ISSN 0208-7774 TRIBOLOGIA 2/2019 p. 37–41
DOI: 10.5604/01.3001.0013.4148

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THE INFLUENCE OF ADDITIVES ON THE OXIDATIVE STABILITY AND FATIGUE LIFE OF LUBRICATED FRICTION PAIRS

WPŁYW DODATKÓW NA STABILNOŚĆ OKSYDACYJNĄ I TRWAŁOŚĆ ZMĘCZENIOWĄ SMAROWANYCH WĘZŁÓW TARCIA

Key words: additives, mineral oil, greases, lubricity properties.

Abstract The objective of the study was to determine the influence of different additives, namely, graphite, nanostructures of carbon, and polymer PTFE on the lubricating properties in reference to grease based on paraffin oil without an additive. The synergies of different additives were examined when both were simultaneously added. The improvement of the friction properties may be caused by the chemical elements that are absorbed on the surface. The steel-steel friction contacts were lubricated with the use of the developed lubricants. The experiments were carried out with the use of a four-ball pitting tester. The relationships between additives and the tribological properties were analysed. The correlation between thermal stability of lubricants and fatigue life was evaluated.

Słowa kluczowe: dodatki, olej mineralny, smary plastyczne, właściwości smarne.

Streszczenie Celem badań było określenie wpływu różnych dodatków, a mianowicie: grafitu, nanostruktur węgla i polimeru PTFE na właściwości smarne w odniesieniu do smaru na bazie oleju parafinowego bez dodatku. Oceniono synergię działania dodatków, gdy oba zostały dodane jednocześnie. Poprawa trwałości zmęczeniowej może być spowodowana przez pierwiastki chemiczne, które są absorbowane na powierzchni. Stalowe cierne styki zostały nasmarowane przy pomocy opracowanych smarów. Eksperymenty przeprowadzono przy użyciu testera do badania pittingu. Przeanalizowano zależności między dodatkami a właściwościami tribologicznymi. Oceniono korelację między stabilnością oksydacyjną smarów a trwałością zmęczeniową.

INTRODUCTION

The proper design of a lubricant is crucial to ensure the resistance to wear of the friction elements in industrial equipment. The lubricants have to meet many demands concerning the process parameters, such as load, temperature, velocity **[L. 1]**, and environmental requirements with the elimination or considerable reduction of toxic chemical compounds **[L. 2]**. Resistance to wear of the friction joins partially depends on additives that improve the anti-wear properties **[L. 3]**.

The problem of surface fatigue wear relates primarily to the contacts of the rolling elements and connections subjected to vibration, and they are a major factor in the degradation of functional properties of the object, which include elements of rolling bearings, gears, and camshafts. The systematically is increasing interest in improving the reliability and durability of the nodes rolling/sliding which work in extreme conditions. This is the cause of the rapid development of research aimed at reducing the wear by fatigue **[L. 4–6]**.

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The users of rolling bearings expect reliable operation during a given time, so fatigue wear during that time is unacceptable. Because of this, the fatigue wear is measured as the time after which signs of the fatigue wear were observed in 10%, 50%, and 90% of tested balls, and these indicators are refer to as L_{10}, L_{50}, and L_{90}. The properties of friction and wear of materials and lubricants are investigated with the use of tribological tests. Much research is conducted to identify the relationships of the different tribological properties of lubricants **[L. 7]** and the influence of grease compositions on lubrication properties **[L. 8, 12]**, and some of them are referred to morphological surface properties and tribological functionalities **[L. 9]**, the influence of tribological properties on structure changes **[L. 10]**, and a few studies concern molecular modelling of tribological properties **[L. 11, 13]**. In this article, we analysed the influence of polymer, fullerene, and graphite on resistance to oxidation and pitting. The additives were added separately, and two of them were added together. We considered the synergy of their impact.

MATERIALS AND METHODS

The greases were a compound with lithium thickener and different additives, namely, polymers (T), carbon nanostructures that contain fullerene (F), and graphite (G). The composition and abbreviation of the designed lubricant are given in **Table 1**.

