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Tribological Analysis of Nanoparticles Additives in Mineral oil

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Abstract – In present studies research has been done on the effect of nanoparticles of graphene and ultra-fine particles of hexagonal boron nitride on tribological properties especially wear and friction of Mineral based SAE 15W-40 diesel engine oil. Different oil samples were prepared by adding graphene and hexagonal boron nitride. Tests with different oil additives concentrations were conducted under the same conditions. Tests were conducted on a pin-on-disc tribometer. Results indicated improved coefficient of friction and wear rate on certain concentrations. The morphology of pins surfaces was analyzed using the scanning electron microscope. Worn surfaces showed improved results as compared to blank oil. The surfaces of pins were also analyzed by a surface roughness tester. By using a 0.05 wt% concentration of graphene nanoparticles in oil nearly 51% reduction in friction was observed. Similarly, by using a 0.15 wt% concentration of hexagonal boron nitride reduction in wear rate of up to 66% was observed. Optimized results were obtained by using a 0.15 wt% concentration of Graphene and a 0.05 wt% concentration of HBN. A 26.8% reduction in COF and 64.3% reduction in wear rate was observed using graphene while a 38% reduction in COF and 25.33% reduction in wear rate was observed using HBN.

Keywords – Lubrication, Tribology, Nanoparticles, Hexagonal Boron nitride, Graphene, Friction, Wear

I. INTRODUCTION

In today's world machinery needs lubrication for better efficiency and for long life. Wear and friction by the time damage the machines and make them less efficient. wear is inevitable it cannot be eliminated but it can be minimized. When two surfaces slide against each other the ups and downs of their surfaces lock with each other and resist motion between them. This resistance is known as friction, and it can be minimized by using a lubricant which slides between these surfaces to provide smooth motion. Wear is a phenomenon in which solid surfaces are degraded by the continual removal of material or by plastic deformations. It is either caused by erosion or by corrosion. Friction in transmission and axles of vehicles consumes a lot of energy. Also, friction in the piston skirt and pistons of the engine causes much energy loss. The interaction between the surfaces of the engine is minimized by using lubricant. The lubricant develops an oil film between two sliding surfaces. when the sliding speed and viscosity of lubricant decrease and load increase then, the interacting surfaces again interact with each other directly. Nanoparticles owing to their small size they can move into closed surfaces and provide good lubrication for moving surfaces. Researchers have done testing on different nanoparticles additives lubricants. GU,Caixiang et al. investigated the combined effect of ceria and calcium carbonate nanoparticles in 40CD oil. Tests were conducted on four ball tribotester. The worn surface was examined by x-ray photoelectron spectrum. Using 1:1 nanoparticles of both and 0.6% concentration optimum results were obtained. The wear spot diameter was reduced by 33.5% and COF by 32%. By tribochemical reactions the films of calcium, cerium and oxides were formed on the worn surfaces.[1] Peng DX et al studied the tribological properties of paraffin oil by using oleic acid surface-modified nanoparticles of diamond and Sio_2.Ball on ring tribotester was used. Using a little concentration of nanoparticles the tribological properties were improved as compared to pure paraffin oil. Worn surfaces were examined using SEM.[2]

Bon-Cheol Ku et al. studied the effect of fullerene nanoparticles in mineral oil on tribological properties. Extreme pressure and antiwear properties were tested on four ball tribotester. Tribological properties were tested by measuring friction coefficient and measuring friction surface temperature. The wear scar diameter decreased as viscosity increased. Using nanoadditive oil less wear was detected. When viscosity of raw oil was low and load was high difference in COF was founded. Results indicated addition of fullerene nanoparticles in raw oil improved tribological properties.[3] Zhang et al studied the effect of Cu nanoparticles with serpentine powder on CD-15W-40 diesel oil. At optimum mass ratio of 7.5:92.5 of Cu nanoparticles to serpentine maximum tribological properties were obtained. A smooth and compact tribofilm was formed on worn surfaces that reduced the wear and friction.[4] Padgurskas J et al studied the effect of Cu, Fe and Co nanoparticles on the tribological properties of Mineral oil. SEM observations indicate that Cu nanoparticle lubricant possesses most effective wear resistance. It was also noted that mixture of nanoparticle Cu, Fe and Co is more effective rather than their own.[5] Ingole et al. studied the rutile and anatase phases of P_{25} and anatase phase of Tio_2. By adding 0.25% of Tio_2 Reduced coefficient of friction was achieved. While observed through SEM and TEM uniform film of Tio_2 was deposited on the sliding surface. Results indicated that anatase Tio_2 nanoparticles have superior thermal stability as compared to P25.[6]

SM Alves et al studied the tribological properties of nanoparticles of oxides (Zno and Cuo) additives using vegetable base lubricant. The results indicated improved tribological properties due to formation of tribo-film on the worn surface. Antifriction properties of lubricant significantly improved.[7] Muhammad ilman et al studied the effect of hexagonal boron nitride and aluminum oxide nanoparticle using SAE15W40 diesel engine oil. Four balls tribotester was used for measuring COF and wear rate. Reduction in COF and wear rate was observed by adding HBN nanoparticle in comparison to with or without aluminum oxide particles. The worn surfaces were smooth and wear scar diameter was reduced after using HBN nanoparticles.[8] Xiang et al. studied the effect of Fe_3o_4 nanoflakes as lubricant additives in #40 base oil. The chemical composition of oil did not change after 48 hours. Coefficient of friction was reduced by 18.6% when 1.5% magnetite nanoflakes were used. Due to formation of tribo-chemical film on the surface the frictional properties were improved. The particle size of nanoparticles reduced due to distortion in basal planes. After worn out of film, a new film formed on the surface by tribo-chemical reactions.[9] XingliangHe et al. investigated effect of 2D alpha zirconium nanoplatelets in mineral oil.65% reduction in friction was observed when dissolved with mineral oil.[10] Qingming Wan et al investigated that Boron nitride nanoparticles have excellent tribological properties. Two tests were conducted frictional and antiwear properties were investigated by using tribo-tester. Rheometer was used for analyzing rheological behavior of lubricant oil. The 0.1 % of nanoparticles concentration was found to be optimal by comparing line roughness and friction coefficient of wear surface. The analyses of worn surface under SEM and AFM and X ray energy dispersive spectroscopy analysis of element shows good tribological properties of lubricant oil which have boron nitride nanoparticles.[11] Further study on mineral based multi grade engine oil consisting of CuO nanoparticles was done by Jatti et al. Pin on disc tribotester was used for experimentation. Tests were conducted in varying load and nanoparticles concentrations. Results indicated improved lubricating properties of oil containing Copper oxide nanoparticles. It was due to nanoparticles entered friction zone with lubricant flow. While seen in SEM worn surface was smoother due to presence of nanoparticles. From viscosity tests it was found that viscosity of oil is function of concentration of nanoparticles. By using this copper oxide nanoparticles in mineral engine oil up to 50% reduction in friction was achieved.[12] Bhaumik, S et al. Studied effect of copper oxide nanoparticles in mineral oil using pin on disc tribometer. The pin material was EN24.0.24% concentration of both Copper oxide and Graphite nanoparticles had positive effect on coefficient of friction and wear rate. There was reduction in COF about 28.5% and 70% in wear rate by using nanoparticles of copper oxide and graphite lubricant. Viscosity and flash point index also increased with increasing concentration. The worn surfaces were examined under SEM, which indicated improved surface in case of Copper oxide and graphite nanoparticle lubricant as compared to simple mineral oil.[13]

