparticles as an additive in base oil; the empirical data shows that all concentrations increased the coefficient of friction. Hisakado et al. [10] investigated the anti-wear effectiveness of the silver nanoparticles dispersed in ethanol with ceramic specimens. It was found that there was significant wear protection but enhanced friction, due to ploughing or adhesion mixed of wear debris and silver nanoparticles.Wu et al. [11] analyzed the significance of CuO, TiO_2, and diamond nanoparticles in API-SF engine oil and a base oil, the experimental results show that the nanoparticles, especially CuO added to standard oils exhibit good friction-reduction and anti-wear properties.Arumugam et al. [12] has greatly investigated the tribological properties of biodegradable automotive lubricant, chemically modified rapeseed oil with and without TiO_2 nanoparticles, focusing on the anti-wear characteristics of nano rapeseed oil. Zhou Jing et al. [13] have found various influencing factors such as the concentration of nanoparticles in oil, sliding speed, applied load, contact form of friction pairs and lubricating oils with dispersion of Cu nanoparticles as additive, for the enhancement of the tribological properties of base fluid. Nallasamy et al. [14] synthesized and dispersed MoS_2 nanoparticles in the polyalphaolefin base oil for machine tool slide ways application. It was found that the formation of a thin tribofilm of the nanolubricant at the wear surface has 24 % reduction in coefficient of friction and an increase in load-carrying capacity. Yaogang Wang et al. [15] investigated the lubricating properties of different vegetable-oil-based nanofluids through a comparative evaluation between frictional test and grinding experiment. From the results it was observed that the lubricating properties of different nanofluids in the frictional test were in good agreement with those in the grinding experiment.

Laura et al. [16] investigates the effect of CuO, TiO_2, Al_2O_3 and multi-walled carbon nanotube at various treat rates on the tribological properties during the lubrication processes in industrial application. The results showed significant improvements with small filler concentrations of nanoparticles. Naumov et al. [17] examined the tribological properties of iodine which has been used as a micro additive in cutting-fluid components (CFCs) at various operations of mechanical treatment of metals and alloys. The results showed the use of iodine as a CFC effectively affects the cutting characteristics and resistance characteristics of cutting tools. Cong Mao et al. [18] assessed the tribological properties of cutting fluid with the inclusion of Al_2O_3 nanoparticles and it exhibited a noticeable friction reduction and anti-wear properties.

Hongmei Xie et al. [19] investigated the performance of SiO_2/MoS_2 hybrid nanoparticles were employed as lubricant additives in the base oil, and their tribological properties were evaluated. The experimental data reveals that the nanoparticles are attributed to the physical synergistic lubricating actions of nano-SiO_2 and nano-MoS_2 during the rubbing process.Tijerina et al. [20] included hexagonal boron nitride (h-BN) and graphene (G), over bare mineral oil in the form of 2D nanosheets, resulted in the decrease of the wear scar and friction coefficient along with a huge enhancement in thermal performance, even for the small fraction of nanofillers. Anuj Kumar Sharma et al. [21] investigated the effect of alumina/graphene (GnP) hybrid nanoparticle additives on tribological properties of lubricant as cutting fluid in turning of AISI 304 steel. The results establish that mixing of GnP with alumina enhanced its tribological properties. The developed hybrid nano-lubricant significantly reduced the tool flank wear and nodal temperature by 12.29 % and 5.79 %, respectively compare to alumina based lubricant. Many researchers investigated the behavior of the nano-cutting fluid with respect to the respective machining environment, parameters such as coefficient of friction, tapping torque, cutting force etc. But the study exhibiting the extreme pressure and anti-wear properties of mineral oil based cutting fluids dispersed with silver nanoparticles have not done. In the present study, nanoscale silver has considered as an additive for the mineral based cutting fluid its extreme pressure properties and wear preventive characteristics were evaluated as per ASTM standards.

