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Extreme Pressure Properties of 600 N Base Oil Dispersed With Molybdenum Disulphide Nano Particles

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Abstract This work presents the extreme-pressure behavior of 600 N base oil dispersed with MoS_2 Nano particles with 1 volume percent of polyisobutylenesuccinamide as dispersant. MoS_2 Nano particles were dispersed in 0.05, 1.0 wt. % and tested for Extreme pressure behavior on a 4 ball wear tester using the test method ASTM D 2783. The weld load and load wear index of base oil and oil dispersed with Nano particles are evaluated and compared for improvement. Prior to dispersion, the MoS_2 Nano particles are suitably surface modified to make them uniformly disperse in oils. The seizure load, weld load and load wear index of Nano particles dispersed oils have improved remarkably compared to Base oil. Metallographic studies done on the wear balls show that Nano particles get deposited on the worn area preventing the welding of the surfaces and hence higher weld load. The wear scar of bottom there balls are also found to be less for Nano dispersed oils compared to base oil and hence lower load-wear index.

Keywords 600 N Base Oil, MoS_2 Nano Particles, Base Oil, Extreme Pressure, Polyisobutylenesuccinamide, Surface Modification, Seizure Load, Load Wear Index, Weld Load

1. Introduction

Molybdenum disulfide (MoS_2) is the inorganic compound which is classified as a di-chalcogenide. Molybdenum atoms are sandwiched between layers of sulfur atoms. Because of the weak vanderwaals interactions between the sheets of sulfide atoms, MoS_2 has a low coefficient of friction, resulting in its lubricating properties. MoS_2 with particle sizes in the range of 1-100μm is a common lubricant additive used in most of 2s and 4s engine oils MoS_2 retain its lubricity almost in all cases and also finding a use in critical applications such as Aircraft engines.

Extreme pressure or Extreme temperature lubricants have been developed for two main fields-the lubrication of Gears and as lubrications in metal working. Friction and surface damage caused by high temperatures and pressures can be reduced by applying extreme pressure (EP) and anti-wear (AW) additives. These tend to be sulphur-chlorine and phosphorous containing compounds designed to react chemically with the metal surfaces, forming easily sheared layers of sulphides, chlorines or phosphide and thereby preventing severe wear and seizure. The advantage of using nano materials in lubricants are 2 fold: one they form a barrier between two mating surfaces thereby preventing wear and secondly the spherical nano particles cat as rollers thereby reducing friction.

2. Literature Review

MoS_2 in particular have attracted considerable interest due to their wide range of promising applications [Fendler et.al, 1995]. During the last decade, a number of attempts were made to synthesize inorganic nano particles as lubricant additives [Liu et.al, 2000]. One of the main difficulties of using nano particles as additives is their dispersion in the lubricant oils. With the surface modification of nano particles trough long chain high molecular weight hydrocarbons, more and more inorganic compounds stably dispersed in lubricant oils become feasible [Rapoport et al, 1997]. V. N. [Bakunin et al, 2004]. investigated the tribological behavior of surface-capped MoS_3 nanoparticles (nano-MoS_3) in hydrocarbon oils in combination with ZDDP at test temperatures in the range of 100–160 ^{0}C and at ZDDP content of 0–1.0 wt% in oil. It was demonstrated that this combination of additives demonstrates high anti-wear and antifriction efficiency, especially at high temperatures and low ZDDP content. Under the tested conditions, the best tribological properties are demonstrated by the composition comprising 500 ppm Mo and 0.1 wt% ZDDP in oil. Xun Fu et al. studied the tribological properties of MoS_2 micro-sized spheres with diameter of 0.5–3m modified by self-prepared surfactant quaternary ammonium salt of 2-undecyl-1-dithioureido-ethyl-imidazoline (SUDEI) as an additive in base oil 500 SN. The tests for improvement in tribological properties were carried out on a four ball tester and an Optimol SRV oscillating friction and wear tester in a ball-on-disk contact configuration. It was found that the

MoS_2 micro-sized spheres product was a much better extreme-pressure additive and anti-wear and friction-reduction additive in 500 SN than commercial colloidal MoS_2.

3. Research Methodology

3.1. Lubricant Base Stock and Selection of Nano Particles

600 N oil is selected as it is the base stock for all gear oils. The base stock contains small amount of sulphur (2 to 3%). In the literature, several types of metal, metal oxide, inorganic and organic nano particles were used to improve the tribological properties of lubricants, most of them are not suitable as lubricant additives due to their corrosive or abrasive properties. The research explores the study of MoS_2 nano particles inclusion for the improvement of extreme pressure properties of 600 N oils. Molybdenum disulphide (MoS_2) nano particles are procured form M/s Nanoshel, USA.