Waleed Khalil et al. studied the effect of two lubricating oils mobile gear 627 and paraffin mineral oil with multi walled carbon nanotubes. Varying concentrations (0.1, 0.5, 1 and 2 wt. %) of nanoparticles was used on fourball tribotester. The load carrying capacity, friction coefficient and antiwear properties were tested. Results indicated reduction in wear by 68% and 39% in case of MWCNT mineral oil as compared with mobile gear 627 lubricant. COF was reduced by 57% and 49% in both cases. The SEM observations showed formation of tribo layer of nanoparticles on the worn surfaces.[14] Fatima Leonor et al. studied tribological behavior of copper nanoparticles in mineral and synthetic ester base oil. The 0.3 concentration of copper nanoparticles was dispersed in both oils. Tribological tests were conducted on pin on disc tribometer. Under varying load, sliding speed and bath temperature condition tests were conducted with and without nano additives lubricants. The results showed reduction in friction coefficient and wear by using nano additive mineral oil .[15] Naveen Kumar et al. studied behavior of Ni promoted molybdenum disulfide nanosheets in mineral base oil. Four ball tribotester was used. By simple reflux technique and ultra-sonication nanosheets were exfoliated. These nanosheets had good dispersibility in solution. The 0.5% of concentration was optimum for obtaining 40-45% wear reduction and slightly improved friction coefficient about 15-20%. [16] Graphene structure evolve under friction. Studies revealed graphene layers and its interlayer distance effect its tribological properties. Higher degree exfoliation cause ordering in graphene structure and have positive effect on tribological properties. The ordering occurs in parallel with sliding direction and from its internal slippage it helps in reduction of friction.[17]

N.W Awang et al investigated Cellulose nano crystal nanoparticle as a green additive used in engine base oil to improve it tribological properties. Piston- skirt line tribometer was used to measure tribological properties under variable temperature, speed, load and concentration of nanoparticle. Worn surfaces were examined in EDS and SEM. By mixing CNC in engine oil improved properties were achieved. By using 0.1 % of CNC in engine oil lowest COF and strongest resistance against wear was observed. EDX analysis showed carbon and aluminum were in abundance in the mixture.[18] Paul,G et al reviewed the articles on graphene as an additive in lubricant. Research work on different types of nano-lubricant dispersed with graphene and its derivative are explained in detail. It includes graphene composite additives, surface functionalized graphene additive and their effect on tribological properties of conventional lubricants. The important factors responsible for improved tribological properties were found to be concentration, dispersion stability, number of layers of graphene sheets and lubrication conditions.[19] Waleed Alghani et al investigated that using (0.4wt% Tio_2 + 0.2 wt% graphene) in PBO-GII nearly 38.83% reduction in friction and 15.78% reduction in specific wear rate was observed. EDX showed the presence of nanoparticle additives on the surface of ball specimens. SEM also showed the improved worn surface as compared to blank oil.[20] Hongmei Xie et al studied the enhancement of tribological properties of water-based lubricant by using combination of Graphene/Sio_2 as an additives. Apparatus includes ball-on-plate tribo-tester and two high rolling mills. Using 0.1 wt% Sio_2 and mixing 0.4 wt% graphene in water produced best results. Nearly 48.5% reduction in friction and 79% in wear volume was observed. From TEM it was seen that Sio_2 acted as a pillar between layers of graphene and prevented the assembly of graphene layers. This combination additive lubricant decreased the rolling force in magnesium alloy rolling and provide smooth surface in production of magnesium alloy.[21]

The COF was reduced by 33-36% when graphite nanoparticles of size 20-40μm were used in SAE15w-40 oil. Oil stabilization was done by magnetization stirrer and ultrasonic technique. The oil sedimentation didn’t occur after the period of 30 days. There was reduction in temperature nearly 6-7% while testing graphite nanoparticles in lubricant.[22] Majeed et al. studied the effect of exfoliated nano-graphene and iron oxide in paraffin oil on tribological properties. For testing four ball tribotester was used. Nanoparticles of varying concentrations 0.4%, 0.8% and 1.2% were added in paraffin oil of 400g. Size of nanoparticles was

10nm. Viscosity of lubricant increased about 0.29% and 0.08% in both XGnp and Fe_2o_3. when (40-100)^{0}C temperature was increased. By adding 0.4% and 0.8% of nanoparticles about 24.45% and 38.60% wear scar diameter reduction achieved. By increasing temperature continuously viscosity increases which further decreases wear and friction.[23] Charoo and Hanief analyzed graphite, hexagonal boron nitride and tungsten disulfide nanoparticles in SAE 20W50 oil. The concentration of nanoparticles was 0.5% by weight. Results indicated that hexagonal boron nitride reduced friction and wear most as compared to other combinations. The Raman spectroscopy revealed that presence of these nanoparticles on the worn surface after it had been washed with acetone.[24] Furthermore, Vats and Singh studied effect of ODA nanoparticles of graphene oxide in mineral based paraffin oil. Tests were conducted under varying load and 0.2% concentration of nanoparticles in lubricant. Results indicated improved friction, anti-wear and dynamic viscosity. Raman spectroscopy showed presence of ODA graphene nanoparticles on worn surface. COF was reduced by 75%.[25] Kong et al studied the effect of graphene size and thickness on lubricant tribological properties. It was found that using multi-layer graphene and small particle size has significant effect on reduction of friction of lubricant. Through SEM analysis it was inferred that using small particle size and multilayer graphene, smooth surfaces were observed as compared to samples of pure lubricant. Tests were conducted on ball on plate tribotester.[26] Guimarey et al investigated the effect of two engine oil additives (graphene and molybdenum disulfide) on tribological properties. The tests were conducted on two configurations ball-on-plate and rotational ball on three pins. On using 0.10 wt% and 0.20 wt% graphene 20% friction reduction and 22% reduction in wear was observed. While using 0.05 wt% of MSNP reduction in wear scar of 42% in width while 60% in depth was observed. The results were also justified by analyzing the specimen using Scanning electron microscope and 3d profiler.[27]

Sangharatna Ramteke and H Chelladurai studied hexagonal boron nitride nanoparticles effect on tribological performance of 20w-40 engine oil. 1 wt% of HBN was found to be optimum for wear reduction in cylinder liner and piston rings of engine. Surface roughness analysis also revealed that using 1% wt of HBN additive in SAE20W-40 oil was better as compared to conventional oil.[28]

Suprakash Samanta and Rashmi R. Sahoo studied tribological performance of covalently linked HBN and Graphene oxide nanocomposite as an additive in paraffin oil lubricant. Using 0.5 wt% of this HBN/GO nanocomposite lubricant in paraffin oil, reduction in COF of 50.7% was achieved. Wear rate was also very low as compared to base oil. Post surface analysis showed the presence of tribological layer on the wear track which was responsible for the protection against the wear and reduction in COF. This nanocomposite additive has application in load bearing lubrication.[29]

Sangharatna M. Ramteke and H. Chelladurai studied the impact of HBN nanoparticles on wear, performance and emission characteristics of diesel engine oil. Different oils were formulated using 0.5 wt%, 0.75 wt% and 1 wt% concentrations. 1 %wt concentration formulated oil was quite stable and upon testing it indicated improved COF and Wear.[30]

