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RESEARCH

Tribological Properties of IF-MoS_2 Nanoparticles as Lubricant Additive on Cylinder Liner and Piston Ring Tribo-pair

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A B S T R A C T

Friction and wear behaviors of different concentrations of IF-MoS_2 nanoparticles in SAE 20W40 were studied. First of all tribological tests with SAE 20W40 + IF-MoS_2 were carried out on a four ball wear test machine as per ASTM D 4172 standard to study its wear properties. Detailed friction and wear studies on cylinder liner and piston ring tribo-pair were conducted on pin-on-block universal tribometer under lubricated conditions of SAE 20W40+ IF-MoS_2. These experimental studies were conducted at different operating parameters to ascertain the influence of nanoadditive on friction and wear of cylinder liner and piston ring tribo-pair. A minimum coefficient of friction of 0.0772 was observed for 0.5 wt% of IF-MoS_2 at normal load of 100 N at sliding velocity of 0.03 m/sec. A substantial reduction of 65 % in the wear of cylinder liner and piston ring tribo-pair was also observed when lubricated with SAE 20W40 and 0.5 wt% of IF-MoS_2. Scanning electron microscopy and energy dispersive spectrometry analysis of the worn out surfaces was also carried out to find the causes for observed friction and wear behavior.

1. INTRODUCTION

Lubricant performs a number of critical functions; it includes lubrication, reduction in friction and wear, cooling and protecting metal surfaces against corrosive damage. Most of the lubricants that are produced from mineral oil don't have all the desired tribological properties. It has already been established that addition of solid lubricant particles, such as, MoS_2, h-BN, WS_2 and IF-MoS_2 to mineral oil improves the tribological properties of lubricants to a large extent [1-11]. In these research studies, it has been observed that MoS_2 nanotubes and other nanoparticles mixed with lubricating oil possess better friction and wear reducing properties, as compared, to the base oil, depending on the contact conditions. Extensive research in open literature reported that addition of nanoparticles in particular concentration and size show excellent friction and wear reduction characteristics [12-18]. The piston ring and the cylinder liner tribo-system of an internal combustion engine is always point of interest for tribologists, for being a significant source of friction losses in engines. Power loss, efficiency, fuel consumption, wear, emissions, and cooling are affected by the piston ring-cylinder liner interface lubrication. The reduction of wear and friction losses in an internal combustion engine is a function of good lubrication. Studies of the mechanism of piston ring lubrication and related friction phenomena have found that piston rings and cylinder liner contribute significantly to the total engine mechanical friction losses [19-21]. In general, high friction occurs at, or near, dead centers, *i.e.*, at top dead centre and bottom dead centre due to boundary lubrication. This condition is further aggravated at top dead centre due to the presence of higher temperature. Therefore, reduction of friction and wear of cylinder liner and piston ring assembly is essential not only for increasing life of the IC engine but is also beneficial for reducing fuel consumption and emissions.

It is evident from the above literature review that addition of particular concentration of nanoparticles to the conventional lubricant reduces the friction coefficient and increases the wear resistance. Researchers used different forms of MoS_2 as lubricant additives, *i.e.*, micro particles, nanoparticles and nanotubes. However, very little research has been carried out to study the effect of IF-MoS_2 in conventional lubricants in practical application, such as, piston ring and cylinder liner tribo-pair in an IC engine.

In this article, two prong approach was adopted to ascertain the effect of various concentrations of IF-MoS_2 as lubricant additive on a piston ring and cylinder liner tribo-pair of an IC engine at various sliding speeds and loads. In the first set of experiments the effect of IF-MoS_2 as additive was studied using a four ball wear test machine. In the second set of experiments the effect of the IF-MoS_2 nanoparticles as additive was studied on actual tribo-pair using a universal tribotester.

