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PROPERTIES OF LUBRICANTS DESIGNED FOR WC/C-COATED ELEMENTS OF TRIBOSYSTEMS

Key words

Tribosystem, WC/C coating, wear, scuffing, pitting, lubricating additives, lubricity.

Abstract

Synthetic-oil based lubricants designed for WC/C-coated elements of tribosystems were formulated. These lubricants were mixtures of poli- α -olefin oil (PAO-8) and different contents of an ecological additive package (containing products of chemical or biochemical conversions of substances of plant origin) and essential improvers such us anti-foaming agents, dispersants, and corrosion inhibitors. AW/EP and antipitting properties of the lubricants in a WC/C-WC/C tribosystem were investigated. On this basis, the most efficient lubricants were indicated. It has been found that lubricants with improved ecological qualities can reduce wear and scuffing of the tribosystems. However, the problem to be solved is the formulation of lubricants preventing pitting in WC/C-WC/C tribosystems.

Introduction

The tribological system consists of three main components: tribosystem material, lubricant, and environment [1]. During operation, tribosystems properties

can be changed, the nature of which is formed by lubricant components [2–3]. Many interactions and connections occur between the ingredients and tribosystem material, which determine the final properties of the tribosystems [4–5]. The complexity of reactions in the tribosystems increases the duration and expenses of forming new lubricants. The usage of low-friction WC/C-coated elements enables a change in the approach to lubricant properties and simultaneously provides the possibility to enhance their ecological qualities [6–7]. However, this complicates the possibility to presumptively form lubricant properties.

The aim of this work was to develop model lubricants designed for tribosystems made of 100Cr6-steel elements coated with Tungsten Carbide/Carbon multilayers WC/C (a-C:H:W type).

1. Objects and test methods

WC/C coated materials cause a special interest due to their low friction coefficient and wear resistance [8]. However, their pitting susceptibility is significantly worse than steel [9–10]. The analysis of the WC/C coatings [11] and 100Cr6-steel properties allowed the selection of a lubricant base (poly- α -olefins), dedicated for this type of coatings [7, 11]. Moreover, the usage of minimum quality (<0.5% w/w) of classical antiwear and extreme pressure additives (AW/EP) was planned. However, the basic lubricant composition composites (1–25% w/w) are unconventional additives, such as products of chemical or biochemical conversions of substances of plant origin. As needed thickeners, antioxidants and corrosion inhibitors may be used. The composition of basic additives package and PAO-6 oil as the solvent is presented in Table 1. The ecological components in the additives package are substances derived from chemical (AW-I – fatty acid methyl esters, glycol and fatty acid diesters, estolides) or biochemical (AW-II – products of enzymatic esterification of fatty acids with alcohols of different structure) modifications of products of plant origin.

On the base of PAO-8 oil, model lubricant compositions including 5–25% w/w of AP were prepared, as presented in Table 1. Lubricant compositions were supplemented with other necessary functional additives (Tab. 2). Table 2 presents a model lubricant composition, which is a result of selection tests of individual component. Tests were conducted in a model tribosystem with concentrated contact [12].

Low friction WC/C-coated 100 Cr6-steel ball bearings with a diameter of 0.5 inches, a roughness (Ra) of 0.032 μm , and hardness of 62 ± 2 HRC, which constitute a four-ball tribosystem were used as testing material. Steel balls were used as reference material. During pitting, the upper ball was replaced with WC/C-coated cone. Before the tests, all test materials were separately cleaned in petroleum ether using an ultrasonic cleaner for 10 minutes.

Table 1. The composition of additives package (AP) used for forming of lubricants for WC/C-coated tribosystems

Component	Content [% w/w]
Solvent (PAO-6 oil)	89.0–25.0
Ecological additive I (AW-I)	5.0–25.0
Ecological additive II (AW-II)	5.0–25.0
Multifunctional additive (AW/EP)*	1.0–5.0
Polymer thickeners *	0.0–15.0
Antioxidant*	0.0–5.0
* commercial additive	

Table 2. Model composition of oil for lubricating WC/C-coated tribosystems

Component	Content [% w/w]
Base oil PAO-8	94.37-55.0
Additive package (tab. 1)	5.0-25.0
Antifoaming additive	0.03-1.0
Corrosion inhibitor	0.1-4.0
Washing and dispersing agent	0.5-10.0

Slide movement was modelled by means of a four-ball tribosystem with either constant or increasing load. The extreme-pressure functions of lubricating compositions were tested with increasing loads in the tribosystem [12]. Surface fatigue durability of WC/C coated elements were tested accordingly to method described [13]. Conventionally, the surface fatigue durability L_{10} is timed in minutes after which, in 10% of cases, surface damage to the friction element occurs.

