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INVESTIGATION OF THE INFLUENCE OF ANTIWEAR ADDITIVES DISPERSED IN HYDRAULIC OIL ON FRICTION AND WEAR

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The influence of antiwear additive dispersed in hydraulic oils containing zinc dialkyl dithiophosphates is tested. The tested additives are dispersed in the hydraulic oil at different concentrations. Tests were carried out to test the friction and wear of bearing steel lubricated by hydraulic oil dispersed by the tested additives using reciprocating wear tester.

It was observed that friction coefficient decreased as the additive content increased. The lowest values were observed at 0.6 wt. %. Further increase in additive content slightly increased friction. Wear decreased with increasing additive content. The lowest wear values were observed at 1.0 wt. %. The reduction in friction and wear may be attributed to the mechanism of action of the protective film formed from the decomposition products of the additive. The film worked as solid lubricants and decreased friction and wear. The anti-wear behavior of the tested additive can be explained on the basis of the formation of organometallic compounds, where their function depends on forming iron sulfide layer on the sliding steel surfaces of relatively high hardness that resisted excessive wear. Inspecting the topography of the worn surfaces of the test specimens and steel counterface by optical microscope confirmed the enhancing influence of the tested additive in reducing wear.

KEYWORDS

Anti-wear additives, hydraulic fluids, wear, friction, reciprocating motion.

INTRODUCTION

Lubricants consist of base oils and additives. Base oils are hydrocarbons and they tend to oxidize, thermally decompose, and polymerize, [1]. Studies revealed that the hydrocarbons react with oxygen and form polar species such as carboxylic acids which adsorb onto the metal surface and react with the metal forming metal complexes. These metal complexes are soluble in oil. The effect of the polar molecules of the base fluids on their ability to lubricate under boundary conditions was studied, [2 - 5]. The effect of polar groups, such as carbonyls, alcohols and olefins, branching and effective carbon chain length are included as factors that have the potential to affect wear, [6, 7]. Although the various polar groups did affect the wear rate, they did not control friction. It was found that the

predominant factor affecting friction was the effective chain length. Besides, low temperature properties improve as the number of double bonds or branching increase.

During sliding, chemical reactions are produced as a result of the frictional heating. These reactions include oxidation of the surface, lubricant oxidation and degradation, surface catalysis, polymerization, and the formation of organometallic chemistry. These reactions produce inorganic and organic products of various molecular weights up to 100,000 for hydrocarbon lubricants. Precipitation of high molecular weight products from solution forms films of friction polymers, [8 - 10]. It was suggested that the chemical compositions of the films are mainly micrometer and submicrometer sized particles of iron and iron oxides as well as high molecular weight organometallic compounds.

It was observed that fresh anti-wear compounds like zinc dialkyl dithiophosphates (ZDDP) do not function without an accompanying base fluid, [11]. The implications of this are that successful antiwear films incorporate a mixture of reaction products that must perform to bear the load under highest stress conditions through the solid film and to distribute load and provide shear film to prevent high forces from deforming the surface through the soft polymeric film. The effect of preheating oil and additives on their lubricating properties was discussed, [12]. Zinc dialkyl dithiophosphates were added to the base oil at different concentrations after prehearing. The experiments showed that addition of zinc dialkyl dithiophosphate to as received oil up to 0.5 wt. % zinc content caused significant wear decrease. Besides, dilution of the preheated additives in the as received oil did not enhance the wear resistance, while addition of preheated zinc dialkyl dithiophosphates to the preheated oil showed significant wear decrease.

Steel surfaces lubricated by oils containing a ZDDP were investigated, [13]. It was proved that wear decreased due to the formation of the tribofilm in boundary lubrication regime. ZDDP is widely used in hydraulic oil to resist corrosion and wear, [14]. ZDDP decomposes and forms a tribofilm of metal phosphates and oxides, [15 - 18]. ZDDP can be replaced by ionic liquids, [19], that possess stronger polarity and adsorption to the metallic surfaces offering effective wear protection.

