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TRIBOLOGICAL PERFORMANCE OF ANTIWEAR ADDITIVE DISPERSED IN HYDRAULIC OIL

Touny A. R. M., Mahmoud M. M. and Ali W. Y.

Department of Production engineering and Mechanical Design, Faculty of Engineering, Minia University, El-Minia, EGYPT.

ABSTRACT

The antiwear properties of hydraulic oils containing zinc dialkyl dithiophosphates are discussed. The tested additives are added to hydraulic oil at different concentrations. Tests were carried out to investigate the friction and wear of steel lubricated by these additives using pin on disc wear tester.

The experiments of the present work reveals that friction coefficient significantly increased as the applied load increased. Addition of the additive into hydraulic oil decreased friction coefficient, where the lowest friction values were observed at 1.0 wt. % of the additive content. The same trend was observed when the test specimens were lubricated by relatively high viscosity hydraulic oil. Besides, wear decreased with increasing additive content. The lowest values were measured for the 1.0 wt. % additive content. The viscosity improver decreased the values of wear.

The decrease of friction and wear can be attributed to the decomposition products of the additive that work as solid lubricants. While increasing the viscosity enabled the oil to form relatively thicker oil film between the sliding surfaces.

KEYWORDS

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

INTRODUCTION

The service life as well as reliability of fluid power system greatly depend on the anti-wear additives in hydraulic oils. The increase of oil pressure, velocity and temperature accelerates the use of anti-wear additives. Vegetable oils are can be used as lubricants under certain conditions. They should be chemically modified. Oxidative and thermal stability of vegetable oil can be improved by eliminating the hydrogen, [1 - 6], where the friction modifier effect of the lubricant can be enhanced. The relatively low viscosity is one of the main drawbacks. The increase of the power of machines should be accompanied by studying the parameters influencing the friction and wear by introducing new lubricating additives, [9 – 16], to reduce friction, wear and energy consumption. The anti-wear additives have the main role in enhancing the tribological performance of the lubricants. Sulfur, phosphorus, and chlorine

are the conventional lubricant additives. Because they have hazardous effect on the environment, [17 - 19], it is necessary to invent effective green additives.

Sulphur containing additives are dispersed in most commercial transmission oils as anti-wear and extreme-pressure additives. In condition of excessive load, they are used to prevent metal to metal contacts. Decomposition products of compounds containing phosphorus, sulphur, or chlorine react with metal surfaces forming the reaction products that act as solid lubricants. It is generally accepted that the anti-wear and extreme pressure properties of organosulphur oil additives are related to the C-S bond energy of monosulphides. The weaker the C-S bond energy, the easier the formation of a protective film, resulting in better anti-wear efficiency. Calcium sulfonates are generally used as detergent additives and corrosion inhibitors in lubricating oil. Moreover, they possess anti-wear properties in boundary lubrication, [20 - 23]. The boundary film formed on rubbing surfaces mainly consists of calcium carbonate. Recently, the influence of the addition of calcium sulfonate detergent (CaSu) on the anti-wear properties of sulfuride olefin (SO) and tricresyl phosphate (TCP) was studied, [24]. Test results indicate that CaSu can improve the antiwear properties of SO and TCP. In the case of the lubrication of CaSu plus SO, the improved antiwear property is caused by the formation of a surface deposition film containing $CaCO_3$ from the CaSu and the neutralization of CaSu that could prevent excessive corrosion wear. In the case of the lubrication of CaSu plus TCP, calcium phosphate was formed and incorporated into the surface film, which possesses good anti-wear characteristics.

Nano-additives are extensively used due to their relativity high thermal stability and wear resistance, [25 - 27]. Different metal borate nano-particles were investigated, [28 - 35]. Their mechanism of action depends on the formation of tribochemical film due to the deposition of the nano-particles on the sliding surface. The size, shape, and concentration of the nano-particles affect the friction and wear. The favorable wear resistance of flaky zinc and calcium borate is related to the lamellar structure, [36 - 42].