2. EXPERIMENTAL DETAILS/PROCEDURE

2.1 Preparation of lubricant

In these tribotests, IF-MoS_2 nanoparticles with a diameter of 50 nm were used, which were mixed with the engine oil SAE20W40 in different concentrations. The commercially available engine oil grade SAE20W40 and molybdenum disulphide (IF-MoS_2) were procured from the commercial source. The IF-MoS_2 nanoparticles black in color with density of 4.2 g/cm^3 and melting point of 1180^o C were added in base engine oil of grade SAE20W40 in different concentrations (weight % 0.5, 1.0 and 1.5). The nano IF-MoS_2 mixed engine oil was kept in a test tube and stirred for 4 hours using WENSAR ultrasonicator at a temperature of 50 ^{o}C and frequency of 40 kHz. The properties of the SAE20W40 engine oil are shown in the table 1. There was no significant change observed in the physical and chemical properties of the lubricant SAE20W40 with the addition of 0.5, 1.0 and 1.5 wt% IF-MoS_2 nanoparticles. These properties include viscosity, flash point and pour point. Short tube and cone on plate viscometers were used to measure the kinematic and dynamic viscosities of the lubricant respectively. ASTM D97 and ASTM D92 standards were used to measure the pour point and flash point of the lubricant respectively.

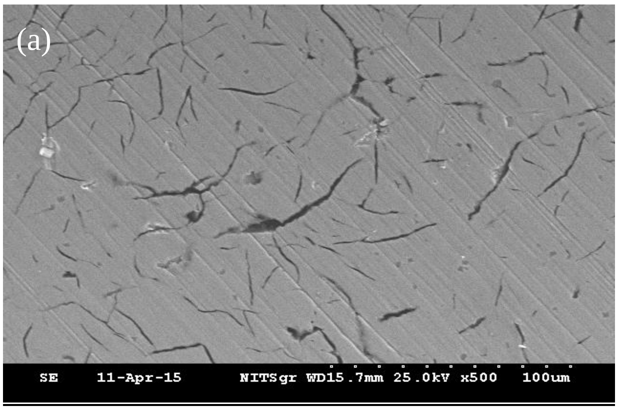
Table 1. Properties of lubricant oil grade SAE20W40.

Kinematic viscosity	40 °C 100 °C	116 mm^2/s 15.1mm^2/s
Viscosity index		135
Dynamic viscosity	-10 °C	2800 m Pas
Density	15 °C	879 kg/m^3
Flash point		236 °C
Pour point		-30 °C

2.2 Preparation of sample

For conducting experimental studies on universal tribometer, cylinder liner and piston ring pin was used as tribo-pair. Cylinder liner and piston ring were obtained from a used heavy duty diesel engine. The material for the liner is grey cast iron of G-4000 grade with density of 7.15 gm/cm^3 and other constituents as Carbon: 3.0-3.5 %; Silicon: 1.80-2.80 %; Manganese: 0.70-1.0 %; Copper: 0.20-0.50 %; Sulphur: 0.15 %; Phosphorus: 0.07 %; The cylinder liner was cut in rectangular block of dimension 45 mm X 25 mm and the piston ring was cut in 3 mm X 4 mm with 6 mm length. The material for the pin is steel with other constituents as Carbon: 0.8-0.95 %; Silicon: 0.35-0.50 %; Manganese: 0.25-0.55 %; Chromium: 17-18.50 %; Sulphur: 0.04

%; Phosphorus: 0.04 % Molybdenum: 1.0-1.25 %; Vanadium: 0.08-0.15 %. Samples were polished and the average roughness was measured with the help of surface profilometer. The roughness was measured at four different locations and then averaged for each sample. The average roughness R_a value for the cylinder liner samples was 0.1775, 0.1905 and 0.1641 µm. Surface morphological studies of cylinder liner and piston ring pin were conducted on SEM Hitachi 3600 and are shown in Fig. 1.



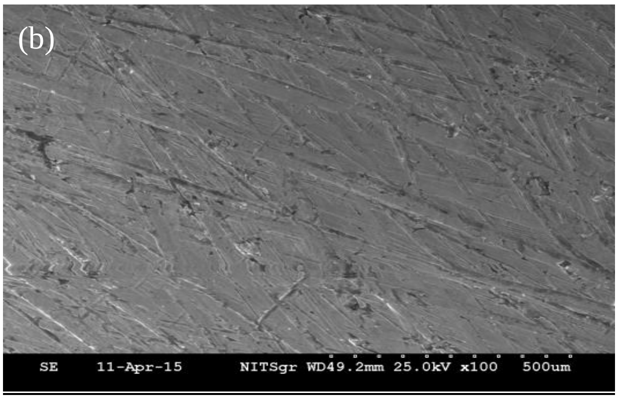


Fig. 1. SEM micrographs of (a) cylinder liner and (b) piston ring pin.