The interactions of copper nano-particles with the oil additives such as viscosity index improver, dispersant, detergent, antioxidant and friction modifier on the tribological performance were investigated, [20 - 32]. It was indicated that copper nano-particles enhanced wear resistance. Addition of ZDDP are improved the antioxidation performance of the tested additives. It was found that the combination of ZDDP and tungsten disulfide (WS_2) nano-particles improved the tribological performance of oils, [33, 34], where the wear resistance was enhanced and oxidation was reduced. It was shown that magnesium silicate hydroxide (MSH) dispersed by magnesium oxide and silica showed better wear resistance than base oil, [35].

An oil additive containing phosphorus and nitrogen dispersed in synthetic ester proved to be effective in reducing wear, [36]. Hydraulic oil were developed to meet the increased power in different application, [37 – 39]. Some of the lubricant additives are polar compounds that they are attracted and adhered to the metal surfaces, [40, 41]. Ester

molecules are more polar than the mineral base oils. ZDDP was added to hydraulic oil dispersed by highly polar dispersants. Sulphur and phosphorus compounds, [42], increase the extreme-pressure (EP) ability of the lubricant.

The friction modifiers were used to eliminate stick-slip between steel and nylon in the hydraulic cylinder, [43]. It was indicated that stick-slip was caused by the adherence of iron oxide transferred from the steel surface into seal surface. It was proved that certain soaps exhibit stick-slip than carboxylic acids. Stick-slip is caused by the by the fluctuations of the friction force occurred in slide ways of machines, metal forming and hydraulic cylinder that running at low sliding velocities. The fatigue of the sliding surface as well as poor surface finish are the main reasons of stick-slip.

Lubrication reduces friction between the two sliding surfaces by separating them by the lubricant film. The particles dispersed in oil fill the peaks and valleys and reduce the friction. The lubricant additives act in different mechanisms. The addition of CeO_2 and $CaCO_3$ spherical nanoparticles into lubricating oils, [44, 45], reduced both wear and friction compared with base oil. Besides, it was reported that the $CaCO_3$ nanoparticles have microball bearing effects leading to the decrease of on friction. It was revealed that nano-particles as additives in oils provided material filling behavior and micro-ball bearing effect between the rubbing surfaces such as carbon black soot particles, spherical zinc aluminate spinel ($ZnAl_2O_4$) nanoparticles, lanthanum borate, Polytetrafluoroethylene (PTFE), MoS_2 nano-sheets and nano-tubes as well as nano magnesium silicate, [46, 47, 48, 49 - 60].

Hydraulic fluids are based on the mineral oil that causes problems for human beings and environment. Proposed hydraulic fluid free of mineral oil and biocides was developed to be compatible to the environment, [61]. It consisted of glycerol, carboxymethyl chitosan, and water. Hydraulic fluids are widely used in different processes and engineering applications. Glycerol and chitosan were applied in hydraulic fluid, [62 – 68].

In the present work, the tribological performance of anti-wear additive dispersed in hydraulic oil will be investigated, where the friction and wear will be evaluated.

EXPERIMENTAL

Experiments were carried out using reciprocating pin-on-plate wear tester. The test rig consists of bearing material pin of 8 mm diameter and 20 mm length. The pin is loaded against stainless steel plate by 10 N load, Fig. 1. The stainless steel disc (counterface) is assembled in the reciprocating table that sealed by plastic sheet to prevent the oil leakage. The rig is fitted by Arduino to plot the friction force measured by load cell. Wear was measured by weight loss of the pin before and after test. Then the worn surface of the tested pin was inspected by optical Microscope, Fig. 2.

In the present experiments mineral base hydraulic oil ISO 46 was used. The tested oil additive (OLOA 26008A) that contains zinc/phosphorus compounds and is known as zinc dialkyldithiophosphate (ZDDP) was dispersed in the hydraulic oil. The contents of the tested wear additive were 0.2, 0.4, 0.6, 0.8 and 1.0 wt. % relative to the base hydraulic oil.