Lubricant additives such as zinc dialkyl dithiophosphates(ZDDP) are used to extend machine lifetimes, [43]. It was proved that the addition of ZDDP effectively increases the scuffing load. Wear of the surfaces of machine elements is caused by scuffing and pitting. The addition of the additives to the lubricants can prevent the failure of the oil layers and enhance scuffing resistance by introducing protecting tribofilm, [44 - 51]. It was found that ZDDP formed a thick reaction tribofilm on the sliding surfaces that decreased metal-to-metal contact, [52 - 56]. Besides, ZDDP tribofilm consisted of iron sulfide and amorphous phosphate.

Polymethacrylate polymers were inspected as multi-functional lubricant additives. They showed quite good viscosity index and friction, [57]. The decrease of viscosity with temperature could compensate and friction modifiers could reduce friction in both boundary and mixed lubrication. The two mentioned lubricant properties can affect the performance of the hydraulic fluids. In addition to that, there are several types of lubricant additives such as polar polymeric molecules that can adsorb onto the sliding surfaces and form protective layers in the mixed and boundary lubrication regimes like lubrication of hydraulic cylinders.

Isopropyl triisostearyl titanate containing graphene oxide (T-GO) was investigated to enhance the dispersion stability in hydraulic oil. The lubrication performance of T-GO hybrid hydraulic oil was attributed to the formation of graphene-like tribo-film that was able to reduce the friction and protect the sliding surfaces from excessive wear, [58]. The performance requirements of the hydraulic oil such as antirust, lubrication and anticorrosion, [59, 60], should be guaranteed by adding nanoparticles such as molybdenum disulfide (MoS_2), aluminium oxide (Al_2O_3), copper oxide (CuO), zinc oxide (ZnO), titaniumdioxide (TiO_2), and graphene, [61 - 87].

The present work investigates tribological performance of anti-wear additive dispersed in hydraulic oil, where the friction and wear were measured.

EXPERIMENTAL

Experiments were carried out by use of pin-on-disc wear tester, Fig. 1. Friction test period was 30 minutes under constant sliding velocity of 1.0 m/s and varying values of load (8, 10, 12, 14, and 16 N). The test specimen, in the form of cylindrical pin of bearing steel, had 10 mm diameter and 20 mm height. The material of the counterface was stainless steel of 0.5 µm R_a surface roughness. The Readings of the friction force were recorded and the average was considered. Wear was calculated by the difference between the weight of the pin before and after the test.

Mineral base hydraulic oil ISO 46 was used in the present experiments. The tested oil additive (OLOA 26008A) contains zinc/phosphorus compounds and is known as zinc dialkyldithiophosphate (ZDDP). Two types of viscosity additives are used the first will be noted as low viscosity while the second will be high viscosity. The concentration of the tested wear additive was 0.2, 0.4, 0.6, 0.8 and 1.0 wt. % relative to the base oil.