3.2. Characterization of Nano Particles

The nano material is characterized using SEM & EDX to verify the size, shape and chemical composition. The loose agglomerates magnified in SEM are as shown below

Element	Weight%	Atomic%
S K	21.04	44.36
Mo L	78.96	55.64
Totals	100.00	100.00

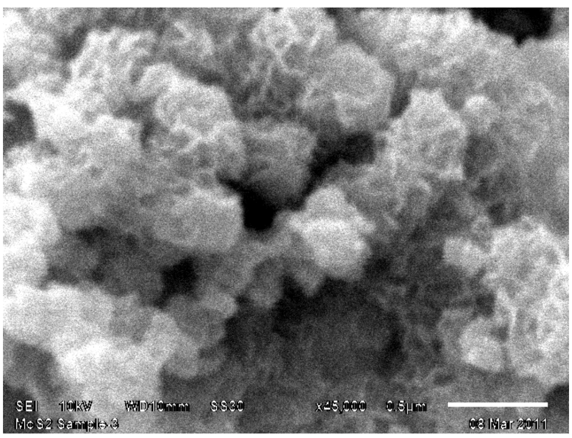

Figure 1. SEM *Image And* EDX Spectrum of Mos2 Nano Particles

3.3. Extreme pressure test machine and procedure

The Four-Ball EP Test measures a lubricant's extreme pressure properties under High Hertzian contact in pure sliding, or pure rolling, motion. The test is used to determine the load carrying properties of a lubricant at high test loads. The Four-Ball EP Test rotates a ½-inch diameter ball in contact with three similar balls held stationary in the test cup. The contact surfaces are covered with test lubricant, a load is applied and a timed test is performed. Normally, the wear scars on the three lower balls are measured and averaged. The test is generally terminated at the load where the rotating ball 'welds' to the three stationary balls.

The Load-Wear Index (LWI) quantifies the wear protection at increasing loads. The Last Non-Seizure Load (LNSL) indicates the transition from elasto-hydrodynamic to boundary lubrication and metal to metal contact.

3.4. Evaluation of EP Properties of Gear Oils Using ASTM D 2783

This test method covers the determination of the load carrying properties of lubricating fluids. The following two determinations are made

1. Load-wear index (formerly Mean-Hertz load).
2. Weld point by means of the four-ball extreme-pressure (EP) tester.

Summary of the method:

The tester is operated with one steel ball under load rotating against three steel balls held stationary in the form of a cradle. Test lubricant covers the lower three balls.

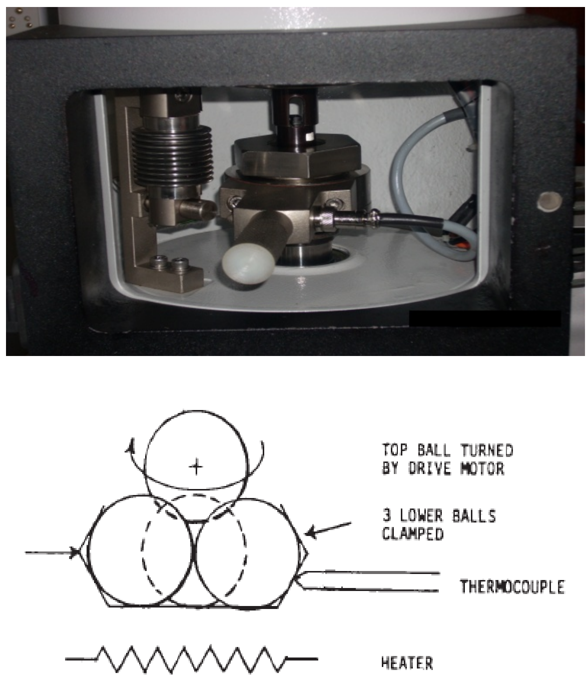

Figure 2. Schematic Image and Photograph of 4 Ball Wear Tester

The rotating speed is 1760 ± 40 rpm. The machine and test lubricant are brought to 18 to 35°C and A series of 10 tests of 10-s duration are carried out at increasing loads until welding occurs. The first run was made at an initial load of 80 kgf and the additional runs were carried out at consecutively higher loads according to the standard method until welding occurs.

A check run is made at this point and if welding does not occur on the check run, the test is repeated at the next higher load until welding is verified. If ten loads have not been run when welding occurs, the total was brought to ten by assuming, according to the standard, that loads below the last non seizure load (LNSL) produce wear scars equal to the compensation scar diameter.