2.3 Friction and wear tests

In order to ascertain the fact that tribological properties of liquid lubricant are improved by addition of IF-MoS_2 as additive, wear tests were carried out on a four ball wear test machine. This method covers a procedure to evaluate anti-wear properties of fluid lubricants in sliding contact. Three 12.7 mm diameter steel balls made from AISI standard steel No. E-52100 were clamped as shown in Fig. 2. A fourth 12.7 mm diameter top steel ball is pressed with a force of 392 N into cavity formed by the three clamped balls in the oil cup making a three-point contact. The temperature of the test lubricant is regulated by heating element at 75 ^{o}C and the top ball is rotated at 1200 rpm for 1 hour. Four ball wear test machine with a microscope capable of measuring the diameters of the scars produced on the three stationery balls to an accuracy of 0.01 mm manufactured by Ducom Instruments Pvt. Ltd. (India) was used.

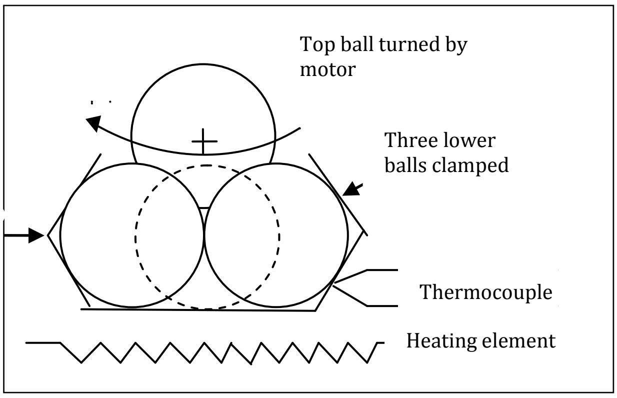


Fig. 2. Schematic diagram of a four-ball wear test machine.

Friction and wear experiments were conducted with a universal tribometer (Rtec, USA), using a pin- on-block arrangement. The piston ring pin was held fixed as upper sample and the lower sample cylinder liner was mounted on the reciprocating drive. The schematic diagram of universal tribometer is shown in Fig. 3. All the experiments were conducted at room temperature. The tests for friction and wear were performed at different sliding velocities (20 and 30 mm/s) and different loading conditions (100, 150 and 200 N) on the contact surfaces. The length of stroke was kept 2 mm in all the tests and test duration was fixed as 15 minutes for each experiment. All experiments were repeated three times in order to reproduce the results.

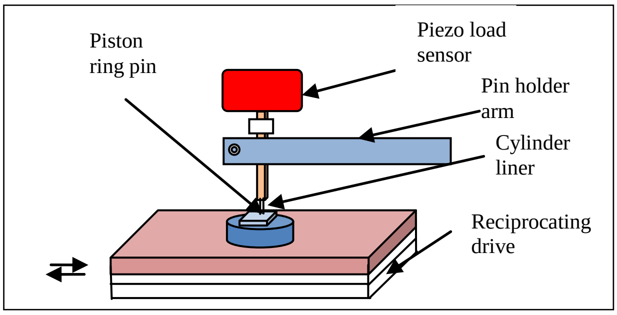


Fig. 3. Schematic diagram of universal Tribometer.

3. RESULTS AND DISCUSSION

Friction and wear tests were conducted on four ball wear test machine and universal tribometer under various conditions of load and sliding velocity. These are discussed in the following sections.