The experiments have been carried out on the special versions of the four-ball-machine. The modified four-ball-machine is intended to identify surface fatigue in concentrated contacts under conditions of pure rolling. The steel-steel friction contacts were lubricated with the use of the investigated lubricants.

Table 1. Lubricating compositions
Tabela 1. Kompozycje smarowe

Grease abbreviation	Additives		
	Polymer T	Fullerene F	Graphite G
P	–	–	–
P-T	x	–	–
P-G	–	–	x
P-F	–	x	–
P-TG	x	–	x
P-TF	x	x	–

Oxidation resistance of greases was determined based on the oxidation onset temperature. Resistance to oxidation was determined based on the oxidation onset temperature (OOT) that was obtained from the Differential Scanning Calorimetry (DSC). The results were obtained for samples using a LABSystem SETARAM TG/DSC apparatuses that provides information about the temperature at which oxidation begins while heating in the atmosphere of oxygen. The temperature was extracted from the DSC curve and used for assessment of the resistance to oxidation of the base oils and compositions. The following parameters were used for DSC: sample of 3.5 ±0.3 mg, the range of the temperatures was 20–400°C, the speed of warming was 5°C/min, and the atmosphere was O_2.

The PetroOXY™test was used as the method of oxidation stability determination. The tests were conducted at 120°C, with continuous oxygen flow and the determined mass of the sample (10g). A characteristic parameter of Petrooxy tests is the time when the change of maximum pressure achieves 10%.

The surface fatigue (pitting) experiments were carried out on the T-03 Four-Ball Machine with the test contact shown in **Fig. 1**. The test parameters are given in **Tab. 2.**

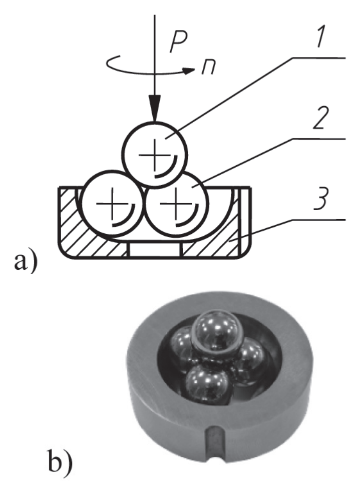

Fig. 1. Four-ball frictional contact: a) scheme (1 – bottom ball, 2 – upper balls, 3 – path), b) photographs
Rys. 1. Czterokulowy węzeł tarcia: a) schemat (1 – kulka dolna, 2 – kulki górne, 3 – bieżnia), b) fotografia

Table 2. The parameters values of the tribological fatigue test
Tabela 2. Wartości parametrów testu zmęczeniowego

Parameter	value
Rotational velocity of the upper ball	1450 rpm
Initial load of the test couple	981 N
Final load of the test couple	5886 N
Number of the test runs	24

In the tribological test results indicated the time to damage of 10%, 50%, and 90% of the all investigated friction contacts (24), and they were identified and designated adequately as L_{10}, $L_{50,}$ and L_{90}.

The resistance to oxidation of the greases is given in **Figure 2**, and the oxidation stability is presented in **Figure 3**.

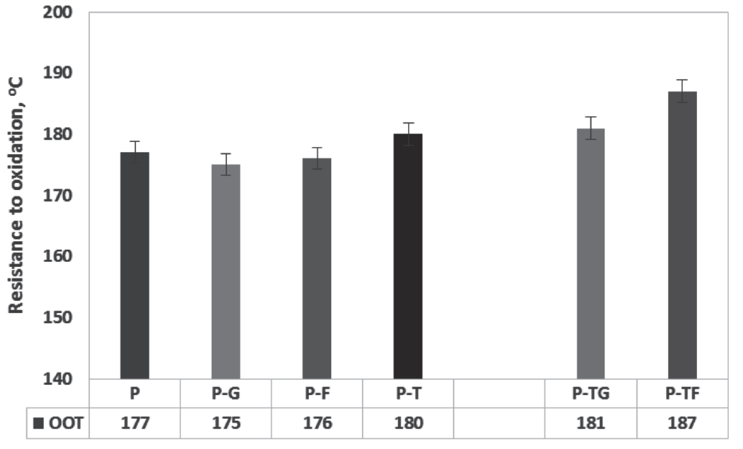

Fig. 2. The influence of the used additive on the resistance to oxidation according to DSC
Rys. 2. Wpływ zastosowanych dodatków na odporność oksydacyjną zgodnie z DSC