2. EXPERIMENTAL PROCEDURES

2.1 Synthesis and characterization of silver nanoparticles

For the present work, the Chemical reduction method has been adopted to prepare the stable silver nanoparticles. The proposed silver nanoparticles were synthesized, reducing silver nitrate by sodium borohydride in the presence of CTAB (Cetyl Trimethyl Ammonium bromide) as stabilizer. Later, the synthesized solution was allowed in a cold bath for 2 hours. The formed silver nanoparticles colloidal solution was observed to be in yellowish brown colour. To assess various parameters such as particle size, shape, fractal dimensions and surface area, the characterization study was done. In the present investigation, the TEM (Transmission Electron Microscopy) and UV–Vis spectroscopy were employed for assuring the presence and to study the morphology of the synthesized silver nanoparticles. The TEM image of silver nanoparticles is shown in Fig. 1.

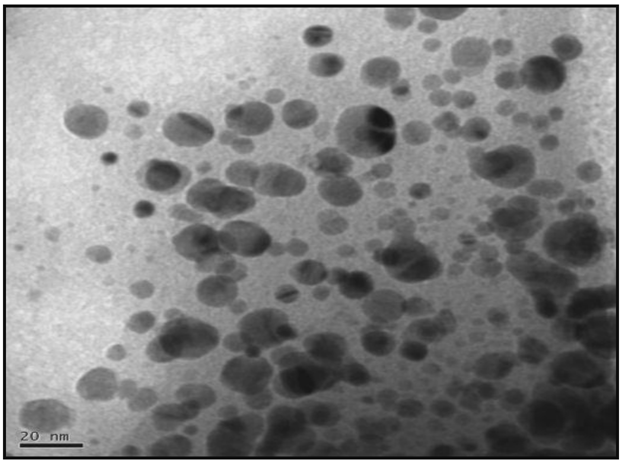

Fig. 1. TEM Image of Silver nanoparticles.

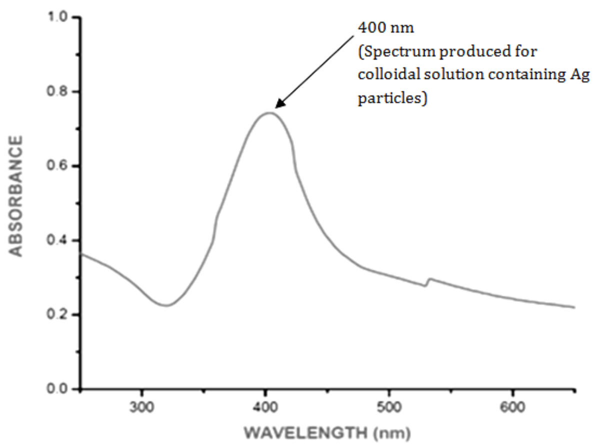

Fig. 2. UV-Vis Absorption Spectra of the Silver Nanoparticles.

It was found that, the nanoparticles are spherical in shape and has the size range of 10-20nm.The UV-Vis absorption spectra are very sensitive to the particle size and their aggregation state, the absorption peak at around 400 nm is attributed to the surface plasmon excitation of silver nanospheres, indicating the presence of silver nanoparticles in the base fluid shown in Fig. 2.

2.2 Preparation of nano cutting-fluid

Ultrasonic dispersion methods are widely used for the dispersion of nano sized materials in liquids. In the present work, silver nanoparticles were dispersed in cutting fluids using ultrasonicator. Silver nanoparticles in the volume fraction of 0.5 %, 1 % and 2 % were dispersed in the mineral oil based cutting fluid by placing it in Labman model (LMUC-2) ultrasonic bath filled with distilled water. The viscosity of the base fluid and nano-cutting fluid were determined by using Brookfield viscometer. Other important properties for lubricants such as flash point and fire point were evaluated as per standard. The details of the properties of the nano-cutting fluid were given in Table 1.

Table 1. Material properties.