Mousavi et al work was on nanoparticles of Zno as an additives in diesel engine oil. Three concentrations (0.1%, 0.4%, 0.7%) of additives were used to formulate new lubricants and they were tested on pin-on-disc tribo-tester. Worn surfaces were characterized by scanning electron microscope. On 0.7% concentration wear in pins was decreased by 86% and pour point reduced by 15.2% as compared to conventional diesel oil. Viscosity of lubricant at 100^{0}c raised by10.14%.[31]. A group of researcher studied the effect of carbon nanotubes as an additive in mineral oil and nanoparticles of carbon coated nickel and nickel oxide in SAE 5W-30 mineral-based engine oil. Using 0.5 wt% nickel oxide as an additive in oil. Friction reduction was maximum upon testing. Combinations of nickel oxide and carbon coated nickel also produces improved tribological properties as compared to conventional oil. Carbon nanotubes also served as a friction modifier for the mineral oil-based lubricants.[33],[32]

Saini et al studied different carbonaceous nanoparticles of graphene multilayer morphology, Graphite spherical and multiwall carbon nanotubes. To know their tribological properties in mineral oil, different mineral oils were prepared with 1% dispersant and increasing nanoparticle concentration form (0.5%-4%). The tribological properties were tested on 4 ball tribotester. Oil stability was observed visually. Graphene displayed excellent results with increase in antiwear ability up to (41-50)% after it nano graphite was second best.[34] The group of researchers reviewed and compared the different nano-additive-lubricants. The MoS_2 additive performed well in SAE 50 oil. Tio_2 nanoparticles were useful for reducing friction in SAE 10w-30 oil.[35] Jason et al studied effect of addition of graphene in mineral oil 15W-40. Various concentrations of graphene were used but on 0.05% reduction in COF of about 12.24% and in wear about 5.14% was exhibited. Through SEM and EDS analysis it was observed that surface of worn balls was enhanced using graphene nanoplatelets. Formation of protective film on sliding surface protected the surface from wear and by the polishing effect of graphene friction was reduced.[36]

Harsh Gupta et al studied the tribological properties of engine oil when 0.5%wt, 1.0 %wt, 1.5 %wt and 2.0 %wt) concentrations of Cuo nanoparticles were blended in engine oil. Pin on disc apparatus was used for testing and it was found out that on adding 1.0 wt% of Cuo nanoparticles in engine oil a significant reduction in COF and in wear was noticed. Due to presence of nanoparticles in oil its viscosity decreased.[37] Nanoparticles of ZDDP, NiO and MoS_2 were used as additive in SAE15W-40 mineral based oil. 1% concentration of additives was found optimum for wear and friction reduction. Load carrying capacity of lubricant increased by 25% and wear 16%.[38] Ashwani Kumar et al studied the tribological properties of used SAE15W-40 engine oil by adding graphene nanoparticle as an additive in it. The results after testing on pin-on-disc tribometer indicated improved Coefficient of friction and wear as compared to unused oil. The life of oil was enhanced using graphene nanoparticles as an additive in used SAE15W-40 oil.[39]

Singh et al investigated tribological properties of graphite nano-flakes and graphene nanoplatelets as an additive in SAE 15W-40 engine oil. It was found using 0.1% of GNP+SAE15W-40 oil mechanical efficiency of engine enhanced by 2% and by using 0.1% GNF+SAE15W-40 oil 1.4% mechanical efficiency was improved. On analysis of piston ring, the wear also reduces by significant value using 0.1% GNP +SAE15W-40 oil. It was due to presence of tribo-film on the wear track which caused reduction in wear and surface roughness.[40]

So mechanical efficiency, fuel saving, friction, wear and environmental toxic emission concern can be solved by using appropriated additives in lubricant for better and long-life performance of machineries.There are a lot of studies on nanoparticle additives in lubricant for improving tribological properties. However, there are number of nanoparticles which need to be tribologically investigated for mineral oil. In present study there will be work on nanoparticles of multilayer graphene and hexagonal boron nitride in SAE15W-40 mineral oil.

II. Materials and Method

A. *Apparatus Used for Experimentation*

The pin on disc tribo-tester Koehler K93500 was used for testing of formulated new lubricants. Disc is made of EN31 material and hardness of 58-60 HRC. The Chemical composition of disc is C (0.9-1.2%) Mg (0.3-0.75%) Si (0.1-0.35%) Cr (1-1.6%) S 0.05% and P 0.05%. The diameter of disc is 165mm and thickness is 8mm. The disc speed range of apparatus is between 50 to 2000 rpm and sliding speed range between 0.26 to 12 m/s.

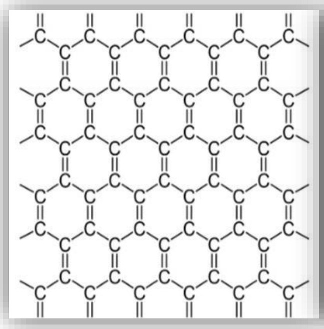
Fig. 1 Koehler k93500 Pin on disc tribo-tester

B. *Selected Lubricant and Additives*

The lubricant selected for experimentation was Delo gold ultra-SAE 15W-40 mineral based diesel engine oil made by Caltex. Four liters oil was used for testing. The additives include nanoparticles of graphene 1-40 nm in size, product of Carbongate technologies and ultrafine particles of hexagonal boron nitride made by Microlubrol, 0.5μm in size on average. Purity of graphene was greater than 85% while that of HBN was 99%. Both has nearly same structure in graphene carbon atoms are bonded by covalent bond with each other and form honeycomb structure. In HBN, B and N atoms are alternatively arranged with covalent bond to from honeycomb structure.

Table 1. Properties of additives

Properties	Graphene	HBN
Size	<3nm	0.5μm
Purity	85%	99%
Made by	Carbongate technologies	μmicrolubrol



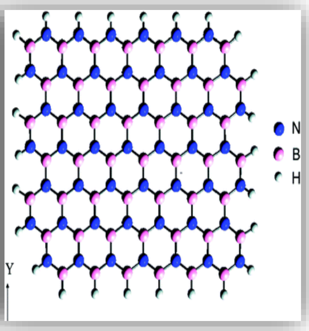


Fig. 2 Graphene structure.[41] Fig. 3 HBN structure [42]

C. *Preparation of specimen*

The mild steel round rod specimen was prepared by lathe machine. The size of specimen is 9mm in diameter and 25 mm in length. Nine such specimens were prepared for testing. These specimen surfaces were first cleaned by sandpaper then they were washed by acetone.

Fig. 4 Mild steel specimen

D. *Formulation of new lubricant*

Seven different lubricants were formulated by adding different concentrations of additives of HBN and Graphene. Firstly, additives were weighed on weighing balance and then they were mixed in 500 ml of SAE-15W-40 oil. Afterwards, it was shaken well before putting it on magnetic stirrer for one hour on 1150 Rpm. The capsule of magnetic stirrer was washed with acetone before use to avoid impurities.

Fig. 5 Dispersed oil after one day

Then beaker was covered with lid and left for one day to observe sedimentation. After one day the particles didn't settle down so much. The compositions of seven lubricants are following in table 2.