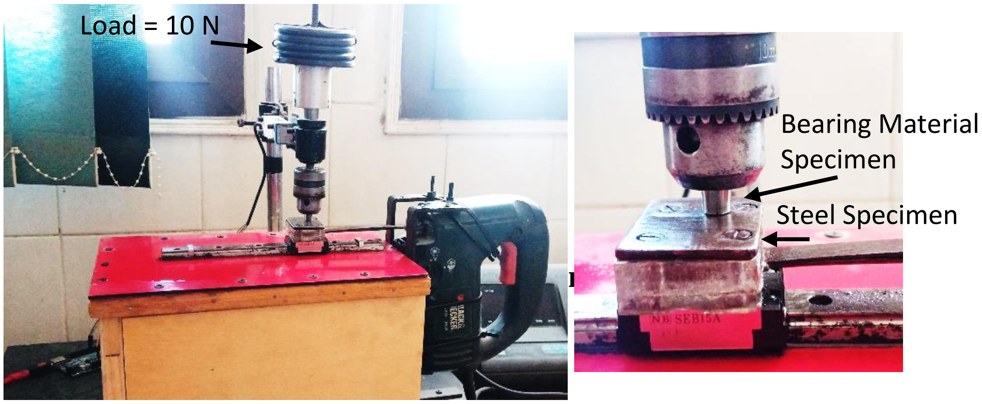


Fig. 1 Reciprocating pin-on-plate wear tester.

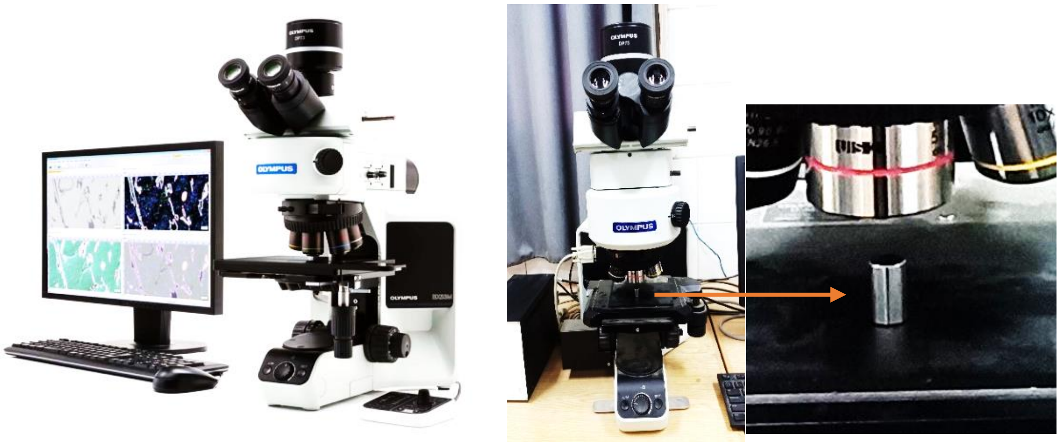


Fig. 2 Arrangement of the inspection of the worn surface of the test specimens.

RESULTS AND DISCUSSION

Experimental observations of friction coefficient displayed by the test specimens showed that friction coefficient drastically decreased down to minimum then slightly increased with increasing additive content, Fig. 2. At 0.6 wt. % content of the tested additive, friction coefficient showed the minimum values (0.013). Further increase in the additive content slightly increased friction values. This behavior can be attributed to the function of the protective film generated from the decomposition products of the additive that work as solid lubricants that result in decreasing friction.

Wear of the test specimens is shown in Fig. 3. It is shown that wear drastically decreased with increasing additive content up to 1.0 wt. %. The anti-wear property of the tested additive can be interpreted on the basis of the chemical reactions and the formation of

organometallic compounds produced from the frictional heating. The tested additive has anti-wear property. Its function depends on forming boundary film on the sliding steel surfaces consists of iron sulfide of relatively high hardness that decelerates excessive wear.