Properties of Nanoparticles			
Nanoparticles		Ag (Silver)	
Size		20 nm	
Shape		Nearly spherical	
Purity		99.0 %	
Colour		Yellowish brown	
Density		0.986 g/mL^3	
Properties of base fluid			
Cutting fluid		Mineral oil based (MO)	
Colour		Brown	
Mineral oil content		58 %	
Density at 20 °C		0.96 g/cm^3	
Properties of nano-cutting fluid			
Test Sample	**Viscosity at 40 °C (mm^2/s)**	**Flash Point (^{o}C)**	**Fire point (^{o}C)**
MO+WNP	54	130 ^{0}C	140 ^{0}C
MO+0.5%Ag	56.11	133 ^{0}C	142 ^{0}C
MO+1%Ag	58.60	136 ^{0}C	145 ^{0}C
MO+2%Ag	64.5	141 ^{0}C	150 ^{0}C

2.3 Tribological test

To determine the extreme pressure and wear preventive characteristic properties of the cutting fluid samples, experiments were conducted in DUCOM TR-30 four ball tester as per ASTM D2783 [22] and ASTM D4172 [23] respectively. The test balls used in this study are 12.7 mm diameter made from AISI 52100 steel with a hardness of RC 65. The specifications of the four ball tester were given in the Table 2. The wear scar diameters (WSD) in the stationary balls were measured using optical microscope. The topography of the worn surfaces of the stationary steel balls collected from the wear preventive characteristic test were investigated by a scanning electron microscope. The EDS test was performed to detect the elements present on the wear scar surfaces. The schematic diagram of the four ball tester arrangement is shown in Fig. 3.

Table 2. Four ball tester specifications.

Test speed	300-3000 rpm
Test loads	100-10000 N
Frictional torque	0-16 N-m
Temperatures	Ambient to 120 ^{o}C
Test Ball	AISI 52100 steel

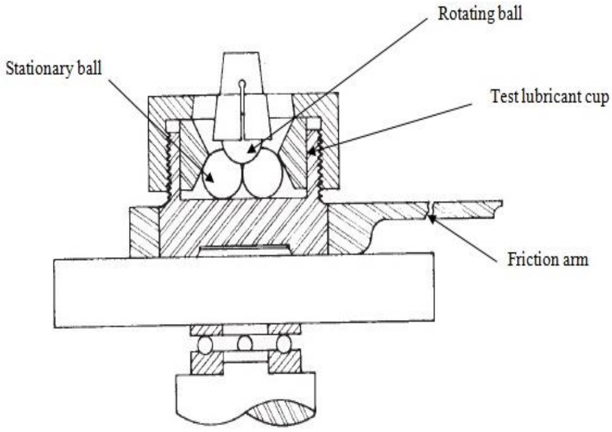

Fig. 3. Schematic arrangement of four ball tester.

3. RESULTS AND DISCUSSION

3.1 Extreme pressure properties of the nano-cutting fluid

Table 3 illustrates the extreme pressure properties of the cutting fluid samples. The wear scar diameter has been greatly diminished from the last non seizure load (LNSL) to initial seizure load (ISL) with the inclusion of silver nanoparticles to the base cutting fluid. Fig.4 shows the variation in the wear scar with respect to different load regions. At LNSL, wear scar diameter for the mineral oil without nanoparticles is 0.415 mm, whereas for the mineral oil +0.5%Ag reported as 0.398 mm. The wear scar has been significantly reduced by 6% for the mineral oil with 2 % Ag. At ISL, for mineral oil without nanoparticles, the scar diameter is 1.015 mm, whereas for the mineral oil +0.5% Ag and mineral oil +1%Ag assessed to be 0.951 mm and 0.91 mm respectively. The ear scar diameter has been diminished by 15 % to a minimum value 0.865 mm for the mineral oil +2% Ag. Figure 5 shows the wear scar diameter is a function of additive silver nanoparticles concentration in the mineral oil based cutting fluid. In all cases, the wear scar diameter increases with the increase in load due to adhesive wear.