Table 2. Formulated lubricants with percentage concentration of additives.

Sr. no	Wt% of Graphene	Wt% of HBN
1	0.05	0
2	0.15	0
3	0	0.05
4	0	0.15
5	0.15	0.15
6	0.15	0.35
7	0.35	0.15

E. Experiment conditions and parameters

The ASTM G99 standard for wear test was adopted for the testing of wear and friction of new formulated lubricants. The specimens were washed with acetone and dried prior to testing. Following were the test parameters for the experimentation shown in table 3.

Table 3. Fixed parameters for testing

Parameter	Value
Load	45N
Pin dia	9±0.5mm
Trak radius	40mm
Disc speed	400±5 Rpm
Temperature	35±1deg C
Sliding distance	1005m
Specimen	Mild steel

F. Methodology and Experimentation

Placed the specimen pin between the jaws and adjusted the height of the pin with respect to the disc utilizing the thumbscrew provided on the specimen holding plate. Track radius of 40 mm was set by adjusting slider scale assembly. Applied the 45N weight on the hanger of the loading lever. Apparatus was calibrated using Pin on disc tester application. In calibration mode observe the value of LVDT voltage while tightening the LVDT lock screw by using thumb nut. When LVDT voltage value reaches near to zero then press tare button of both wear and friction. Set the test time in the control panel to 10 minutes. Pour the formulated lubricant in the lubrication tank. Input the test parameters in pin on disc tester software. Wear and friction in software should also display zero before starting. Apparatus is started by start button on control panel. After that speed of rotating disc was set to 400Rpm. After 10 minutes tester automatically stops. After completion of test, specimen was removed from the specimen holder.

III. RESULTS

A. Friction Analysis of Formulated Lubricant

The seven formulated lubricants were tested on tribo-tester. Four tests were conducted by adding one additive at a time in blank oil. While other three were conducted by mixing both additives HBN and Graphene. Results in shape of graph of first four test is shown below in Fig 6. It is observed that COF reduces significantly when 0.05% concentrations of HBN and graphene were added in blank oil. By taking average value of COF, it is noted that nearly 51% reduction in friction was observed by using 0.05% graphene nanoparticles. It was due to the honeycomb 2D structure of graphene layers, which are less than 3nm in thickness so they can enter in small interfacial crevices. These graphene nanoplatelets have polishing effect on the interfacial surfaces so friction is reduced due to easiness in sliding by polished surfaces. Another graph Fig 7 is shown below explains the effect of concentrations of additives on the COF of blank oil. The other three test results in which mixing of additives has been done are shown in Fig 8. In these results, the mixture of 0.15% of HBN and 0.15% of Graphene showed improved COF as compared to other concentrations. Nearly 36% reduction in COF was observed.

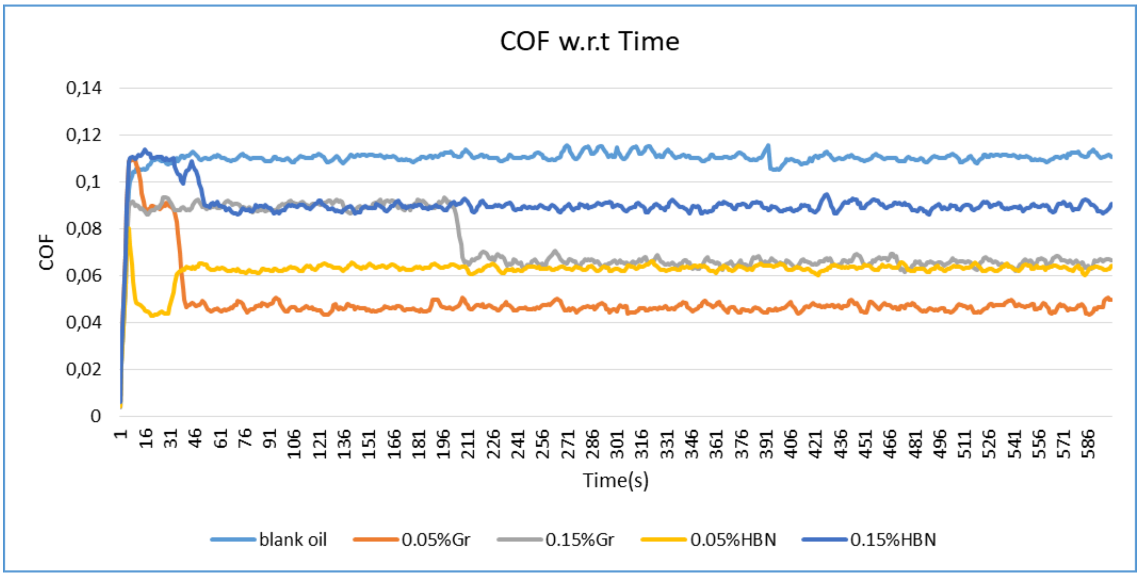


Fig 6. Graph showing COF with respect to time of different formulated lubricants

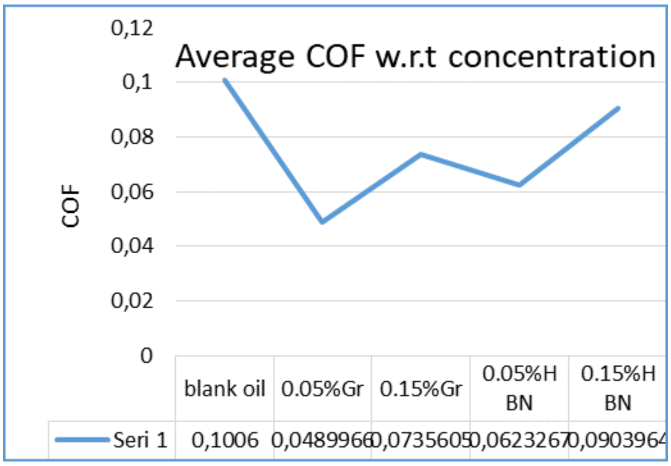


Fig 7. Comparison of Average COF obtained using different samples of formulated oils

The graph shown in Fig 9 describe about the effect of the percentage concentrations of mixed additives on COF of blank SAE15W-40 oil. From graph it is observed that mixture of concentration of 0.15%HBN and 0.15% Graphene showed reduction in COF while mixture of 0.35% Graphene and 0.15% HBN showed second best result in minimizing COF.

