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THE TRIBOLOGICAL PROPERTIES OF LUBRICATING GREASES BASED ON RENEWABLE OILS

WŁAŚCIWOŚCI TRIBOLOGICZNE SMARÓW PLASTYCZNYCH SPORZĄDZONYCH NA ODNAWIALNYCH BAZACH OLEJOWYCH

Key words:

lubricating greases, antiwear properties, antiscuffing properties, dispersion phase, base of oil, four -ball machine, vegetable oils

Słowa kluczowe:

smar plastyczny, właściwości przeciwzużyciowe, właściwości przeciwzatarciowe, faza dyspergująca, baza olejowa, aparat czterokulowy, oleje roślinne

Abstract

The paper discusses the influence of vegetable oil basis on lubricating properties of their selected compositions. Four vegetable oils were used for production of lubricating greases: rapeseed, sunflower, soybean, and castor, all thickened with modified silica of Aerosil® type.

The tribological properties of lubricating greases based on vegetable oils were investigated. On their basis, the most beneficial compositions were

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selected. The tribological properties of greases were estimated via measurements of limiting load of wear ($G_{oz/40}$), welding load (P_z), scuffing load (P_t), limiting load of scuffing (P_{oz}), and the limiting pressure of seizure (P_{oz}).

Based on the obtained results, it may be concluded that the best antiwear properties were shown by the lubricating compositions based on rapeseed oil, whereas the best antiscuffing properties have compositions using castor oil as a disperse phase.

INTRODUCTION

Nowadays, the issue of environmental protection gains growing attention. The EU regulations and policy requires a reduction in the use of environmentally harmful petroleum-based lubricants **[L. 1–3].** To manage those requirements, there is a need for lubricating greases that are non-toxic and readily biodegradable. Such components may be obtained from natural sources like vegetable oils, which are increasingly used to produce ecological lubricants **[L. 4–8]**. The non-toxicity and biodegradability of lubricants are particularly desirable in the applications in devices for the food industry **[L. 9, 10]**. This branch of industry requires the use of lubricants of appropriately selected composition, ensuring their ecological character and thus their neutrality to the natural environment **[L. 11–14]**.

At present, there is a strong demand for lubricating greases based on vegetable oils, combining good lubricating properties with their harmlessness to the environment. There is a tendency to replace petroleum-based lubricants with non-toxic vegetable, readily biodegradable counterparts. The vegetable oils have a very good viscosity-temperature as well as lubricating properties, which determine their suitability as a base for lubricating greases. The major disadvantages of these products are low resistance to hydrolysis, low thermal stability, and susceptibility to oxidation **[L. 15–22].**

The aim of this work was the analysis of various types of vegetable oils as a base for the lubricating compositions and their basic tribological parameters applicable in the food industry.

THE SUBJECT AND METHODOLOGY OF RESEARCH

A group of model lubricating compositions made of non-toxic components were prepared. As the dispersion phase, the author used the vegetable base oils of the best tribological and physicochemical properties. The base oils used for the preparation of greases were refined prior to the processing.

In the role of the dispersed phase, the amorphous silica Aerosil was used. The lubricating compositions were prepared to comply the second class of consistency for the use in the food industry. The consistencies of prepared compositions were investigated in according to the requirements of ISO 2137:2011, using a laser penetrometer produced by ITeE – PIB. The lubricating compositions were marked as follows: grease A – based on the rapeseed oil, grease B – based on the sunflower oil, grease C – based on the soybean oil, and grease D – based on the castor oil. To all lubricating compositions, 10% [m/m] of the silica thickener was introduced. The adequate amount of thickener to be added was evaluated in previous research by the author. The tests carried out with compositions containing from 3 to 10% of the dispersed phase. The prepared lubricating compositions were tested for their tribological properties.