An arithmetic mean of at least three parallel test was considered a test result. Outliers were detected by means of a Q-Dixon test with a statistical significance of $\alpha = 0.05$ and eliminated from the data set.

2. Lubricating properties of model lubricant compositions

The result of EP test (P_1) of lubricants is presented in Figure 1.

Tests of EP properties of the developed lubricant proved the effectiveness of introducing classic AW/EP additives. The thinness of the WC/C coating causes its local damages, which results in direct steel-steel tribosystem contact. The AW/EP additives function is to prevent scuffing of the WC/C-coated tribosystems when the coating is damaged. The high scuffing resistance of the WC/C-WC/C tribosystem is granted by the base oil (Fig. 1). The addition of extra 20% of AP causes a 20% increase in the P_1 value. With insufficient content of AP (5÷10%), P_1 is lower than for pure oil base.

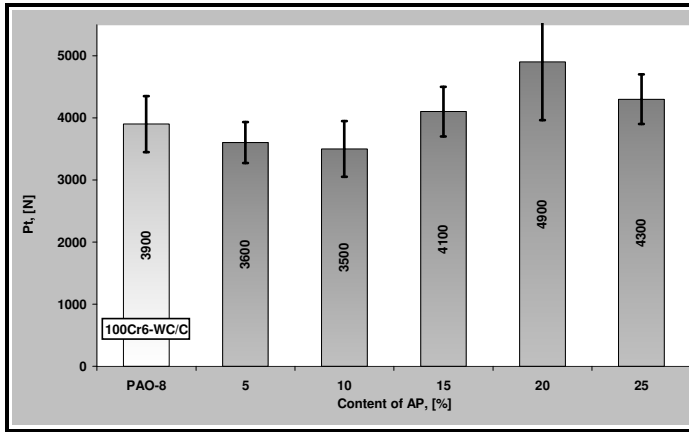


Fig. 1. Influence of AP content on extreme pressure properties of PAO-8 based lubricant

Similar to scuffing, the most effective AW actions (G_{oz}) were shown by 20–25% AP compositions. In this case, no connection between the low content (5 and 10%) of AP and the low value of G_{oz} was observed (Fig. 2). Introducing AP to PAO-8 improves its AW effect (Fig. 2). With its 20% content in the base oil, nearly 50% antiwear effect was gained. However, in every test, the WC/C coating was damaged during friction and the steel base was uncovered. This observation indicates the following:

- WC/C coatings are not effective in concentrated contact.
- In compositions intended for lubricating WC/C coatings, it is advisable to use AW/EP additives.
- Classical friction tests implementing concentrated contact may be inadequate for WC/C-coated tribosystem testing.

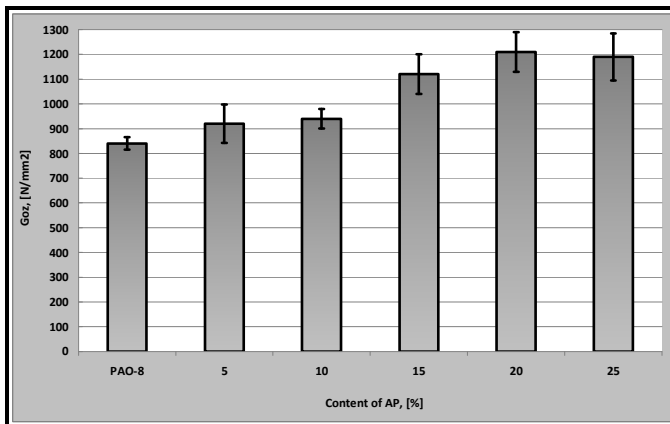


Fig. 2. Influence of AP content on AW properties of PAO-8 based lubricant composition

The developed lubricating compositions did not prevent the WC/C coating damage in concentrated contact. Figure 3 presents the value L_{10} for oil bases (PAO-6 and PAO-8) and their compositions containing 20% of AP (Tab. 1) and other improvers specified in Tab. 2 in proper amounts.

The data in Fig. 3 indicates that WC/C coating pitting depends also on the viscosity of the lubricant. For both PAO oils and PAO-based lubricant compositions, a lubricant with higher viscosity reduces pitting better than a lubricant with lower viscosity. Introducing a set of functional additives into the base oil wear can enhance the pitting resistance of the tribosystem by about a 40% increase of the L_{10} value for PAO-8 oil (Fig. 3). However, this value is a few times worse than for a steel tribosystem operated in comparable conditions. An explanation of causes and the development of anti-pitting methods for WC/C-coated elements require more detailed research in this area.