3.1 Wear preventive characteristics of lubricating fluid (Four ball test)

Wear tests were conducted separately in lubricant SAE20W40 alone and lubricant SAE20W40 with 1.0 wt% IF-MoS_2 on wear testing machine. Wear scar diameter (WSD) of the three stationery balls were measured using the microscope equipped with the four ball wear test machine. The results are shown in the Table 2. It was observed that WSD of the balls in the lubricant SAE20W40 alone were greater than WSD of the balls in the lubricant SAE20W40 + 1.0 wt% IF-MoS_2. There was an average reduction of almost 20 % in the WSD of the ball with additive in the lubricant. The findings were encouraging to conduct further studies in practical applications such as piston ring and cylinder liner in an IC engine. This was probably due to the spherical morphology of the IF-MoS_2 nanoparticles which were entrapped in the contact area between the balls resulting in reduction of the wear scar [6].

Table 2. The WSD value achieved under test conditions of 392 N, 1200 r/min, 75 ^{0}C and 60 min. (ASTM D 4172).

Lubricant	wear scar diameter (WSD) in µm			
	Ball No.			
	1	2	3	Average
SAE20W40	527.35	535.28	538.27	533.62
SAE20W40 +1.0 wt% IF-MoS_2	439.91	451.32	455.21	448.81

3.2 Friction and wear studies of cylinder liner and piston ring

Coefficient of friction (COF) and wear observed between cylinder liner and piston ring with IF-MoS_2 nanoparticles added in base engine oil of grade SAE20W40 in different concentration (wt% 0.5, 1.0 and 1.5) in all reciprocating sliding experimental studies at various loads and sliding speed are shown in Figs. 4-6.

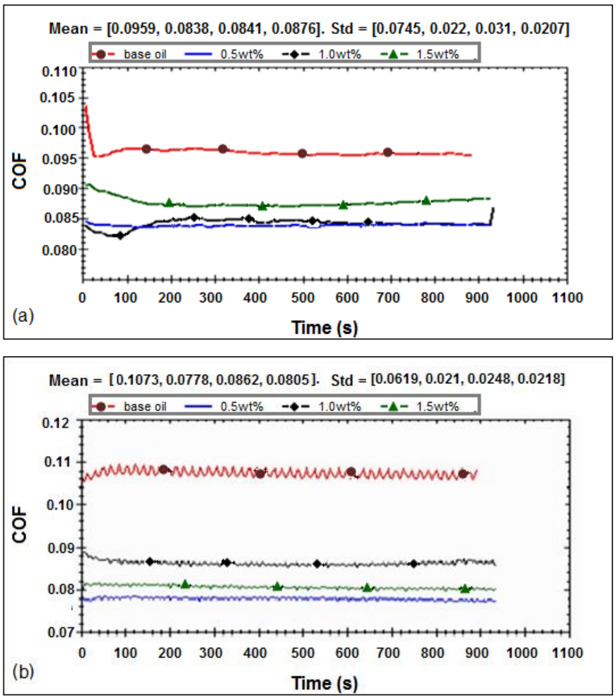


Fig. 4. Variation of coefficient of friction with different concentration of the IF-MoS_2(wt%) nanoparticles in base lubricant SAE20W40 at the normal load of 100 N and sliding speed (a) 20 mm/s (b) 30 mm/s.