The results of analysis proved that polymer additive T and carbon nanostructure F additives are the most effective in resistance to increasing oxidation. For the additive graphite G, the change of the resistance to oxidation, in comparison with base grease P, is not evident.

Additives F and TF have the greatest impact on extending the oxidation induction time of greases. The carbon nanostructure additive F with polymer additive T significantly improves the resistance to oxidation of grease (**Fig. 2**) and greatly influences oxidative stability (**Fig. 3**).

The rolling contact fatigue life (L10, L50, L90 determined from Weibull probability plots) of the steel balls with the use of different greases were determined (**Fig. 4**).

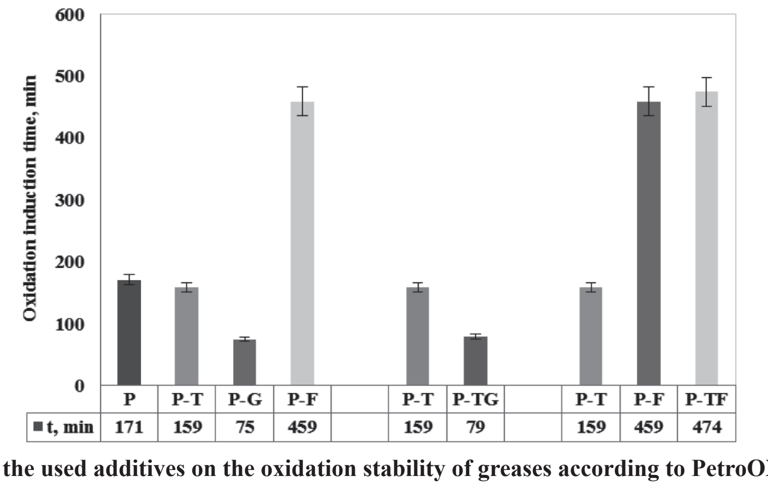

Fig. 3. The Influence of the used additives on the oxidation stability of greases according to PetroOXY
Rys. 3. Wpływ zastosowanych dodatków na stabilność oksydacyjną smaru na podstawie PetroOXY

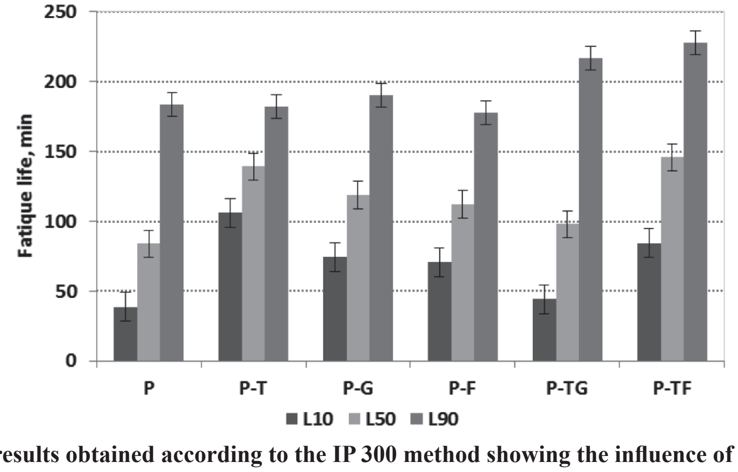

Fig. 4. The research results obtained according to the IP 300 method showing the influence of the greases on fatigue life
Rys. 4. Wyniki badań przeprowadzonych zgodnie z IP 300 przedstawiające wpływ smaru na zużycie zmęczeniowe

The use of the various kinds of additives and their combination to grease P altered the fatigue durability of the friction contact working with the greases used.

