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Full Length Research Paper

Extreme pressure property of Carbon Nano Tubes (CNT) based nanolubricant

Shubrajit Bhaumik*, S.Prabhu, VarunKarpurapu and Nihit Uppala

School of Mechanical Engineering, SRM University, Chennai - 603203 India.

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The paper predicts the exceptional extreme pressure properties of multi walled carbon nano tube as compared with traditional mineral oil which also contained some additives and graphite. The extreme pressure property was predicted by four ball tester. In the test the load bearing capacity of the newly developed nano oil was predicted to have a better value than the commercial available mineral oil. The weld load of the nanolubricant was found to be 200 kgf as compared with the base mineral oil which got welded at 160 kgf. Thus, the finding would be helpful in developing new nanolubricants which would increase the life of the mating parts, reducing the chances of failure of machine and increasing the productivity.

Key words: Mineral oil, multi walled carbon nano tube (MWCNT), pass load, weld load, load bearing capacity, Carbon Nano Tubes (CNT).

INTRODUCTION

With the advancement of new technologies, new critical applications have also taken their birth in various fields. The birth of critical applications has also made the researchers to think regarding the protection of the parent material. Lubrication is an important phenomenon in any process industries. Initially, mineral oil was commonly used. With the advancement of the modern era of mechanisms, the researchers are trying to extend the life of the mating parts. For that, various types of additives have been formulated and added to the base mineral oil. For many years phosphorus, sulfur, nitrogen and chlorine compounds are used as successful AW and EP additives. The use of these compounds decreased because of increase in price of sulfur and nitrogen compounds. These compounds also pose environmental and toxicological hazards. So current research is focused on development of eco-friendly additives. In recent years graphite and molybdenum disulfide have attracted the attention because of their excellent emergency lubricating properties which plays an important role when lubricant film begins to break. The nanoscale materials have drawn ample attention of researchers from distinct research fields in recent years because of its propitious physical and chemical properties. In tribology nanomaterials have been proved to have greater potential as lubricating additives. Carbon nanotubes are one such nanomaterial whose existence was observed in 1990s. Due to superior physical and mechanical properties, carbon nano tubes has found its place in many critical applications. Due to its tubular structures and higher mechanical properties it can be predicted that carbon nano tubes may work as rolling bearings without getting broken between two mating parts which may reduce the frictional coefficient and increase the load bearing capacity of the CNT based lubricant.

Curasu et al. (2012) predicted the frictional reduction capability and excellent AW/EP properties of SWCNTs and obtained the optimum concentration as 0.5 wt%. Hong et al. (2010) concluded that CNT greases distinguish themselves from more common graphitic materials as solid grease additives. The performance of CNT grease could be much better with the improvement

*Corresponding author. E-mail: shubrajit_project@rediffmail.com.

of nanotube quality and purity. Marquis and Chiabnte (2005) concluded that CNT is found to considerably increase the thermal conductivity of many heat transfer fluids such as mineral and synthetic oils, water, water/ethylene glycol mixtures and other commercial heat transfer fluids such as antifreeze. Wang et al. (2007) concluded that when CaF_2 nanocrystals are used as lubricant additive in lithium grease, it improves the wear resistance, load carrying capacity and anti friction with the optimum concentration 1 wt%. Xianbing et al. (2011) concluded that when $CaCo_3$ nanoparticles as an additive in lithium grease significantly improve its anti-wear performance, friction reduction property, load carrying capacity, and extreme pressure property with 0.5%wt optimum concentration.

In this paper, the extreme pressure property of MWNTs has been predicted. MWCNTs have been used as solid additives to base mineral oil in different percentages (0.1, 0.5 and 0.6% wt). The extreme pressure properties of the specimens were compared to that of the base mineral oil without additives and the graphite as an additive. A Four Ball Tester is used to evaluate the tribological properties. The properties of the specimens are listed in Table 1 as follows:

EXPERIMENTAL DETAILS

Base oil: Mineral oil ISO VG 250 is chosen because 250 cSt oils are used in heavy duty industrial applications like gear boxes of many process plants.