The corrected load is calculated for all ten reading and the load wear index is calculated for a lubricant.

$$\text{Corrected load} = \frac{LD_h}{X}$$

Where

L = applied load, kgf, that is, total weight applied, D_h= Hertz scar diameter, mm, and

X = average scar diameter, mm.

Hertz line:

The Hertz line was obtained by plotting the Hertz scar diameter against the load. The Hertz scar diameter (Dh) is the average diameter of an indentation caused by the deformation of the balls under static conditions.

D_h = 8.73 x 10-2 (P)1/3 (1)

where:

D_h = Hertz scar diameter, and

P = the static load applied.

A line of plot on log-log paper where the coordinates are scar diameter in millimeters and applied load in kilograms-force (or Newton) obtained under static conditions.

3.5 Load-Wear Index (LWI)

The *load-wear index (LWI)* is an index of the ability of lubricant to minimize wear at applied load. It is a single parameter that shows the overall EP behavior in a range between well below seizure and welding. Higher is the value of LWI, better is the EP property. It may be calculated from the expression:

LWI (kgf) = A/10

Where:

A = sum of the corrected loads determined for the ten applied loads immediately preceding the weld load.

P is the applied load, dh the Hertz diameter, d the wear scar diameter and n is the total number of occurrences

4. Results and Analysis

4.1. EP Tests on 600 N oils

Extreme pressure test are carried out on 600 N oil dispersed with MOS_2 nano particles.

The following results are obtained

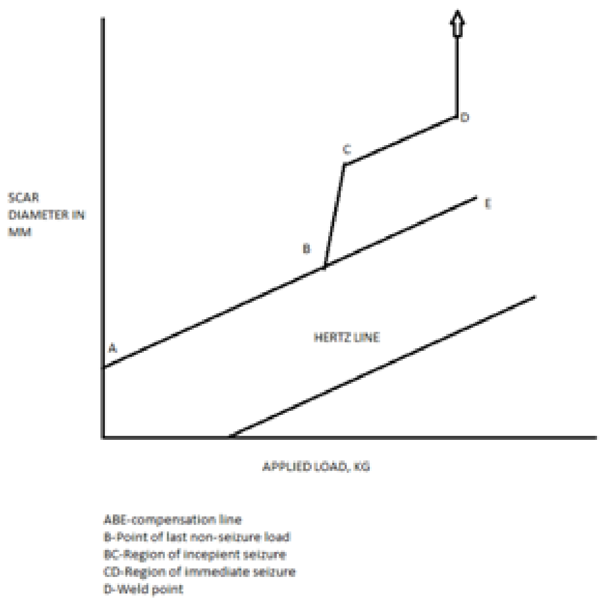

Figure 3. Schematic Diagram of Load Vs Wear Scar

Table 1. Load Wear Indices, Seizure Loads and Weld Loads of Various Oils

Oil	load wear index	Seizure load	weld load
600 N base oil	56.52	120	250
BASE OIL + 0.1% MoS_2	63.32	140	280
BASE OIL + 0.05% MoS_2	84.30	180	280

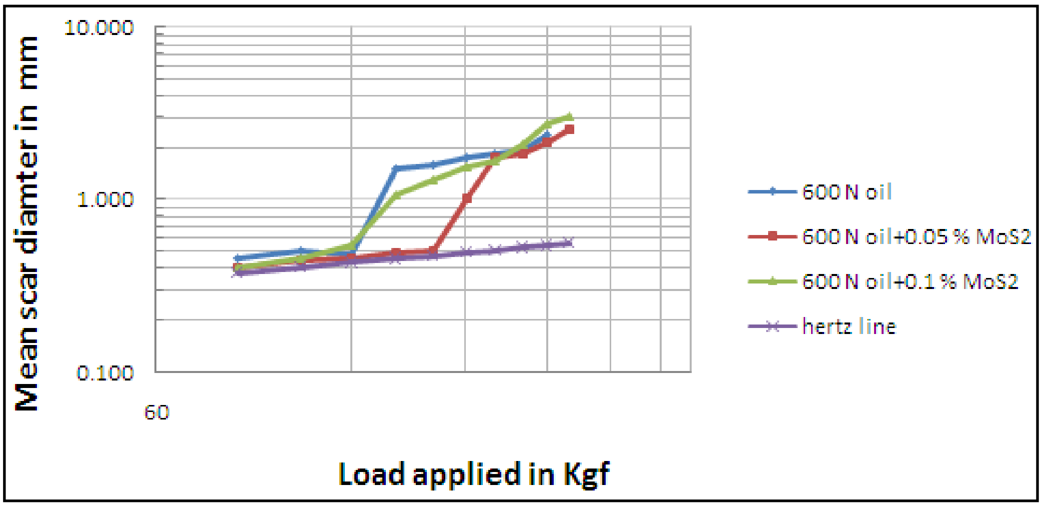

Figure 4. Variation of Wear Scar Diameter with Load

The graphs of Load Vs Mean Scar diameter is plotted for various commercial oils and oils dispersed with nano materials along with the hertz line.