The highest durability was obtained with grease (P-TF) modified with polymers with carbon nanostructures for all of the analysed probability of damages, namely 10%, 50%, and 90%. The results clearly show that the addition of polymer together with carbon nanostructures significantly affects the delay of the appearance of the pitting of the tested friction pair.

The correlation of the lubricating properties of greases in different friction processes were analysed, (**Fig. 5**).

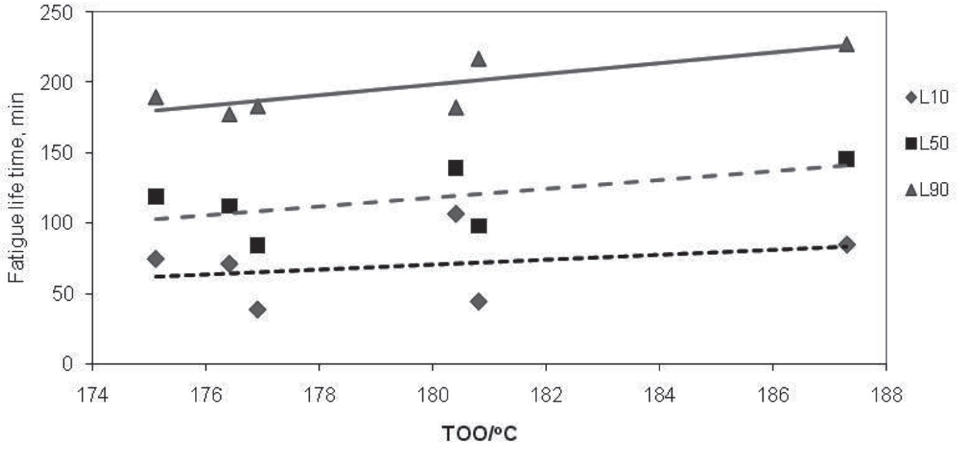

Fig. 5. Correlation between the oxidation resistance and fatigue life of tested lubricants
Rys. 5. Korelacja odporności na utlenianie i zużycia zmęczeniowego badanych smarów

As can be seen from the results shown in **Fig. 5**, the dependence between oxidative properties and fatigue wear is positive, but the correlation for all indicators is not significant, especially when the L10 is analysed. However, with the increase in the probability of damage, and the time of the working friction contact connected with it, the correlation also significantly increased. This is due to the increase in temperature along with the working time extension of the friction contact.

SUMMARY

Studies have shown the positive action of additives for oxidation resistance and fatigue life properties of the tested lubricants. However, the thermal and lubricated properties of the grease differ in relation to the additive. The simultaneous addition of polymer and nanostructures of carbon is the cause of the creation of synergies that significantly improve the properties of the grease.

The results of analysis proved that polymer additive T and carbon nanostructure F additives are the most effective in resistance to increasing oxidation. For the additive graphite G, the change in the resistance to oxidation, in comparison with base grease P, is not evident.

Additives F and TF have the greatest impact on improving the oxidative stability of greases. The carbon nanostructure additive F with polymer additive T significantly improves the resistance to the oxidation of grease and greatly impact oxidative stability.

Oxidizing properties of lubricants are not correlated with the tribological results, but that correlation increases along with the working time of friction contact. The improvement of lubricating properties is dependent on the type of additive.

In the case of the high working temperature of tribological couple, the advantages from the synergy of additives, namely a polymer and carbon nanostructures, were observed.

Studies have shown the positive action of additives for oxidation resistance and the anti-wear properties of the tested lubricants. However, the thermal and lubrication properties of the grease differ depending on the additive. The simultaneous addition of polymer and nanostructures of carbon cause the synergy that significantly improves the anti-wear properties.

Project co-financed by the European Union from the European Regional Development Fund under the Intelligent Development Program POIR 04.01.02-00-0004/16

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