Additives: Multi-walled carbon nanotubes are used as an additive for comparing the tribological properties with classical additives (Graphite).

Preparation of nano lubricant

CNT have good dispersibility in mineral oil. When CNTs are directly added to the base mineral oil, they are not stable. Agglomeration of CNT occurs within no time. In order to get a stable lubricant, we can either use a surfactant or mix CNT to the mineral oil using ultrasonication. In the present work, stable lubricant for a longer time has been produced using ultra-sonication. No surfactant has been used. In ultra-sonication the length of the CNT are broken to increase the ease of dispersion of CNT in oil and hence maintains stability for a longer time. Specimens with various concentrations of MWNTs dispersed in mineral oil were stable up to 156 h.

Extreme pressure test

Four ball tester

A Four Ball Tester is used to evaluate the Extreme Pressure (EP) property of lubricant. The tribosystem consists of three stationary balls fixed in a ball pot which are pressed against the fourth ball fixed to the collet at required pressure. The top ball rotates at defined speed according to the test standards. The load is uniformly distributed over the three points where the three balls touch the fourth ball. The pot is filled with the lubricant. Rotation of the driving spindle causes a frictional torque that produces a scar on the lower balls. The test balls used had a 12.7 mm diameter and a roughness of R_a= 0.016 mm and were made of AISI E 52100 steel. The test standards were performed according to the ASTM D-2783 standard.

The test is performed by adding weights to the apparatus and will run the apparatus for specific time according to the test standards. After the completion of test with respective weight the balls will be removed from the apparatus and are observed. If the scar diameter is above 4 mm or if the ball gets welded then the respective load is called weld load of the specimen and the previous load where the balls do not get welded or the scar diameter is below 4 mm is called pass load.

SEM analysis

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with electrons in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The morphology of the rubbed surfaces was investigated using an FEI Inspect scanning electron microscope with a maximum resolution of 3 nm.

RESULTS AND DISCUSSION

Four ball test results

To study the behavior of MWNTs under the above mentioned conditions, five specimens were compared under same conditions: Base mineral oil, Base mineral oil with CNT as an additive in three different concentrations (0.1, 0.5 and 0.6 wt%) and Base mineral oil with graphite as an additive. The Four Ball Test results in Table 2 show the load bearing capacity of each specimen.

As observed from Figure 1 and Table 2 the pass load and weld load of the base mineral oil is very less when compared to that of the other specimens. From Figure 1 it can be predicted that pass load and weld load values of CNT specimens and graphite specimens are same but is higher than the pure base oil which is being used in industries. This may be because both additives are allotropes of carbon. Since the pass load and weld load values are same it does not mean that all the specimens have same efficiency. The most efficient lubricant among the additive added specimens can be obtained by comparing the scar diameter at their pass Loads. The lower the scar diameter, the higher will be the load bearing capacity. The scar diameters of the four additive added specimens are shown in Table 3.

Though the graphite and CNT are allotropes of carbon, CNT have better physical properties compared to that of graphite. As the elastic modulus of CNT is much higher than graphite, the CNT can withstand more loads than graphite without breaking. So graphite added specimen has high scar diameter as compared to CNT specimens. Among the CNT added specimens there exists variation in scar diameters because of different concentrations of CNT. In 0.1 wt% CNT specimen the amount of CNT

Table 1. Physical properties of the lubricants.

Property	Mineral oil + 0.1% CNT	Mineral oil + 0.5% CNT	Mineral oil + 0.6% CNT	Mineral oil + 0.5% Graphite
Viscosity	249.70	251.85	242.56	249
Flash point	220	218	222	218
Fire point	232	228	234	226

Table 2. Pass Load and Weld Load values from Four Ball Test.