The tribological properties of the lubricating compositions were evaluated on a T-02 of four-ball machine by ITeE-PIB. These properties were determined by measuring of limiting load of wear ($G_{oz/40}$), welding load (P_z), scuffing load (P_t), limiting load of scuffing (P_{oz}), and limiting pressure of seizure (p_{oz}). The friction pair to be tested elements was the steel balls of diameter 12.7 mm, applied in steel bearing type ŁH 15. The roughness of ball surface was Ra = 0.32μm and its hardness was 60-65HRC. The measurement of the limiting load of wear (Goz/40) was carried out by tribosystem load of 392.4 N for entire test run lasting 3600 s. The spindle speed of rotating ball was set up at 500 rpm according to the WTWT-94/MPS-025 test method. The welding load was evaluated according to PN-76/C-04147. This test was carried out in a 10-second runs of four-ball machine in the presence of the lubricant under increasing load until the balls welded. The measurements of lubricating properties in scuffing conditions (i.e. in the constantly increasing load during the tests) were carried out according to the methodology developed by the ITeE – PIB. The test was performed in a linearly increasing load from 0 to 7200 N (ramp 409 N/s) within the time of 18 s at 500-rpm spindle speed. The moment of a sudden increase of the friction point is called the scuffing load P_t. The measurement was carried out until the point of friction reached the point of 10 Nm or the maximum load of device set up at 7200 N. This point was defined as the limiting load of scuffing P_{oz}. The result of each test was determined as an arithmetic average of at least three separate measurements, which did not different from one another more than 10%. The Q-Dixon test at the 95% trustfulness level was used for statistical processing of results.

The limiting pressure of seizure is a measurement of the antiscuffing properties of lubricants in scuffing conditions. The estimation of this parameter was based on a calculation according to the formula: $p_{oz} = 0.52*P_{oz}/d_{oz}^2$, where P_{oz} – limiting load of scuffing and d_{oz} – scar diameter formed on the steel balls used in the tests.

To determine the size of the wear scar on the surface of tested balls, an optical microscope was used. The obtained results were used to determine the size of $G_{oz/40}$ and p_{oz}, or the estimation of antiwear and antiscuffing properties of lubricating greases subjected to tribological tests **[L. 23–26]**.

RESULTS AND DISCUSSION

The results of tribological tests (aimed at antiwear and antiscuffing properties) of vegetable oil-based greases are shown below. The welding load Pz of particular lubricating compositions are presented in **Fig. 1**.

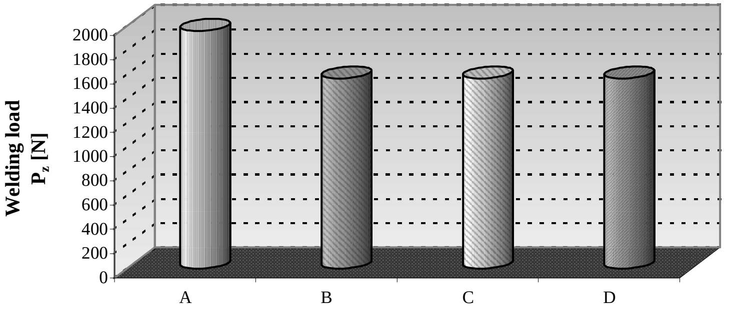

Fig. 1. The welding load of tribosystem lubricated with particular compositions based on vegetable oils

Rys. 1. Obciążenie zespawania węzła tarcia smarowanego kompozycjami wytworzonymi na roślinnych olejach bazowych

The antiscuffing properties at a stepwise increasing load of the tribosystem depend on the type of base oil, which significantly affects the durability of the lubricating film (**Fig. 1**). The most favourable antiscuffing properties were characterized for the grease based on the rapeseed oil (grease A) – about 26% greater value of P_z in comparison to other oil bases. The lubricating compositions produced from the sunflower oil (grease B), the soybean oil (grease C), and the castor oil (grease D) revealed significantly less favourable antiscuffing properties. The above-mentioned lubricating compositions, i.e. greases B, C, D, showed similar antiscuffing properties (the difference between them was about 2–3%). These results confirmed the most effective protection against scuffing of lubricating composition based on the rapeseed oil and at the lowest estimate effective of antiscuffing were ascertained in the cases of the composition produced on the sunflower, soybean, and castor oil base.