Table. 3. Extreme pressure properties of the nano-cutting fluid.

Test sample	Last Non Seizure Load (LNSL) (N)	Average wear scar diameter at LNSL (mm)	Initial Seizure Load (ISL) (N)	Average wear scar diameter at ISL (mm)	Weld load (N)	Load-Wear index (N)	error
MO+ WNP	618	0.415	981	1.015	1236	689.4	3.168
MO+ 0.5%Ag	618	0.398	981	0.951	1236	710.1	2.425
MO+ 1%Ag	618	0.393	981	0.91	1236	726.8	2.561
MO+ 2%Ag	618	0.39	981	0.865	1236	744.9	2.347

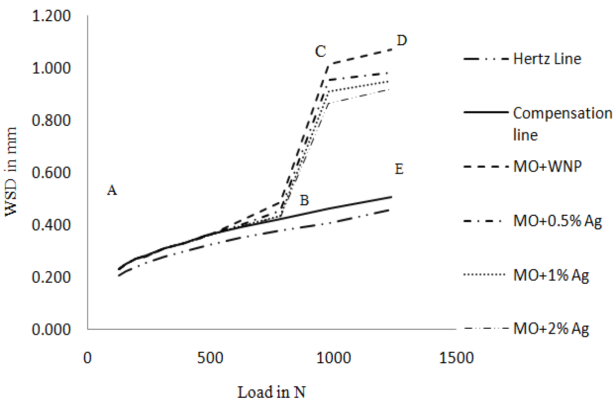

Fig. 4. Wear-Load curve of Extreme Pressure test.

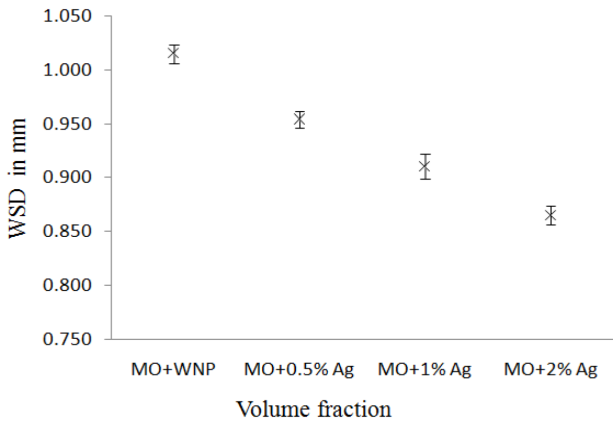

Fig. 5. Wear scar diameter -Extreme Pressure test.

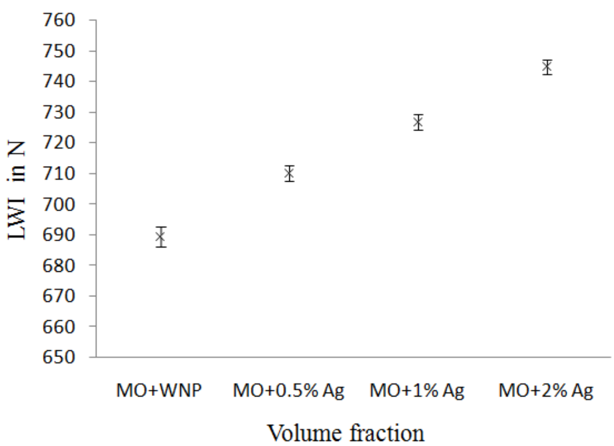

Fig. 6. Load wear index - Extreme Pressure test.

It was observed that all the concentration of nanoparticles exhibits the improvement in the reduction of wear scar diameter. Figure 6 narrates the improvement in the load carrying capacity of the cutting fluid with the inclusion of the additive silver nanoparticles. The load wear index has been increased to a maximum by 8 % for the mineral oil +2%Ag. It can be concluded that the tribological behaviour of the cutting fluid increases with the increase in concentration of silver nanoparticles.