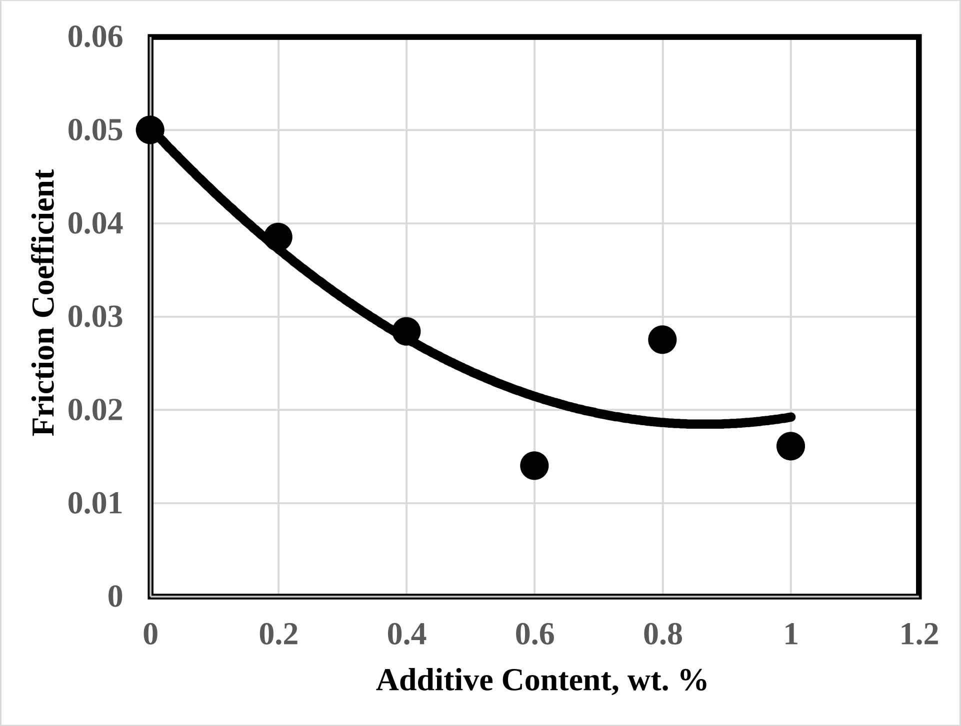


Fig. 2 Friction coefficient displayed by the test specimens lubricated by hydraulic oil dispersed by the tested additive.

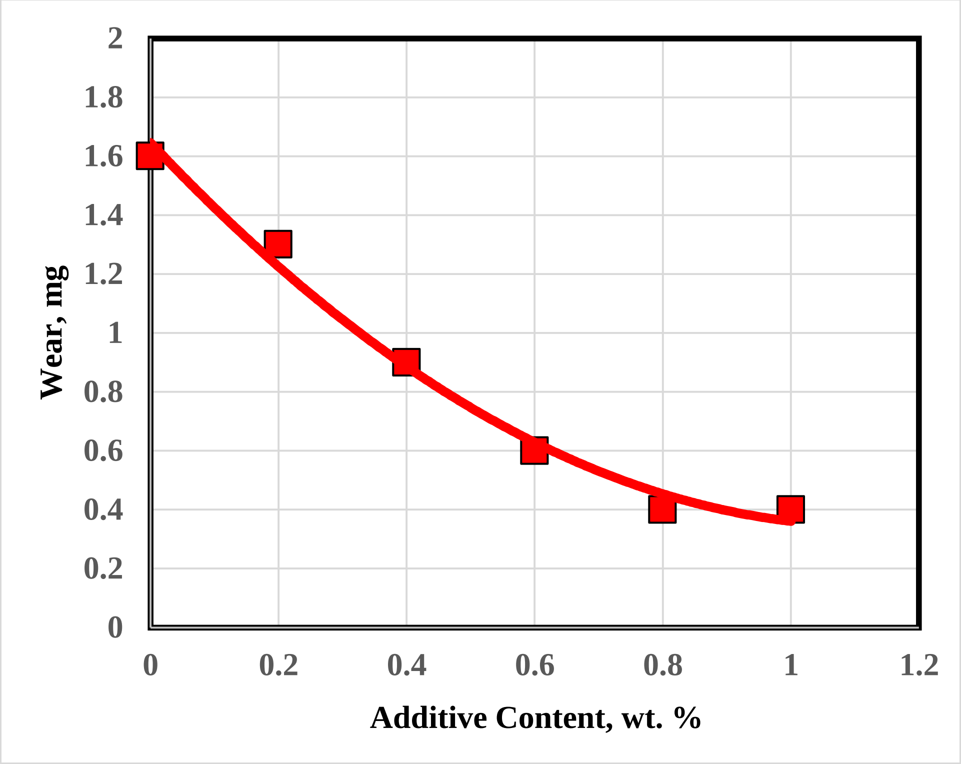


Fig. 3 Wear displayed by the test specimens lubricated by hydraulic oil dispersed by the tested additive.