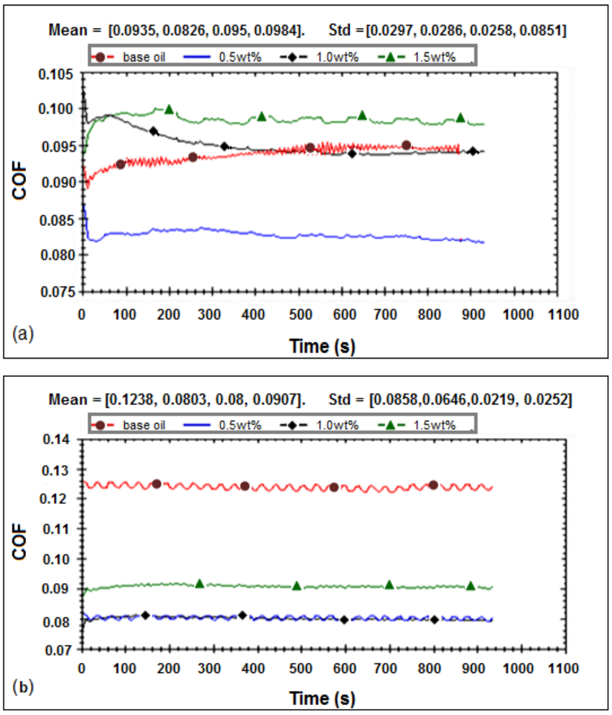


Fig. 5. Variation of coefficient of friction with different concentration of the IF-MoS_2(wt%) nanoparticles in base lubricant SAE20W40 at the normal load of 150 N and sliding speed (a) 20 mm/s (b) 30 mm/s.

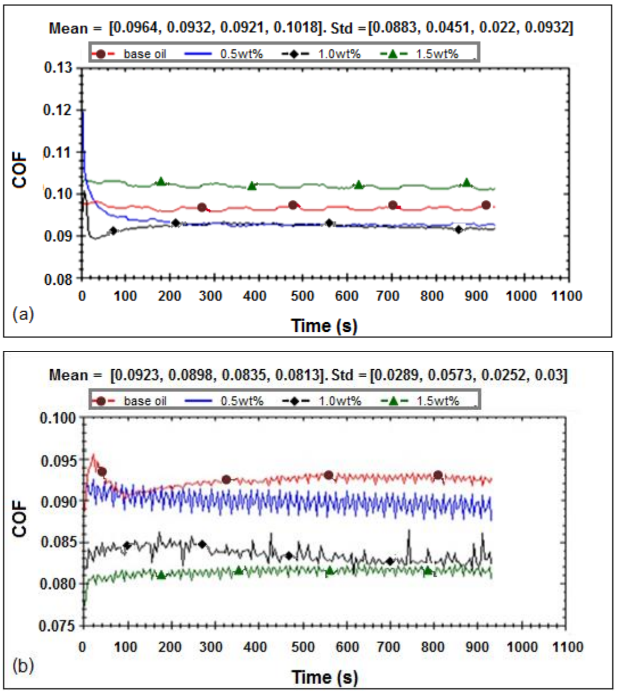


Fig. 6. Variation of coefficient of friction with different concentration of the IF-MoS_2(wt%) nanoparticles in base lubricant SAE20W40 at the normal load of 200 N and sliding speed (a) 20 mm/s (b) 30 mm/s.

3.3 Coefficient of friction (COF)

Figures 4 (a and b), 5 (a and b) and 6 (a and b) show variation of COF with time for normal load of 100 N, 150 N and 200 N respectively. These tests were conducted at sliding velocities of 20 mm/s and 30 mm/s for 15 min. It is evident from the Figs. 4-6 that COF increased with increase in normal load. Lowest COF of 0.0772 was observed for the lubricant SAE 20W40+ 0.5 wt% IF-MoS_2 at 100 N load and sliding velocity of 30 mm/s while highest COF of 0.12383 was observed for the lubricant SAE20W40 at normal load of 150 N and sliding speed of 30 mm/s. It is also evident from Figs. 4-6 that COF is affected by normal load, concentration of the nanoparticles in the lubricant and sliding velocity. Similar results are reported in the literature and the reduction in COF may be attributed to the formation of IF-MoS_2 sheets inside the contact area during friction with bundled platelet structures as reported by *Cizire et al.* [22].

3.4 Wear

The quantitative wear loss was obtained by weighing cylinder liner sample using high precision digital balance before and after each test. Density of the material was used to calculate the wear loss in mm^3. Wear loss vs. load of the cylinder liner is shown in the Fig. 7 (a and b) at various loads under lubrication using SAE20W40 and SAE20W40 + IF-MoS_2 nanoparticles (0.5 wt%, 1.0 wt% and 1.5 wt %) with sliding velocity of 20 mm/s and 30 mm/s respectively . It is clear from the Fig. 7 (a and b) that wear loss is higher with lubricant SAE20W40 and is also evident that in most of the cases the wear of cylinder liner decreased with the increase in concentration of IF-MoS_2 nanoparticles in SAE20W40. Lowest wear of 0.013 mm^3 was obtained at a normal load of 150 N for sliding velocity of 20 mm/s with 0.5 wt% concentration of IF-MoS_2 nanoparticles in SAE20W40. Highest wear of 0.07 mm^3 was obtained at a normal load of 100 N for sliding velocity of 30 mm/s without additive. It is inferred from these results that IF-MoS_2 nanoparticles as additive reduced the wear loss of about 30 to 65 % in comparison to lubricant without additive. However, in all tests negligible wear was observed on piston ring pin. This is attributed to higher wear resistance of pin material due to its higher hardness value.