Specimen	Pass load (kg)	Weld load (kg)
Base mineral oil	126	160
Base mineral oil + 0.1 wt% CNT	160	200
Base mineral oil + 0.5 wt% CNT	160	200
Base mineral oil + 0.6 wt% CNT	160	200
Base mineral oil + Graphite	160	200

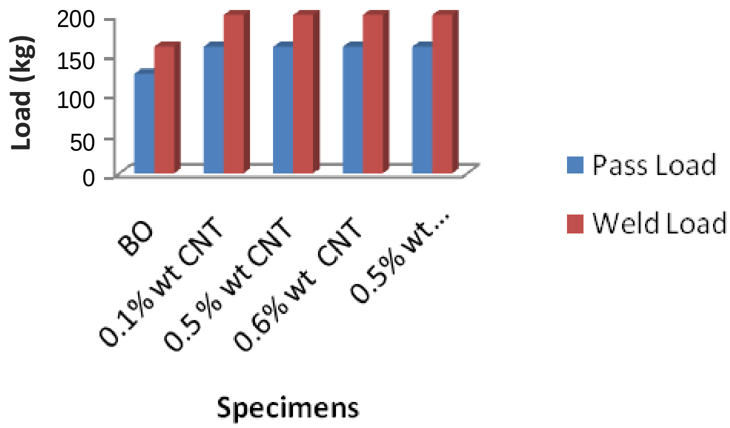

Figure 1. Pass Load and Weld Load values from the Four Ball Test.

Table 3. Scar diameters of different specimens.

Specimen	Scar diameter at pass load (mm)
Base mineral oil + 0.1 wt% CNT	2.431
Base mineral oil + 0.5 wt% CNT	2.225
Base mineral oil + 0.6 wt% CNT	2.313
Base mineral oil + Graphite	3.136

present is not sufficient to make it a better efficient lubricant whereas in 0.6 wt% CNT specimen the amount of CNT present became excessive because the oil reached its solubility state and excess CNT cannot be dissolved in the oil which leads to agglomeration of the nanotubes. This may also increase the fluid friction between tribopairs. Thus, an increasing trend has been observed after 0.5% wt as shown in Figure 2. Hence, 0.5 wt% CNT is the optimum concentration.

SEM analysis

SEM images predict the microstructure of the balls. It can be predicted that the heat generated in case of the mineral oil and mineral oil + 0.5%wt graphite sample is higher due to which white layers are being observed in Figure 3(a) and (c). Thus, it can be predicted that the lubricant film is not stable in case of mineral oil and mineral oil + 0.5%wt graphite. On the contrary, the image

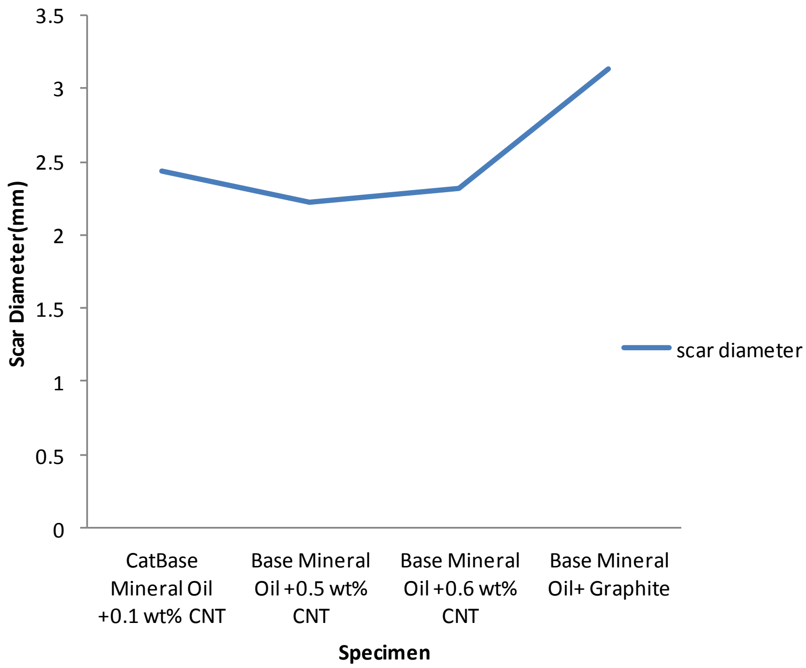

Figure 2. Scar diameters on balls.