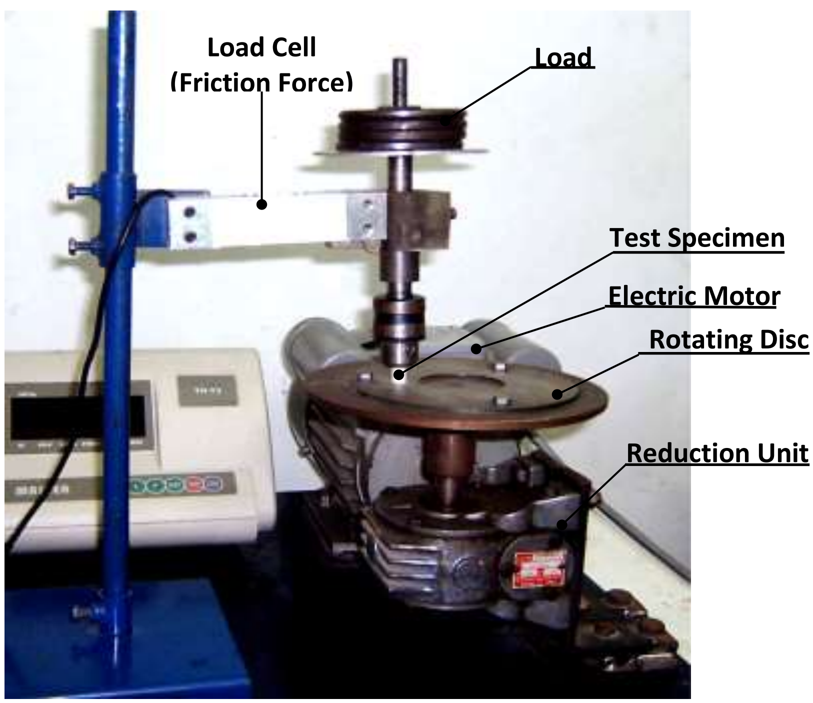

Fig. 1 Arrangement of friction test rig.

RESULTS AND DISCUSION

The results and discussion of the experiments carried out using low viscosity are shown in Figs. 2 – 5. Friction coefficient displayed by low viscosity hydraulic oil versus applied load is shown in Fig. 2, where friction coefficient significantly increased with increasing the applied load. When the concentration of the tested additive dispersed in the hydraulic oil reached 0.6 wt. %, friction coefficient showed the minimum values. Further increase in the additive content up to 1.0 wt. %, Fig. 3, caused relatively lower friction values. It seems that the decomposition products of the additive containing phosphorus react with metal surfaces and form the reaction products that work as solid lubricants. The anti-wear and extreme pressure behavior of the tested additives are related to the formation of the protective film that resulting in decreasing friction. At 1.0 wt. % of the additive content, the values of friction coefficient were 0.04 and 0.09 at 8 and 16 N load respectively.

Experiments carried out using high viscosity hydraulic oil are shown in Figs. 4 and 5. It is clearly seen that friction coefficient displayed slight decrease compared to that test specimens lubricated by low viscosity hydraulic oil. That behavior can be attributed to the ability of oil to form relatively thicker oil film between the sliding surfaces. The 1.0 wt. % of the additive content in the oil still represented the lower values of friction of 0.02 and 0.09 at 8 and 16 applied load respectively. Besides, oil free of additive showed the slight decrease confirming the effect of viscosity improver.