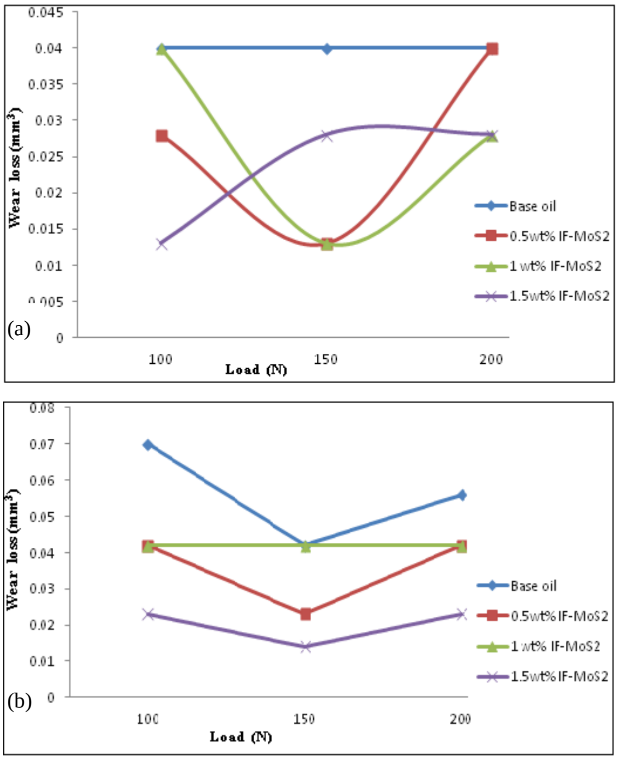


Fig. 7. Wear loss vs. load on cylinder liner at sliding velocity of (a) 20 mm/s (b) 30 mm/s.

SEM micrographs of worn out surfaces of cylinder liner and piston ring are shown in Fig. 8

(a and b). It is evident from Fig. 8 (a) that loss of material has occurred due to adhesion resulting in rough worn out surface, whereas, no such phenomenon has been observed on the worn out surface of piston ring pin as shown in Fig. 8 (b). It is also inferred from the Fig. 1 (a) and Fig. 8 (a) that graphite flakes present on unworn surface have been removed, resulting in higher wear of the cylinder liner. However, SEM micrographs of unworn and worn out surfaces of piston ring pin shown in Fig. 1 (b) and Fig. 8 (b) respectively, reveal smooth wear track formation in the case of worn out surface. This resulted in negligible wear of piston ring pin. EDS studies of the worn out surfaces of cylinder liner and piston ring pin reveal presence of Mo, as shown in Fig. 9 (a and b). However, distinguishing Mo and S in EDS spectra is difficult. EDS results prove that presence of IF-MoS_2 at the interface surface resulted in reduction of friction and wear.