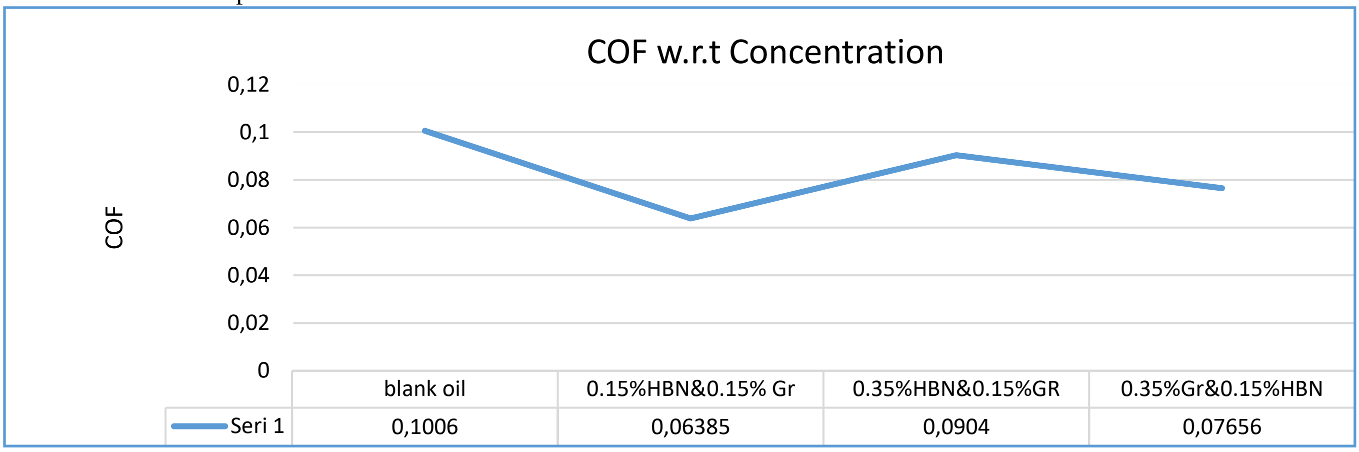


Fig 8. COF graph of mixed additives formulated lubricants with respect to time

B. *Wear Analysis of Formulated Lubricant*

The wear results obtained in the form of graph (Fig 10) from pin on disc tester software for the four test which were unmixed are following. From this graph It is observed that by using 0.15% of HBN in blank oil the wear rate noted was minimum. Second best wear result was from 0.15% graphene additivated lubricant. Another graph (Fig 11) showing below relates wear rate with concentrations of additives in blank oil. In this graph it is observed that wear rate was reduced by 66% using 0.15% of HBN. While using 0.15% graphene reduction in wear rate up to 64% was observed.

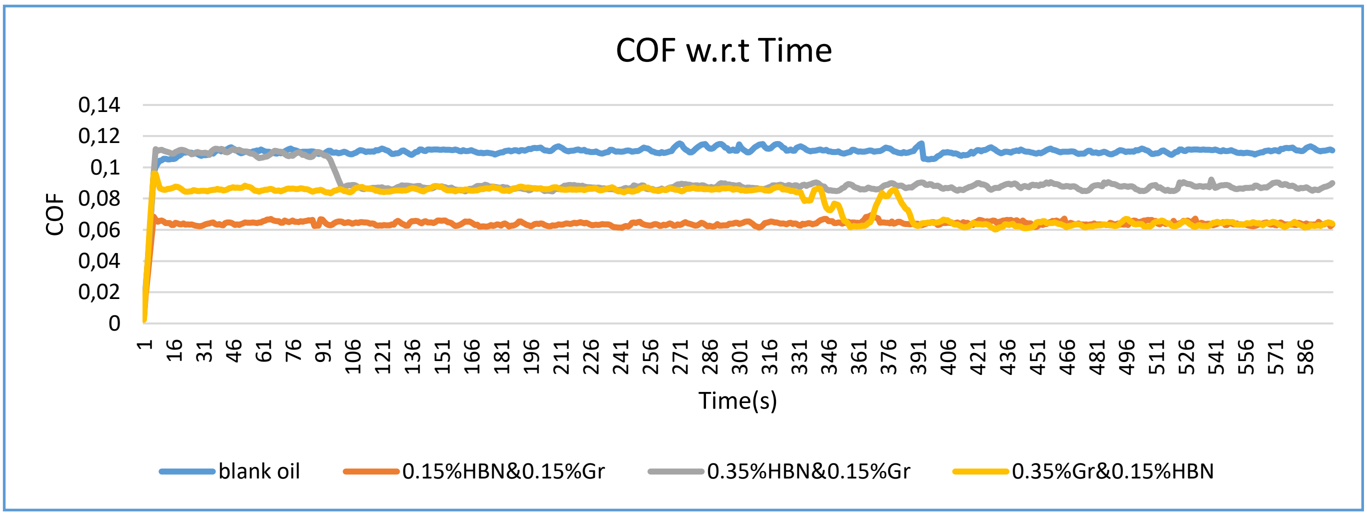


Fig 9. Average COF of mixed additives formulated lubricant on different concentrations.