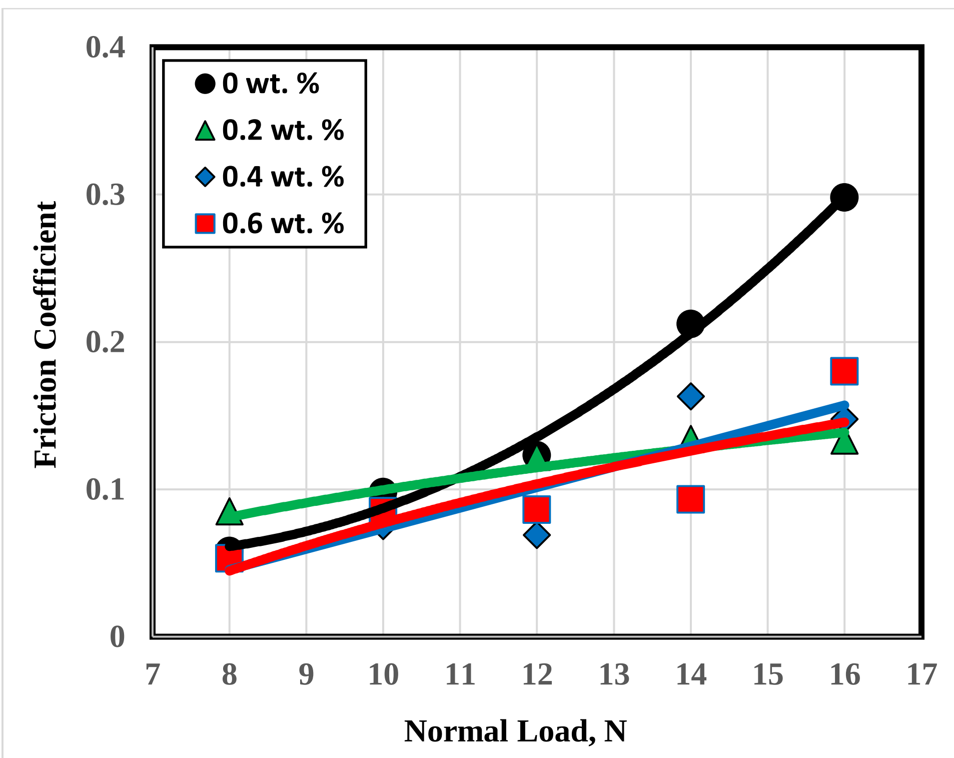

Fig. 2 Friction coefficient displayed by low viscosity hydraulic oil.

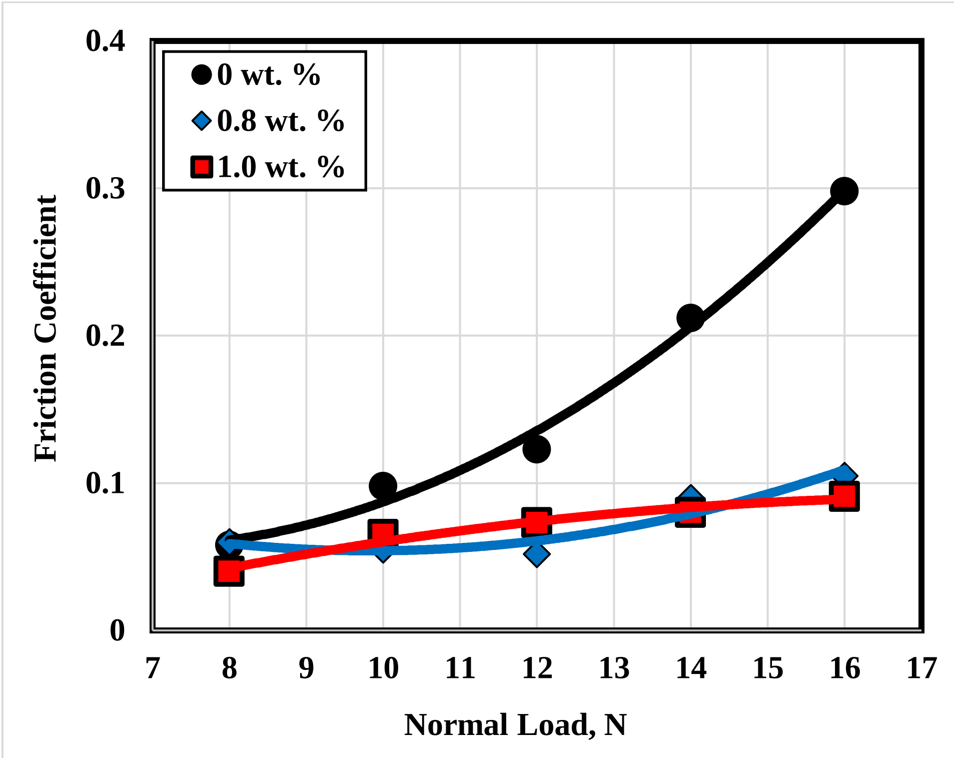

Fig. 3 Friction coefficient displayed by low viscosity hydraulic oil.