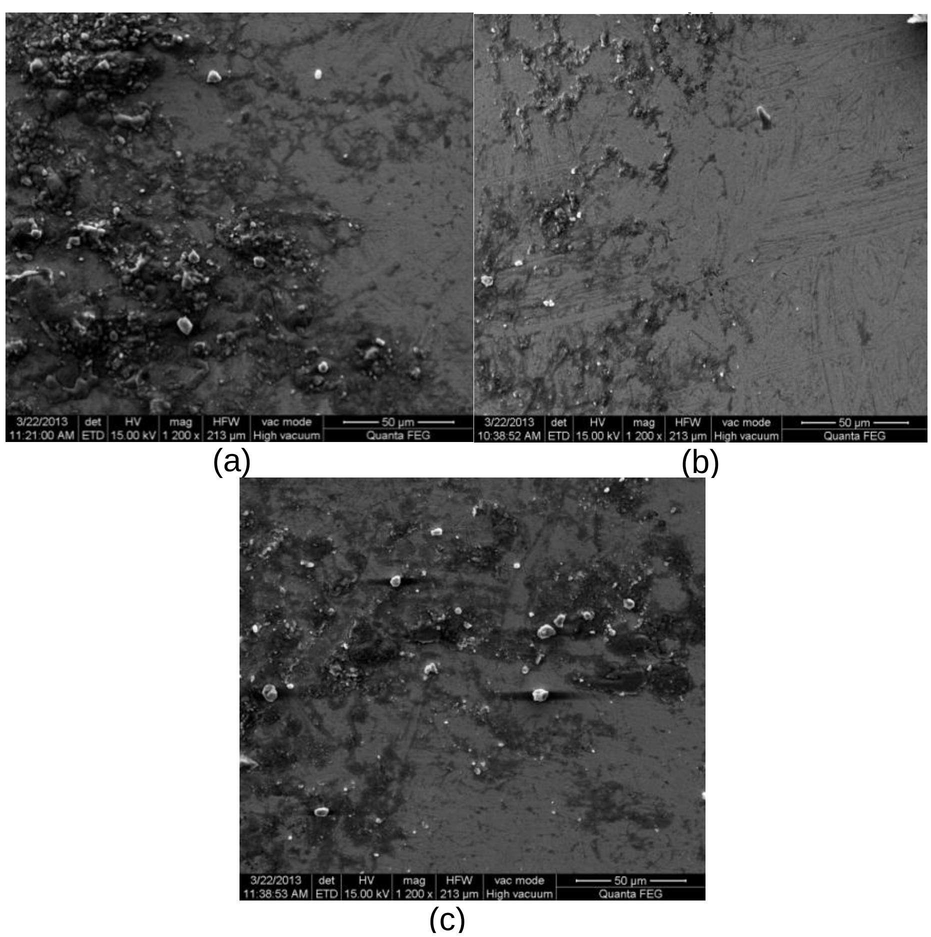

Figure 3. SEM image of metal ball used in four ball tester for pass load of (a) mineral oil (b) Mineral oil +0.5% wt CNT (c) Mineral oil + 0.5% Graphite.

of mineral oil + 0.5%wt CNT predicts lesser formation of heat effected zone. Thus, CNT lubricant film is predicted to be more stable than the mineral oil and mineral oil + 0.5% graphite sample.

Conclusion

From the results predicted in the present work we can conclude that MWCNTs are much more efficient additives than commonly used graphite. The load carrying capacity, which is an important parameter for the lubricant has been predicted to be higher in case of nano lubricants than the conventional lubricant. The present result would be beneficial in developing new nano fluids.

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