The antiscuffing properties of tested lubricating compositions were determined as the limiting pressure of seizure p_{oz}. The obtained results of this parameter were presented in **Fig. 2**.

The obtained values of the limiting pressure of seizure indicated diverse antiscuffing properties of the tested lubricating compositions. Depending on the natural oil used as a base for ecological lubricating greases, the antiscuffing properties significantly varied. The topmost p_{oz} value was recorded for the composition D based on the castor oil, whereas lowest one was characterized by the grease B (on the sunflower oil). The greases B and C revealed comparable values of limiting pressure of seizure. The difference in antiscuffing properties between greases A and D was 129% (in a favour of a composition produced from the castor oil), whereas between the composition A, and composition B or C was 52% in a favour of the composition based on the rapeseed oil.

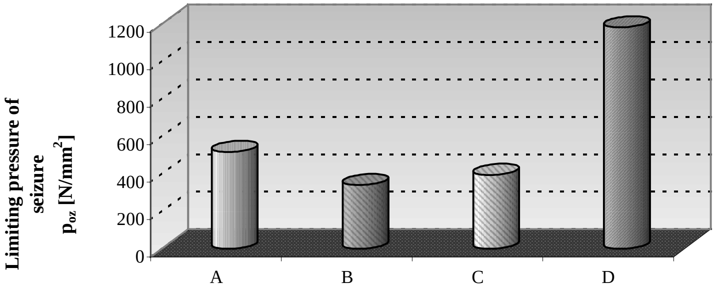

Fig. 2. The limiting pressure of seizure of tribosystem lubricated with compositions based on vegetable base oils

Rys. 2. Graniczny nacisk zatarcia węzła tarcia smarowanego kompozycjami wytworzonymi na roślinnych olejach bazowych

The lubricating compositions produced based on rapeseed, sunflower, and soybean oils did not indicate as favourable changes in antiscuffing properties as did the composition produced on the castor oil (**Fig. 2**). The results of the limiting pressure of seizure indicated that the castor oil, as the base, significantly improved the surface resistance to scuffing in comparison to other lubricating compositions used in the experiment. The p_{oz} parameter provided the information on the pressure in the area of friction at the time of scuffing. Based on obtained results, it can be concluded that the applied base oils do not contribute to the formation of films highly resistant to scuffing. The higher p_{oz} parameter of the lubricating composition based on the castor oil indicated that the character of created film favours a considerable reduction of wear.

For each prepared lubricating composition, the antiscuffing properties under linearly increasing load, (characterized by scuffing load P_t) were tested. The obtained results were depicted in **Fig. 3**.

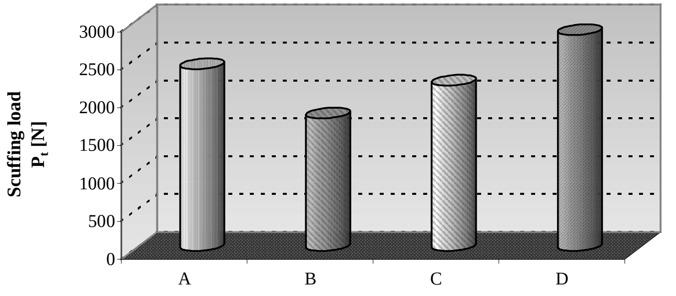

Fig. 3. The scuffing load of tribosystem lubricated with compositions based on different vegetable base oils

Rys. 3. Obciążenie zacierające węzeł tarcia smarowany kompozycjami wytworzonymi na roślinnych olejach bazowych

The scuffing load determines the antiscuffing properties tested under linearly increasing load. The P_t parameter determines the ability of lubricating film to transfer the load. The base oil used for the preparation of particular grease affected the value of scuffing load. The topmost antiscuffing properties in mentioned conditions were indicated by the grease produced on the base of castor oil (composition D). The increase of value P_t was about 62.8% in comparison to grease B. The less beneficial antiscuffing properties were recorded for greases A, B, and C (based on the rapeseed oil, sunflower oil and soybean oil, respectively). A decrease in the P_t value of about 18.8; 62.8 and 30.5%, respectively, was observed in comparison to the composition based on the castor oil (grease D). Therefore, the type of base oil used for production of lubricating grease has an essential influence on the change of the scuffing properties (**Fig. 3**). The topmost durability of the lubricating film was observed for the castor oil as a base that provided the grease of the largest P_t value. Therefore, it can be assumed that the effectiveness of antiscuffing depends on the structure of the boundary layer created by the base oil. The individual molecules of the castor oil in the lubricating film are more closely packed, which contributes to their interactions, and therefore to their ability to transfer of larger loads.