Of the three oils tested, 600 N oil dispersed with 0.05 % MoS_2 gave better load – wear index due to the fact that it gave very low wear scars at non seizure and post seizure loads. The higher seizure load of 600 N Base oil dispersed with 0.05 % MoS_2 gave it higher load- wear index. 600 N oil dispersed with 0.1 % MoS_2 also gave good improvement in load wear index and higher weld load but the improvement is less compared to 0.05 % MoS_2. This may be probably due to overcrowding of nano particles resulting in increase in wear scar at each load thereby decreasing the load wear index.

4.2. Metallographic Studies on Worn Surface of Balls

Metallographic studies are being conducted to assess the possible reason for reduction in friction and wear due to dispersion of Nano materials in the lubricants. The scar area after tests on 4 ball wear test is magnified in SEM and observed for deposition of particles on the surface. The characterization done on SEM – EDX reveals the deposition of Nano materials on the surface could be the possible mechanism for reduction in friction, wear and improvement in EP properties with addition of Nano materials. The detailed characterization done on Scanning electron microscope with EDX attachment is shown in the following figures.

From figs. 5& 6 it may be noted that there is a deposition of MoS_2 on the worn surface due to which there is reduction in the friction thereby wear. Further,it may be noted that the deposition rate is more with 0.1 % MoS_2 dispersion compared to 0.05 % MoS_2. This higher deposition may be due to overcrowding of nano particles and their fusion to the worn surface at higher pressures.

5. Conclusions

All nano particle suspensions improve the EP properties of the base oil.

Dispersion of all nano materials improved weld load as well as last non seizure load .

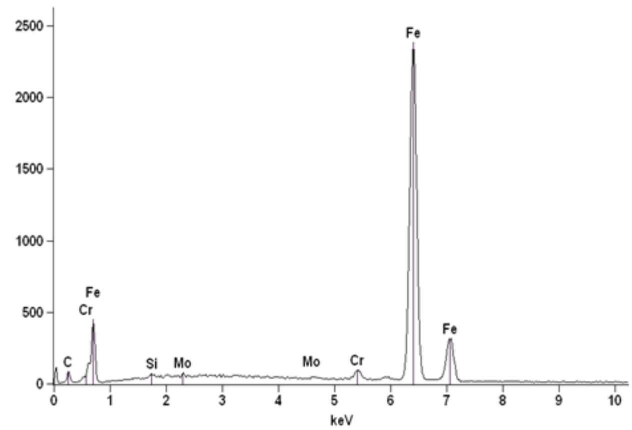

Figure 5. EDX of Worn Out Balls with Baseoil+0.05 MoS_2

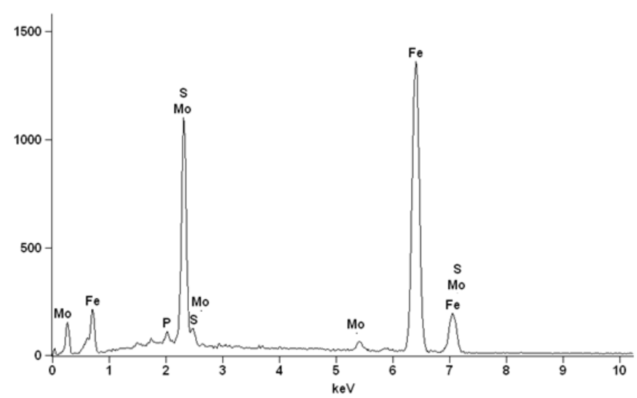

Figure 6. EDX of Worn Out Balls with Base Oil+0.1 MoS_2

Metallographic studies with SEM EDX show that MoS_2

could well deposit on the worn surface preventing seizure and weld.

The optimum weight percentage of nano particles is 0.05 % for good results.

Surface modification and addition of dispersant improved the dispersion of MoS2 nano particles and thereby improved the Extreme pressure properties of 600 N oil.

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