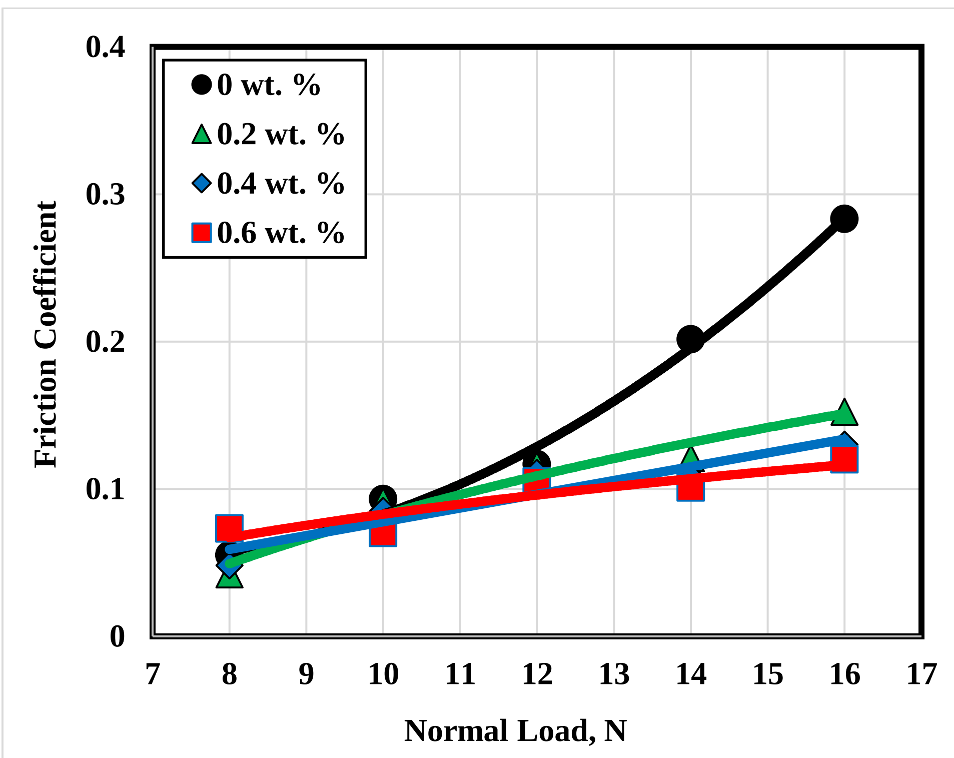

Fig. 4 Friction coefficient displayed by high viscosity hydraulic oil.

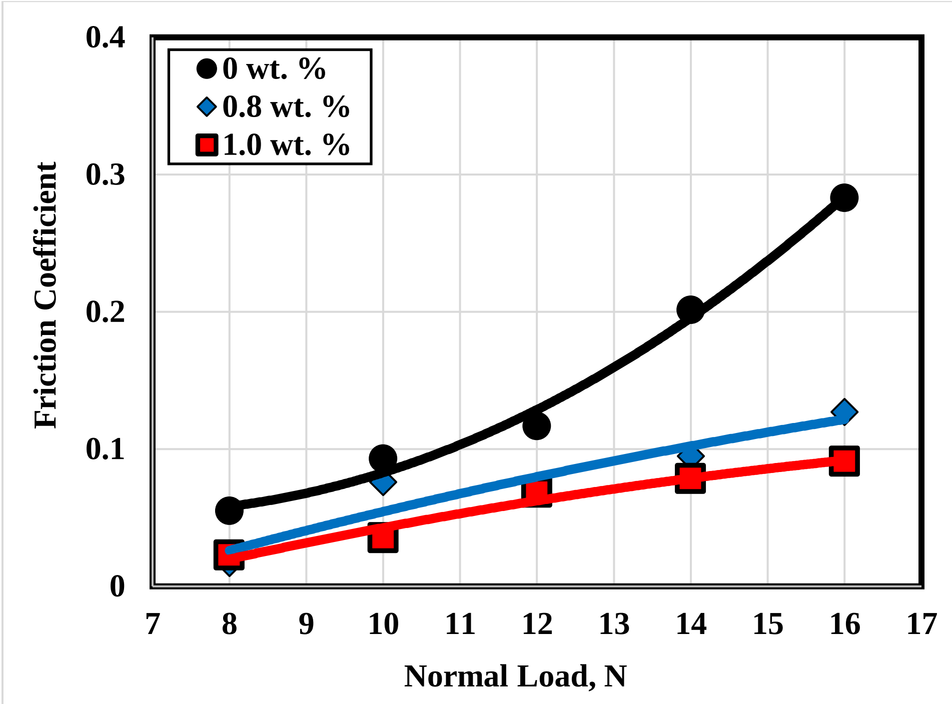

Fig. 5 Friction coefficient displayed by high viscosity hydraulic oil.