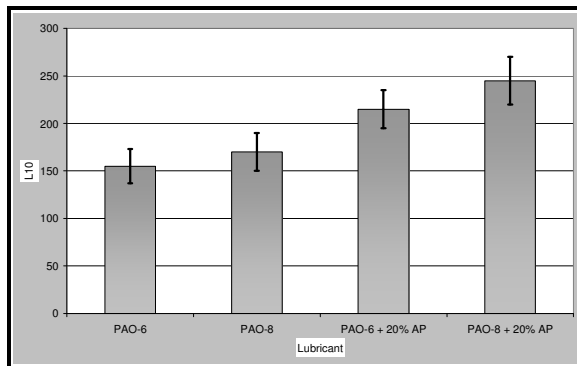


Fig. 3. Pitting of WC/C-coated elements expressed as L_{10} indicator in the presence of various lubricants

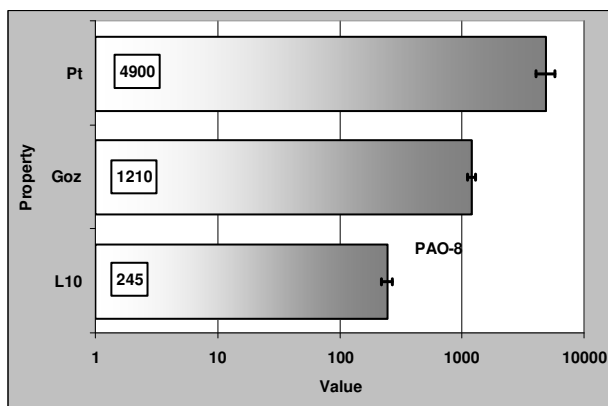


Fig. 4. Scuffing load (P_t , [N]), limiting wear index (G_{oz} , [N/mm²]) and pitting (L_{10} , [min]) results for WC/C-WC/C tribosystem lubricated with PAO-8 + 20% AP composition

Figure 4 presents compilation of values of particular parameters resulted from tests of model lubricant, PAO-8 based with ecological AP in four-ball tribosystem (P_t and G_{oz}) and cone/three-ball (L_{10}).

Data presented in Figure 4 refers to lubricant composition, which was considered as a model intended for lubricating WC/C-coated elements of tribosystems. The developed composition enables the reduction of wear and scuffing and an increase in pitting resistance for the tribosystem. It is still several times lower than values for a steel tribosystem operated in similar conditions. Nevertheless, in some technical cases, a 40% increase of pitting resistance may be considered sufficient.

Conclusions

PAO-8 is the oil with the highest utility potential as an oil base for composing lubricants for WC/C coatings. It is determined by its environmental performance and lubricity in WC/C-coated tribosystem elements. This oil is a good solvent for AP, which is based on products of chemical or biochemical conversions of substances of plant origin. However, the crucial fact is that this oil enables an increase in surface fatigue durability for WC/C-coated elements. This composition of the lubricant provided the most favourable relation between values of three tested parameters: $G_{oz} \sim 1200 \text{ N/mm}^2$, $P_t \sim 5000 \text{ N}$, and $L_{10} \sim 245 \text{ min}$. The developed lubricant enables sufficient scuffing and wearing resistance. Further work ought to focus on developing a composition with higher anti-pitting effectiveness for WC/C-coated elements.

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Kompozycje do smarowania skojarzeń zawierających elementy z powłokami WC/C

Słowa kluczowe

Powłoka WC/C, węzeł tarcia, zużycie, zacieranie, pitting, dodatki smarne, właściwości smarne.

Streszczenie

Wytworzono kompozycje do smarowania węzłów tarcia, w których występują elementy pokryte powłokami WC/C. Bazą tych kompozycji jest syntetyczny olej poli(α)olefinowy PAO-8, do którego wprowadzano różne ilości modelowego pakietu dodatków smarnych, zawierającego produkty chemicznej lub biochemicznej konwersji składników olejów roślinnych. Kompozycje te uzupeł-

niono o niezbędne dodatki uszlachetniające, w tym przeciwpienne, powierzchniowo-czynne oraz inhibitory korozji. Zbadano działanie przeciwwużyciowe i przeciwtarciowe tych kompozycji oraz ich działanie przeciwpittingowe w węzłach tarcia z powłokami WC/C. Uwzględniając wyniki tych badań, wytypowano kompozycje, których właściwości smarne względem powłok WC/C były najkorzystniejsze. Stwierdzono, że możliwe jest wytworzenie ekologicznych kompozycji smarowych, które poprawiają odporność węzła tarcia na zużywanie i zacieranie. Problemem do rozwiązania pozostaje jednak wytworzenie kompozycji smarnych zapobiegających pittingowi elementów z powłokami WC/C.