The experiments also covered the measurements of the limiting load of scuffing for tribosystems lubricated with particular lubricating compositions. The obtained results are presented in **Fig. 4**.

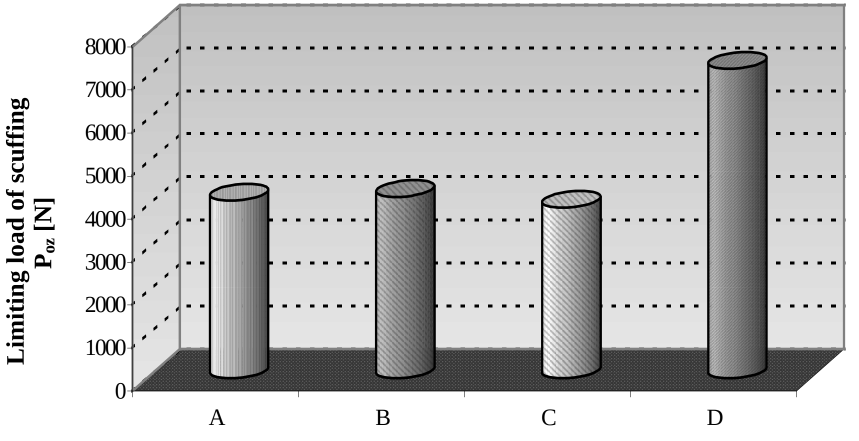

Fig. 4. The limiting load of scuffing of tribosystem lubricated with compositions based on vegetable oils

Rys. 4. Graniczne obciążenie zatarcia węzła tarcia smarowanego kompozycjami wytworzonymi na roślinnych olejach bazowych

The limiting load of scuffing P_{oz} determines the level of the antiscuffing properties of the tested lubricating compositions. The most favourable antiscuffing properties were measured for the lubricating grease produced on the base of castor oil (composition D). The increase of P_{oz} value was about 81.5% in comparison to the composition based on the soybean oil (grease C). Less beneficial properties were recorded for the lubricating greases produced the basis of the rapeseed oil (grease A), sunflower oil (grease B), and soybean oil (grease C). A significant decrease of P_{oz} value was observed, about 74.2; 70.7 and 81.5%, respectively, when compared to the grease D based on the castor oil (**Fig. 4**). The most effective operation of lubricant after the lubricating film interruption was provided by the castor oil, ensuring the maximum value of P_{oz}. The values of P_{oz} were between 3950–4250 N (except for the composition D), which indicates that differences in the grease composition plays an important role only in the conditions of moderate extortion. The lubricating composition based on the castor oil (grease D) achieved the limiting load of scuffing of 7200 N. That proves the significant protection of tribosystem against scuffing in large extortion conditions. The scuffing process causes the increasing pressure in the friction area, which leads to the lubricating film removal from the cooperating surfaces. The protective action against the immobilization of tribosystem is possible to achieve with the use of lubricating compositions able to react with the material of the friction pair.

The antiwear properties of tested lubricating greases were verified via the estimation of limiting load of wear $G_{oz/40}$ of the tribosystem. The obtained results are presented in **Fig. 5**.