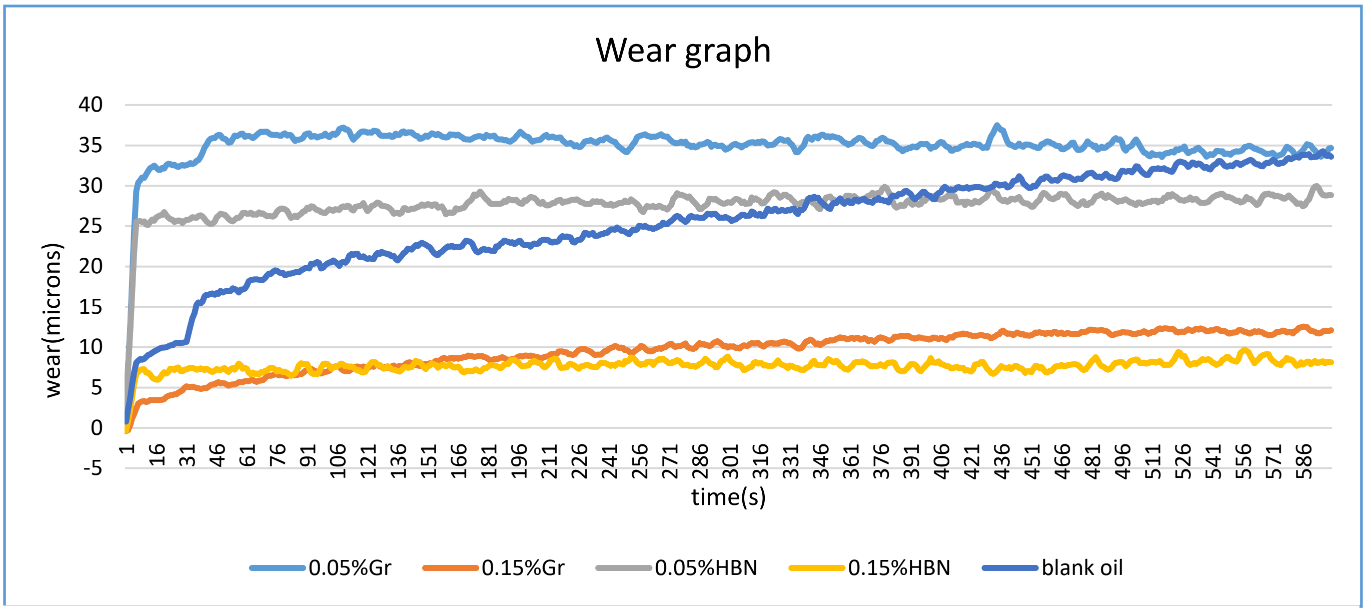


Fig 10. Wear graph of four formulated lubricants with respect to time

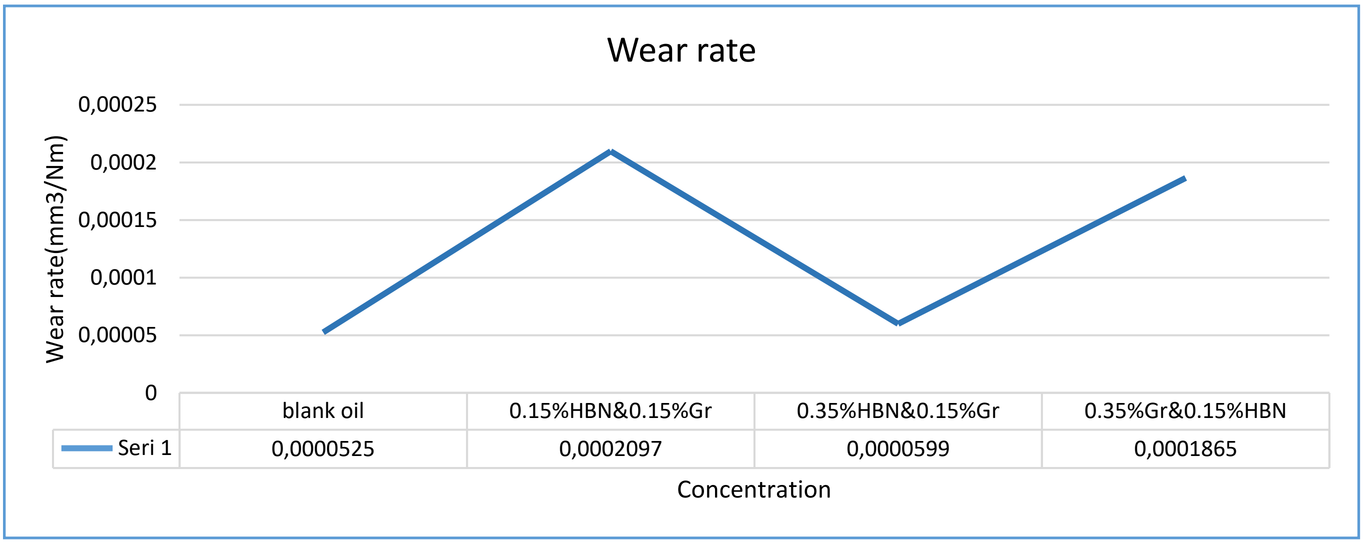


Fig 11. Wear rate of formulated lubricants

The wear results of three tests which were carried out by mixing both HBN and graphene additives in the form of graph (Fig 12) are given below. From this graph its observed that only by mixing 0.35%HBN and 0.15%GR containing lubricant showed wear nearly same as that of blank oil.

There is another graph (Fig 13) which explain how wear rate is affected by different concentrations of the additives in blank SAE15W-40 oil after testing. From this graph it is observed that only wear rate of 0.35%HBN and 0.15% Gr additives containing lubricant was nearly equal to blank oil. All other concentrations increased the wear rate.

C. SEM Analysis

The mild steel specimen pins were analyzed using Scanning electron Microscope. The SEM has great magnifying power which can magnify an image up to nanometer with good detail. The surfaces of specimen were examined for topographical and microstructure analysis.

Three specimens were selected for analysis. These include a specimen on which blank SAE15W-40 oil