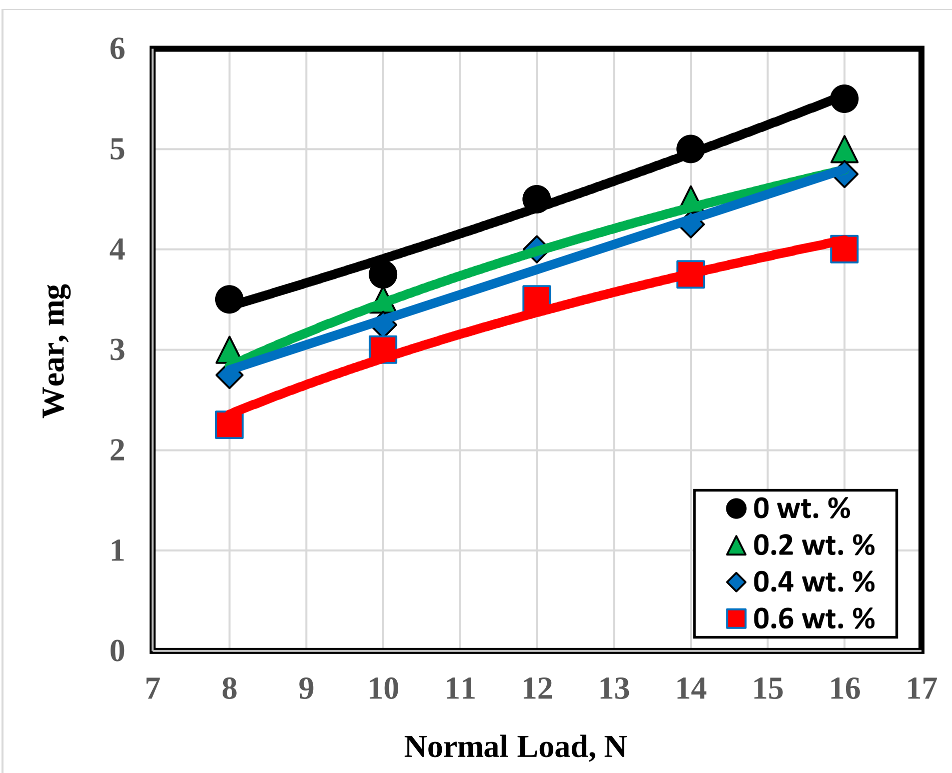

Fig. 6 Wear displayed by low viscosity hydraulic oil.