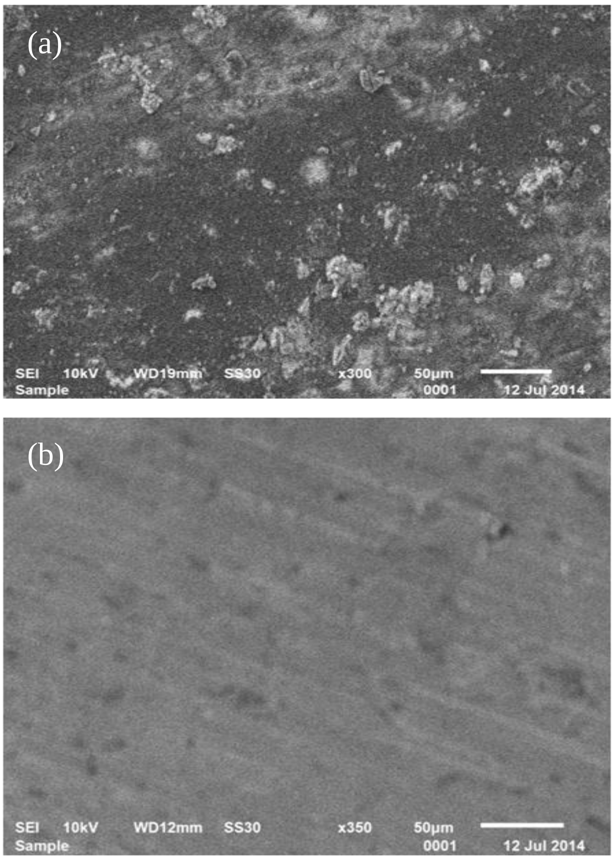


Fig. 8. SEM images of wear surface after the friction test with lubricant+0.5 wt% IF-MoS_2 (a) cylinder liner (b) piston ring pin.

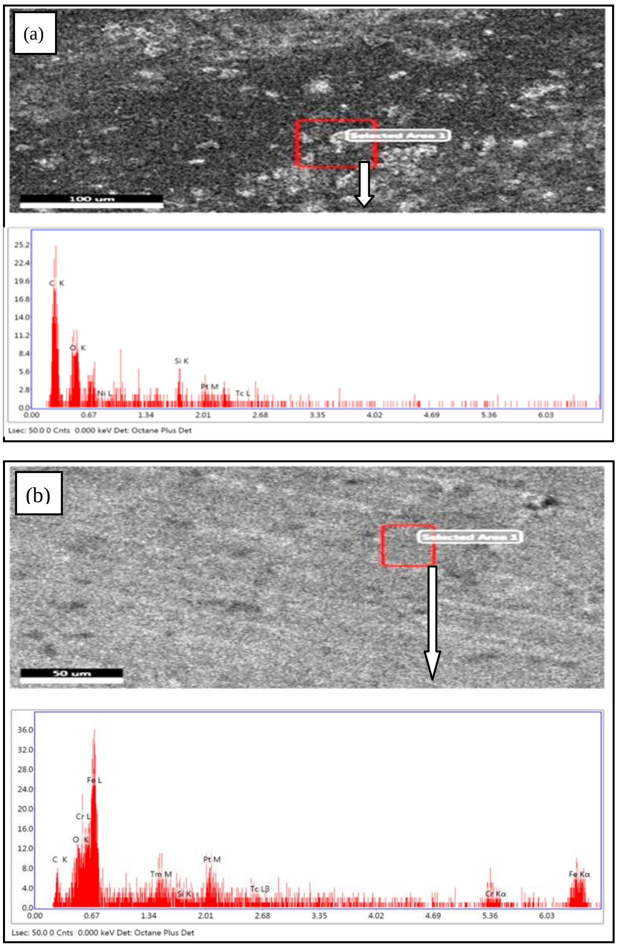


Fig. 9. EDS spectra at the selected area with lubricant+0.5 wt% IF-MoS_2 after the test (a) cylinder liner (b) piston ring pin.

4. CONCLUSION

The nanoparticles of IF-MoS_2 in the base oil show excellent tribological properties under selected operating conditions. Four ball wear preventive test showed 20 % decrease in the WSD of the balls with IF-MoS_2 nanoparticles as additive in the lubricant SAE20W40.Tribometer tests revealed that IF-MoS_2 nanoparticles as additive reduced the wear loss of about 30 to 65 %, in comparison to lubricant without additive at all sliding velocities. The minimum value of coefficient of friction (0.0772) was observed at 0.5 wt% of IF-MoS_2 under normal load of 100 N at sliding velocity 30 mm/sec. The value of coefficient of friction and wear loss is function of the sliding velocity, load and concentration of the nanoparticles in the lubricant SAE20W40.

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