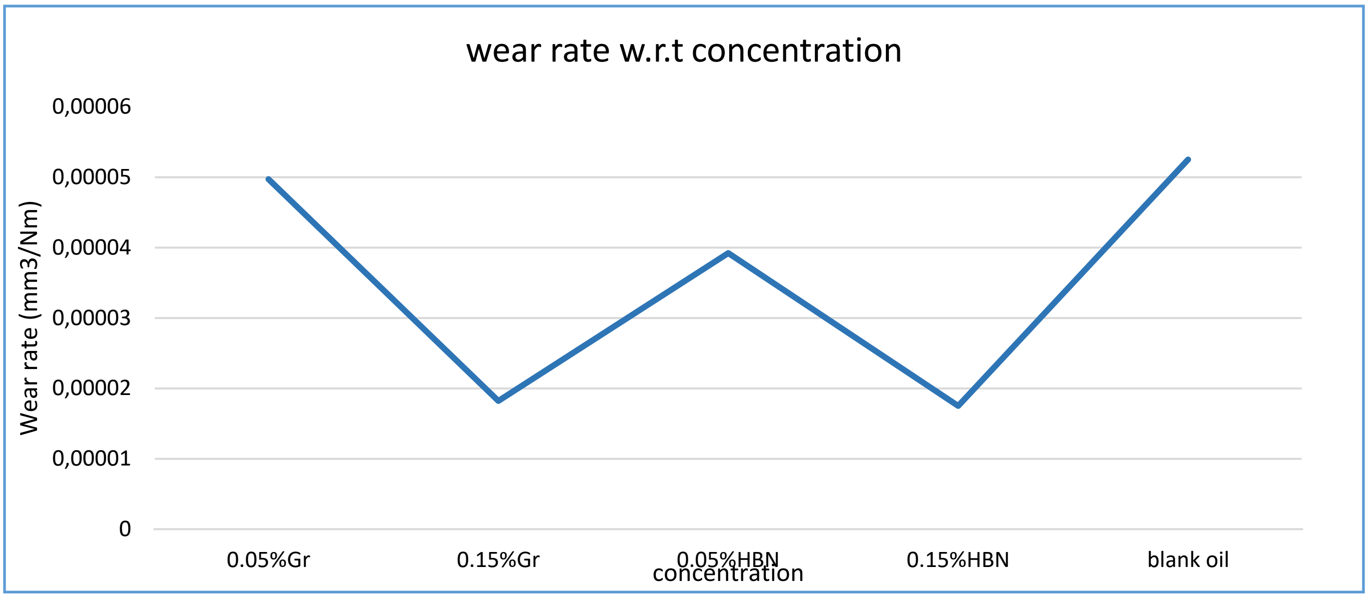


Fig 12. Wear graph of mixed additive lubricant with respect to time

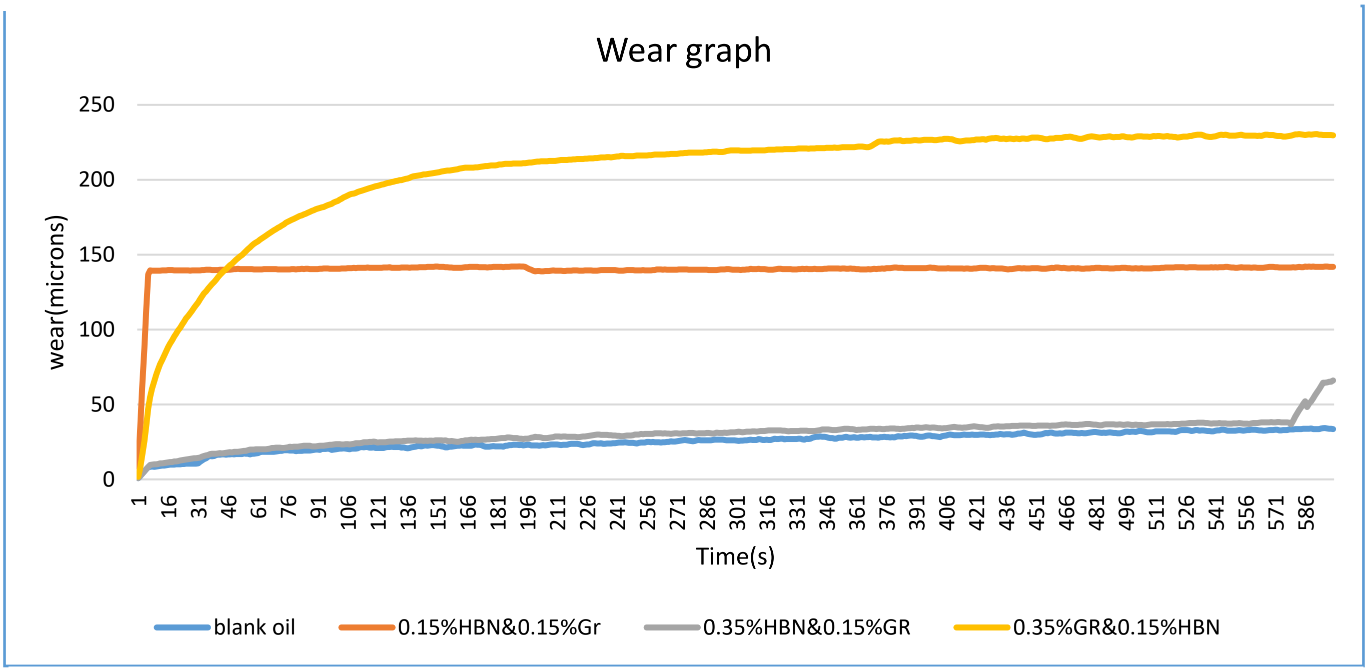
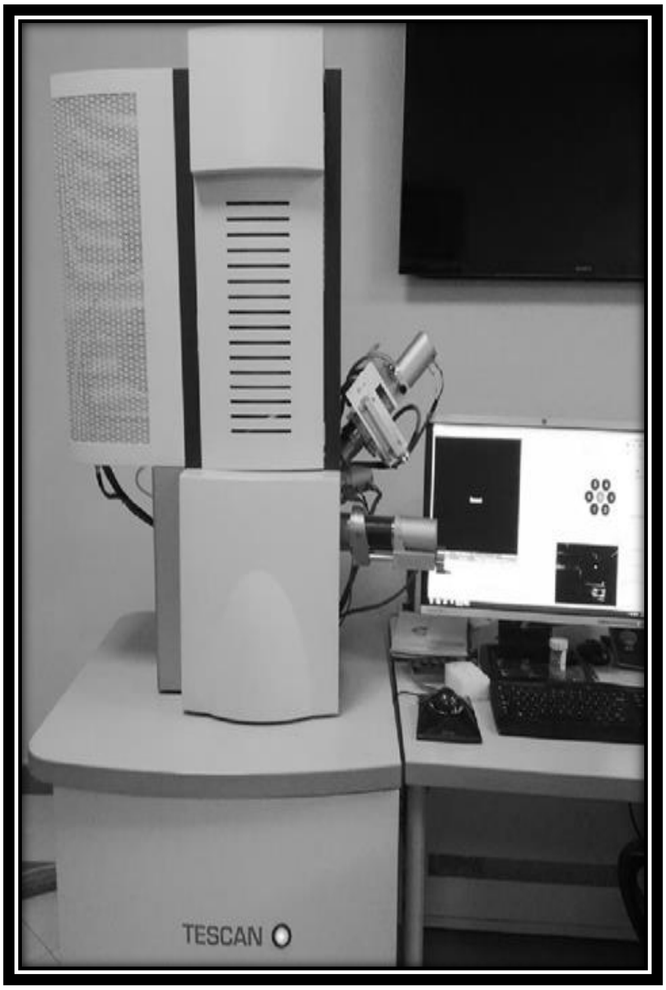


Fig 13. Wear rate of mixed additives formulated lubricants

was tested. Other two specimens were those on which best results were obtained through software. One on which wear result was best and another on which COF was best was selected. The SEM images of these three specimen were analyzed on 250x and 500x magnifications. Only 250x magnification images are shown here in (Fig 15,16,17).



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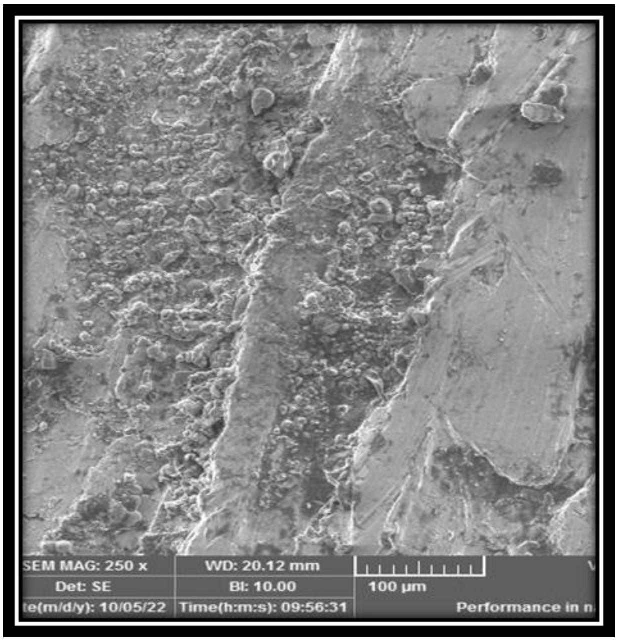