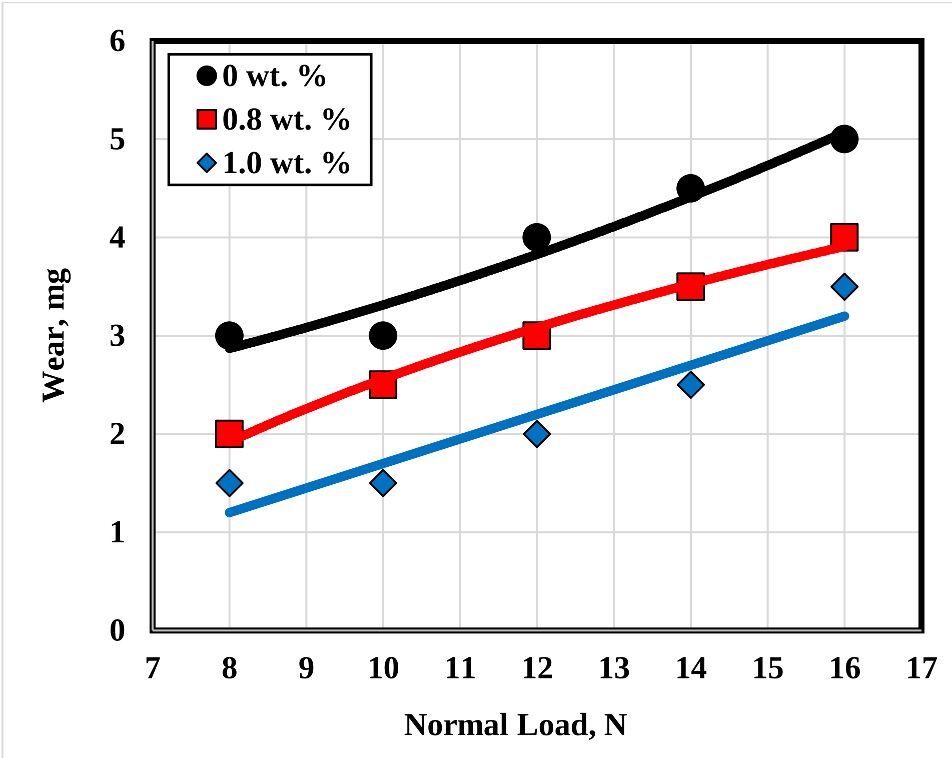

Fig. 7 Wear displayed by low viscosity hydraulic oil.

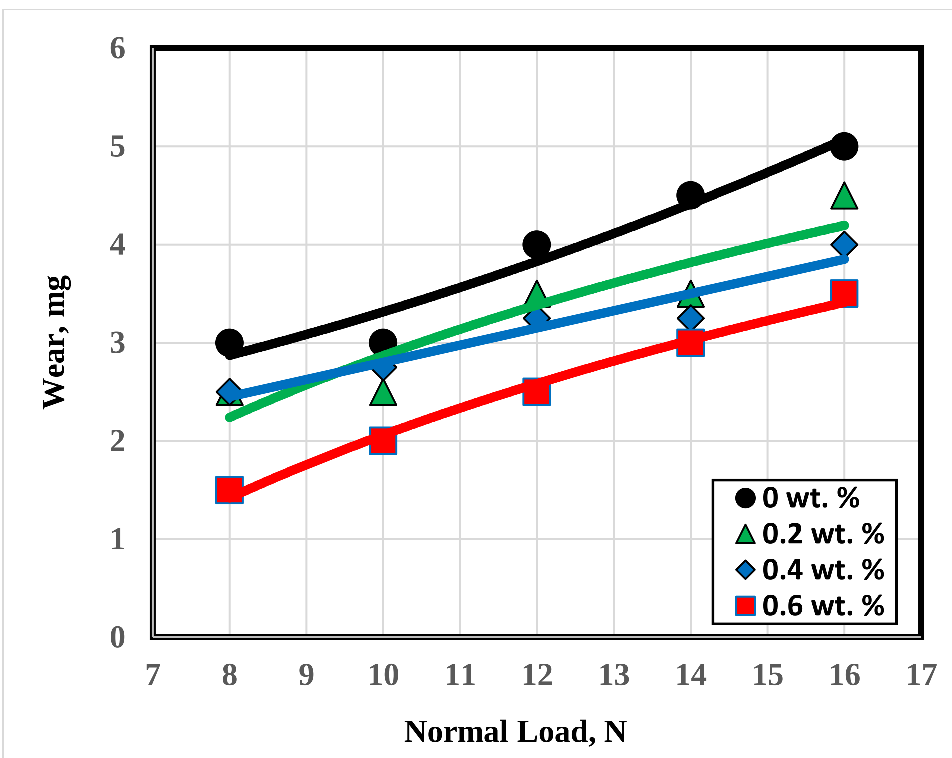

Fig. 8 Wear displayed by high viscosity hydraulic oil.