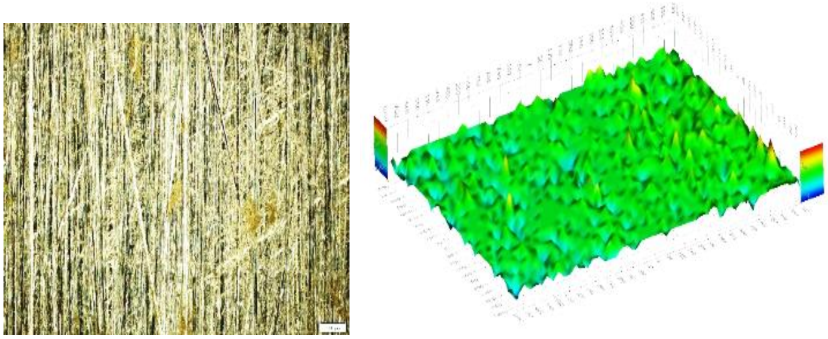


Fig. 4 Photomicrograph and surface topography of the worn surface of test specimens lubricated with hydraulic oil free of additive.

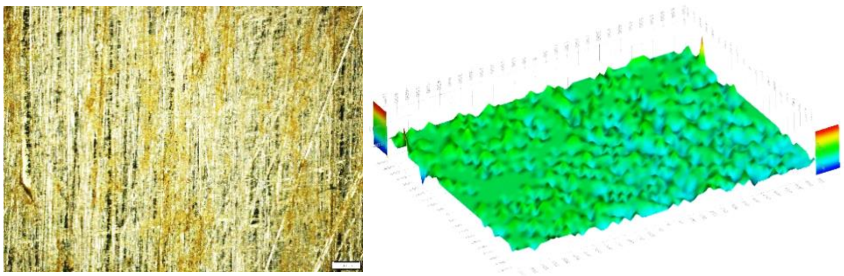


Fig. 5 Photomicrograph and surface topography of the worn surface of test specimens lubricated with hydraulic oil dispersed with 0.2 wt. % additive content.

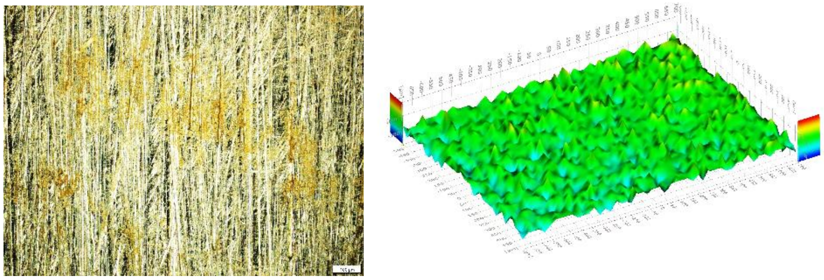


Fig. 6 Photomicrograph and surface topography of the worn surface of test specimens lubricated with hydraulic oil dispersed with 0.4 wt. % additive content.

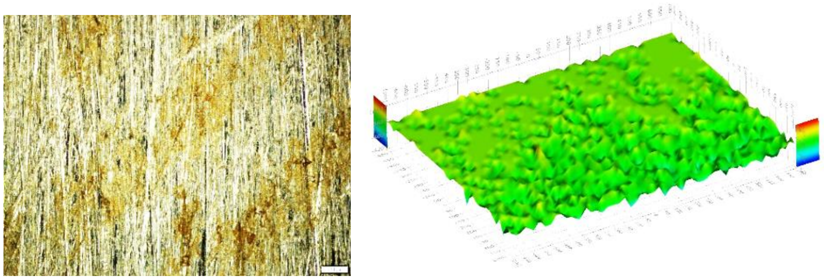


Fig. 7 Photomicrograph and surface topography of the worn surface of test specimens lubricated with hydraulic oil dispersed with 0.6 wt. % additive content.