Fig 15. Blank oil pin SEM image on 250x magnification

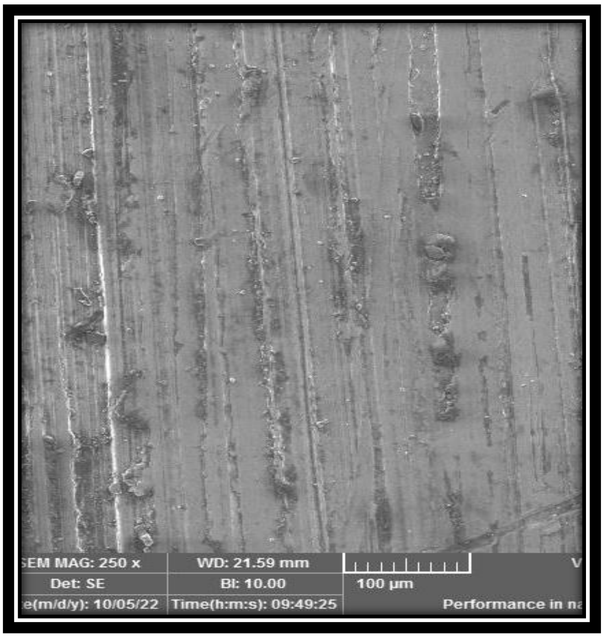


Fig 16. 0.15%HBN pin SEM image on 250x magnification

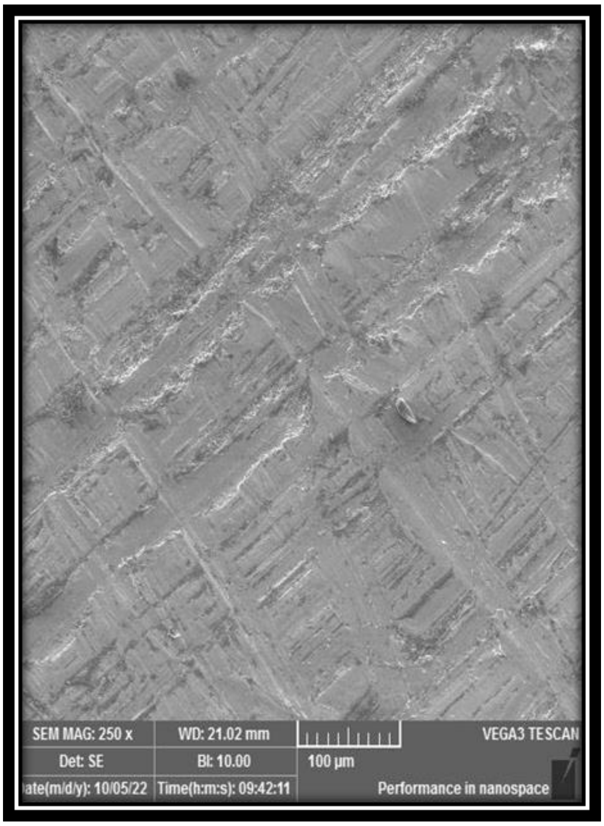
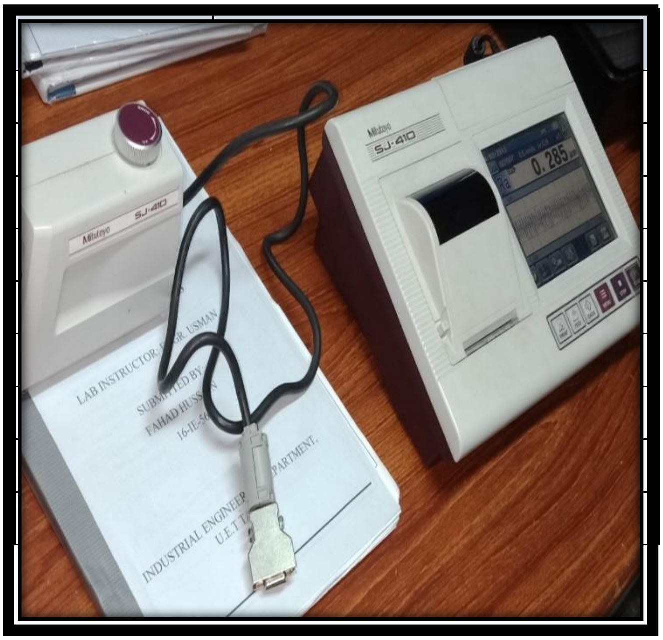


Fig 17. 0.05%Gr pin SEM image on 250x magnification

From these images it can be seen that 0.05% Graphene pin sample and 0.15% HBN pin sample has smoother surface as compared to blank oil. It was due to ductile behavior of HBN which spread over surface easily and prevents wear and polishing and mending effect of Graphene. Which protected the surface form wear and caused less friction. As it spread easily and interlaminar shear

slip between layers of graphene caused reduced friction. There are little plastic deformations and wear debris in these formulated oil specimen pins as compared to blank oil specimen.

Table 4. Specimen samples and concentrations of additives.



D. Surface roughness analysis

Fig 18. Surface roughness tester Mitutoyo SJ-410

The mild steel specimens were also subjected to surface roughness analysis for qualitative analysis. The nine specimens were examined using portable surface roughness tester Mitutoyo SJ-410.

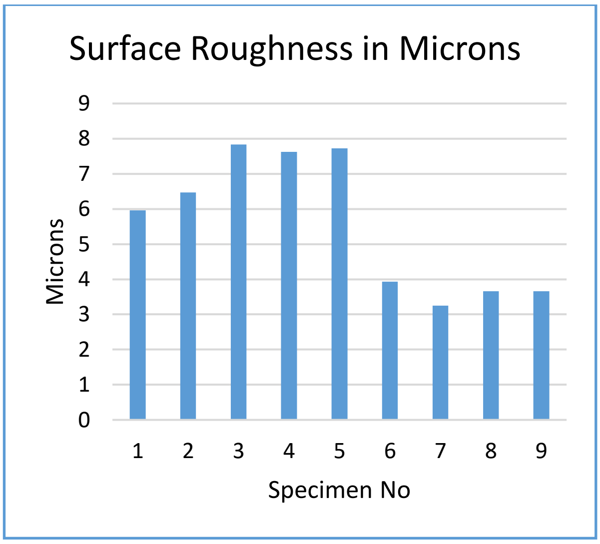


Fig 19. Graph showing average surface roughness of pins on different samples

The table 4 shows the specimen no and % concentration of additives used for testing of specimen on pin on disc tribo-tester

From figure 19 it is observed that on using blank SAE15W-40 oil surface roughness increased a little from untested specimen roughness. Similarly, surface roughness also increased in case of specimen 3,4 and 5. It was due to excess amount of additives in oil which agglomerated and caused increased wear. However, in case of specimen 6,7,8 and 9 surface roughness decreased. It was due to polishing effect of graphene and wear resistance and ductile property of HBN. Which spread over surface easily and prevent wear.

IV. DISSCUSION

From this study, it is revealed that nanoparticles of graphene polish the contact surfaces to provide a smooth surface and provide compensation for mass loss due to wear. 0.05 wt% graphene additivated lubricant had Low COF and 0.15 wt% additivated HBN lubricant had a low wear rate.

These experiments were conducted on 0.05 wt% and 0.15 wt% concentration by weight. Due to the limitation of sources and time, further tests have not been done. Better results are expected for concentration in between 0.05 wt% and 0.15 wt%. Using smaller particle size will also have impact on tribological properties of lubricant.

Furthermore, the experimentation could be done on varying different parameters like Rpm, loading and operating temperature. For knowing the behavior of lubricant on different conditions.

Graphene performed better in reducing COF while HBN performed better in reducing wear. Some other additives might have equally good antiwear and antifriction properties. There is still a need to find better and cheap additives for environment-friendly lubricants.

From the findings of this study, it is imparted that these new lubricants will perform better with reduced COF and wear rate. The life of machine will elongate, maintenance cost will also reduce and smooth operation with low friction and wear will be achieved. This Research work can be extended by varying test parameters including load, temperature, Rpm, track diameter, disc material and pin specimen material and geometry type.Further, viscosity analysis is required to explain the effect of additives concentration on viscosity of formulated lubricant on different temperature ranges. Moreover, find on what viscosity and what temperature wear and friction of formulated lubricant are minimum. Further research work can be done on load carrying capacity of these nanoparticle additives on different concentrations. These additives are not tested on other bio-based lubricants. There is a need to study their effect on tribological properties of other lubricant as well. The drawback of nano lubricants is that they need to be dispersed because they agglomerate with time which causes more friction and wear. By using a suitable surfactant or surface modification of additives the problem of this dispersion stability can be solved.

V. CONCLUSION

From this study following results and observations are concluded.

- By using 0.05% of graphene in SAE15W-40 engine oil nearly 51% reduction in COF was observed and by using 0.15% of HBN nearly 66% reduction of wear rate was observed. It was due to the polishing and mending effect of graphene nanoplatelets and wear resistant and ductile behavior of HBN particles
- By using 0.15% of graphene 26.8% reduction in COF and 64% reduction in wear rate was observed similarly using 0.05% of HBN, 38% reduction in COF and 25% reduction in wear rate was observed. So, for reduction in COF 0.05% graphene is best and for reduction of wear rate 0.15% of HBN additive is best. For the reduction of both wear rate and COF 0.15% of graphene and 0.05% of HBN are greatly beneficial.

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