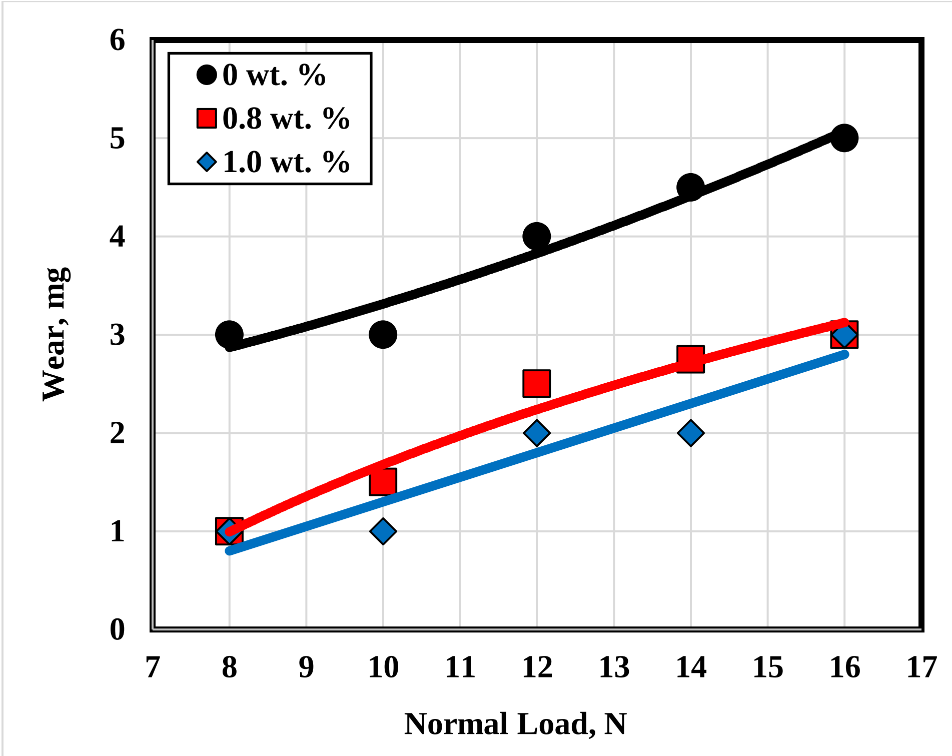

Fig. 9 Wear displayed by high viscosity hydraulic oil.

The results of wear of the test specimens to investigate the effect of the tested additive as well as the viscosity improver are shown in Figs. 6 – 9. It is shown that wear of test specimens significantly increased with increasing normal load when they were lubricated by low viscosity hydraulic oil, Figs. 6 and 7. As the content of the additive increased wear decreased, where the lowest values were measured for the 1.0 wt. % additive content. The enhancing role of the tested additive can be attributed to the chemical reactions such as oxidation of the surface and the lubricant as well as polymerization and the formation of organometallic compounds produced as result of the frictional heating. The tested additive function well with the accompanying hydraulic fluid. The formation of the reaction products can bear the load under severe stress conditions, distribute the load and provide shear film that prevents high forces from shearing. The hydraulic oil contains detergent additives such as calcium sulfonates, (CaSu). They have anti-wear properties especially in boundary lubrication. Their function depends on forming boundary film on the sliding surfaces consists of calcium carbonate. It was proved that CaSu improves the anti-wear properties of additive by deposition on the sliding surfaces and preventing excessive wear.

The results of experiments carried out to test the performance of the tested additive when dispersed in relatively high viscosity hydraulic oil is illustrated in Figs. 8 and 9. The same trend observed in friction was observed in wear, where the lowest wear values were observed for oil dispersed by 1.0 wt. % additive. The influence of the viscosity improver was decreasing the values of wear.

CONCLUSIONS

1. As the applied load increased, friction coefficient significantly increased.

2. Increasing additive content decreased friction coefficient, where the lowest friction values were observed at 1.0 wt. % of the additive content.

3. Friction coefficient decreased when the test specimens were lubricated by relatively high viscosity hydraulic oil.

4. Wear increased with increasing normal load. The lowest values were measured for the 1.0 wt. % additive content.

5. The viscosity improver decreased the values of wear.

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