3.2 Wear preventive characteristics of the nano-cutting fluid

Table 4 illustrates the anti-wear properties of the cutting fluid. The wear scar diameter and coefficient of friction are functions of the additive silver nanoparticles concentration in the base mineral oil and is shown in Figs. 7 and 8. The wear scar diameter is 0.64 mm for the MO+WNP, whereas for MO+0.5%Ag, MO+1%Ag, it is 0.601 mm and 0.587 mm respectively. For MO+2%Ag, the wear scar diameter reduced to a minimum value of 0.557 mm.

Table. 4. Wear preventive characteristics of the cutting fluid.

Test sample	Average wear scar diameter (mm)	error	Coefficient of Friction	error
MO+ WNP	0.64	0.004	0.38	0.008
MO+ 0.5%Ag	0.601	0.006	0.36	0.008
MO+ 1%Ag	0.587	0.004	0.34	0.011
MO+ 2%Ag	0.557	0.004	0.32	0.012

Results show that the silver nanoparticles can improve the anti-wear properties (reduce WSD) of the base fluid obviously, even at a low concentration. When the concentration of nanoparticles increases, the value of WSD decreased. The WSD of the lubricants with silver nanoparticles is reduced by 13 % maximum. The coefficient of friction is a demonstration of energy loss caused by friction. It can be seen that the friction coefficient of the MO+2%Ag nanoparticles is decreased dramatically compared to the MO+WNP with the friction coefficient of 0.38. The minimum value of friction coefficient of the mineral oil containing nanoparticles reaches 0.32 as the addition concentration of nanoparticles with 2%Ag, which indicates that the silver nanoparticles act as lubricant additive having excellent friction reducing property.

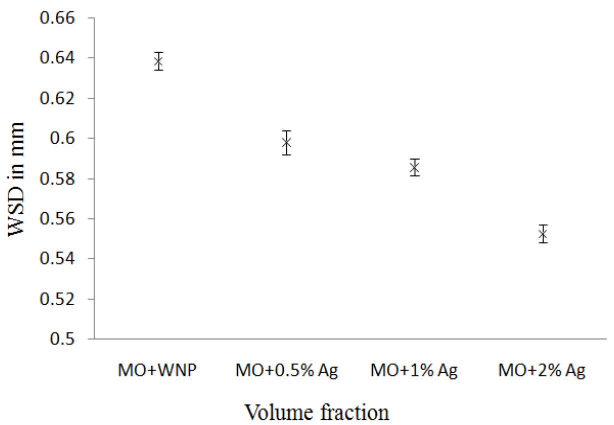

Fig. 7. Wear scar diameter - Wear preventive characteristics test.

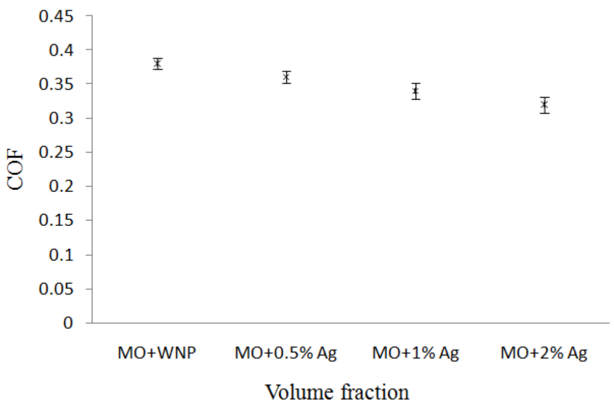

Fig. 8. Coefficient of friction - Wear preventive characteristics test.

3.3 Anti-wear mechanism of nanoparticles as cutting fluid additive

The anti-wear and friction reducing mechanism of nanoparticles as additive might be understood better due to the separation effect of nanoparticles as deposition thin tribofilm to the asperities on the contacting surface of the tribo-pairs. When lubricated with the mineral oil without nanoparticles, many asperities are in contact directly on the rubbing surface of tribo-pairs, which leads to strong adhesion and ploughing between mated asperities forms deep furrows on the worn surface are found in Fig. 9. The inclusion of silver nanoparticles into the base fluid acts as additive, leads to the formation of thin tribo-film that would be deposited on the lubricating surface, which separates apart asperities on the contacting surface and reduces the thick deep furrows on the worn surface and becomes smoother surface.