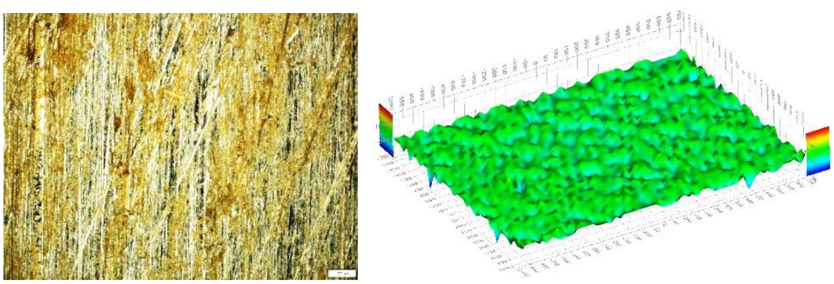


Fig. 8 Photomicrograph and surface topography of the worn surface of test specimens lubricated with hydraulic oil dispersed with 0.8 wt. % additive content.

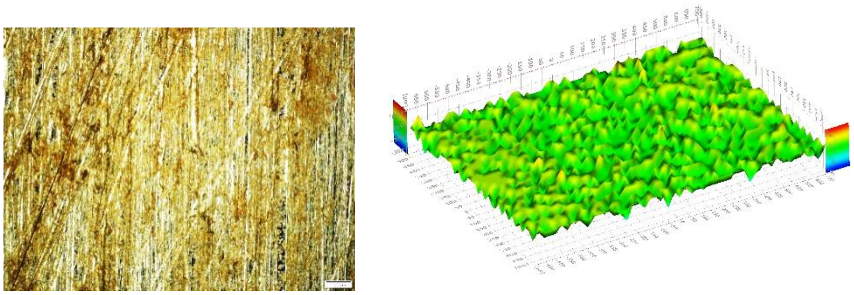
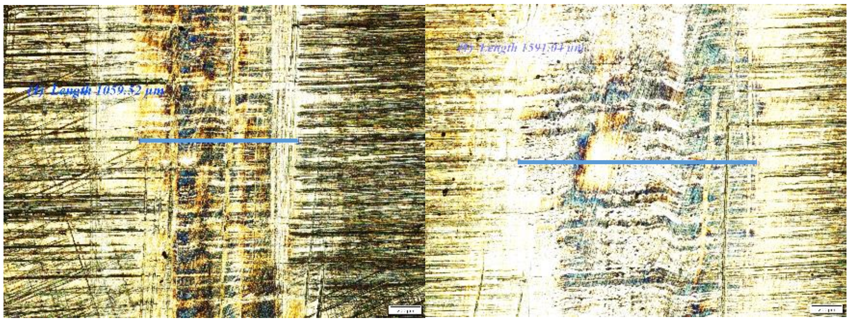


Fig. 9 Photomicrograph and surface topography of the worn surface of test specimens lubricated with hydraulic oil dispersed with 1.0 wt. % additive content.



a. **b.**

Fig. 10 Photomicrograph of the worn surface topography of the worn surface of the stainless steel plate specimens lubricated with hydraulic oil dispersed with; a. 1.0 wt. % additive content and b. oil free of additive.

The worn surfaces of the specimens were inspected by optical microscope after rubbing against the steel counterface to evaluate the wear. The topography of the worn surfaces and 3D profile of the surface texture were analyzed. Figures 4 – 10 displays the detailed images of the wear marks on the surface of pin and the surface of the stainless steel plate. Inspecting the wear tracks formed on the rubbing confirmed the enhancing role of the tested additive in reducing wear. For oil free of additive, the severity of wear is clearly shown, Fig. 4. As the additive content increased the worn surfaces showed relatively

smoother texture, Figs. 5 – 9. The same trend was observed for the stainless steel counterface indicating the effectiveness of the additive.

CONCLUSIONS

1. Friction coefficient decreased down to minimum at 0.6 wt. % content of the tested additive then slightly increased with further additive increase.

2. Wear of the test specimens decreased with increasing additive content. The lowest wear values were observed at 1.0 wt. %.

3. Inspection of the worn surfaces of the test specimens by optical microscope after test confirmed the enhancing role of the tested additive in reducing wear.

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