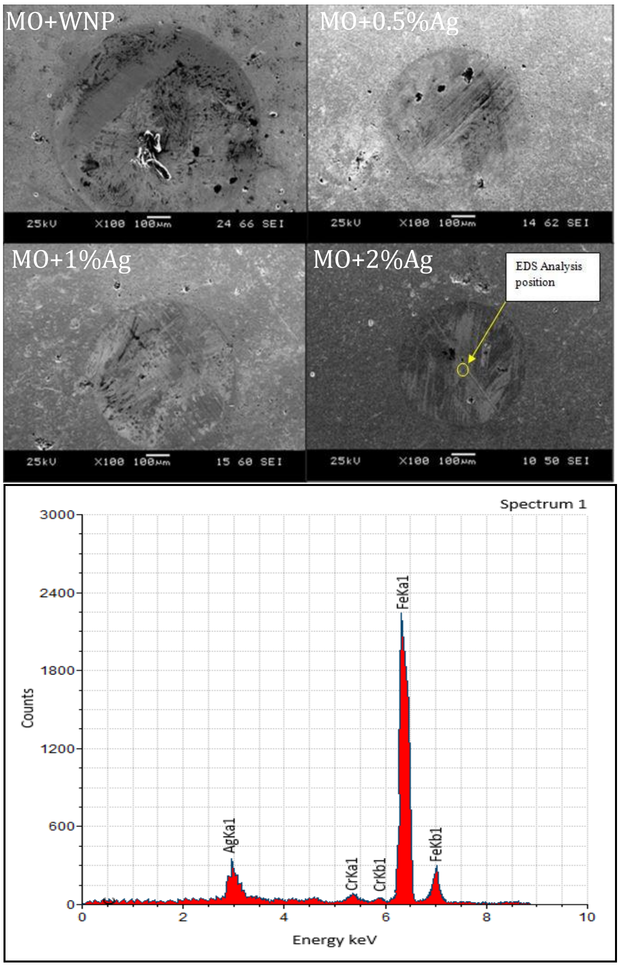

Fig. 9. SEM-EDS analysis of worn surfaces of test specimen.

It is known that the silver has low elastic modulus and hardness, when the high friction shearing force and high pressure acts at the interface would initiate the deformation of silver nanoparticles and due to the continuous shear movement the deformed particles might smear on the worn surface, leads to the formation of protective tribo-film between the asperities. The

EDS test results show the presence Ag particles in the wear surface, indicating the formation of a thin tribo-film, which contributes to the improvement of the tribological behaviour of the modified cutting fluid.

4. CONCLUSIONS

The silver nanoparticles were synthesized, characterized and dispersed in the mineral oil based cutting fluid in various proportions. Experiments were conducted in four ball tester to evaluate the extreme pressure properties and anti wear properties of the nano-cutting fluid. Based on the experiment results, it is concluded that the silver nanoparticles suits as better additive for cutting fluid by reducing the wear scar diameter to an extent of 14 % in the EP test. The load wear index of the base fluid has been increased preventive characteristic tests, the scar diameter to 8 % maximum with the inclusion of silver nanoparticles in the EP test. In the wear and coefficient of friction has been significantly reduced to a maximum extent of 13 % and 16 % respectively. All the concentration of silver nanoparticles exhibits the improvement in the extreme pressure and anti-wear properties of the nano-cutting fluid.

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Nomenclature

COF - Coefficient of Friction
WSD - Wear Scar Diameter in mm
LWI - Load wear index in N
MO - Mineral Oil based cutting fluid
WNP - Without nanoparticles
Ag - Silver nanoparticles