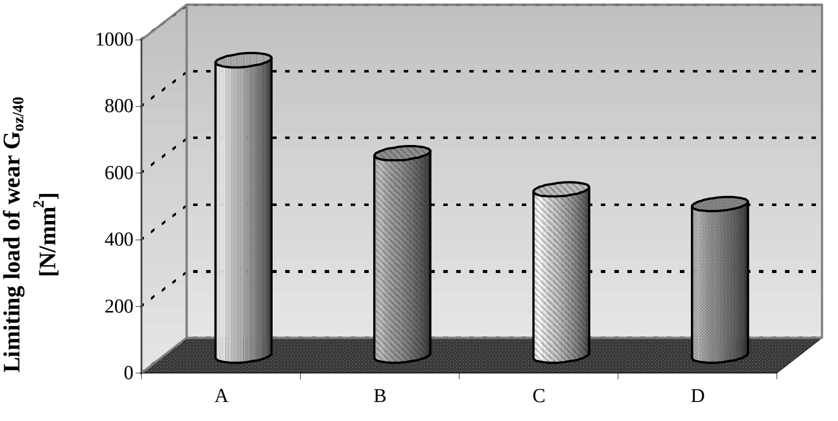

Fig. 5. The limiting load of wear of tribosystem lubricated with compositions produced on vegetable base oils

Rys. 5. Graniczne obciążenie zużycia węzła tarcia smarowanego kompozycjami wytworzonymi na roślinnych olejach bazowych

The results proved that different base oils change the ability of greases to provide antiwear protection of tribosystem. Each of used vegetable oils has a favourable effect on this parameter (**Fig. 5**). The stability of the boundary layer is determined by the value of limiting load of wear $G_{oz/40}$. The larger the index, the more stable is the grease and the better are the antiwear properties. The topmost limiting load of wear was measured for grease A, which was based on the rapeseed oil. The lowest value of $G_{oz/40}$ characterized grease D, based on the castor oil. Grease A revealed about 95% better antiwear than grease D. The composition based on the sunflower oil (grease B) also had very good antiwear properties but worse than grease A by 45%. Greases C and D showed comparable, good antiwear properties. The most favourable application properties were observed for the lubricating compositions based on the rapeseed oil. The comparison thereof to the compositions based on the vegetable oils indicates the better overall antiwear properties, which is not so clearly visible in the case of lubricants produced on the basis synthetic or mineral oils **[L. 27–29]**.

The quality criteria of lubricants designed for the food industry are established individually by the producers of particular devices. On the basis of market research, the lubricating compositions are classified as follows: those of $G_{oz/40}$>600 N/mm^2 have very good antiwear properties; those in the range 400-600 N/mm^2 are regarded as having effective properties; whereas, the compositions of $G_{oz/40}$ value less than 400 N/mm^2 are considered unsatisfactory. The results shown in this paper doubtlessly classify all tested compositions as effective in terms of antiwear properties under constant load conditions.

CONCLUSIONS

The experiments demonstrated a beneficial effect of the use of vegetable oils as a base for lubricating compositions in terms of antiscuffing and antiwear properties.

The composition based on the rapeseed oil had very good antiscuffing properties under increasing load of tribosystem. The other compositions demonstrated less beneficial values of this parameter.

The topmost level of antiscuffing properties were observed for the lubricating greases prepared on the base of rapeseed and castor oil, while the compositions based on the soybean and sunflower oil did not assure the satisfactory antiscuffing protection. Under the linearly increasing load, the maximum antiscuffing protection was revealed by the composition made of the castor oil; however, the other compositions also showed an acceptable level of this parameter.

The use of the castor or rapeseed oil as a base for lubricating composition tend to create an effective protective boundary layers, resulting in increased resistance of the tribosystem to scuffing. The initial phase of scuffing occurs at higher loads of tribosystem.

The use of the rapeseed oil as a base of lubricating grease caused the increase in the G_{oz} parameter in comparison to compositions prepared from other vegetable oils. This increase results in the better resistance of lubricating composition to the disruption of boundary layers.

The obtained results led to the conclusion that the lubricating properties of the tested compositions were significantly dependent on base oil used for their preparation. Some compositions were outstandingly effective in terms of antiwear protection (based on the rapeseed oil), while others were significantly resistant to scuffing process (greases based on the rapeseed and castor oil). It was concluded that the lubricating compositions prepared on the bases of vegetable oils demonstrated generally favourable lubricating properties and may be recommended for the protection of tribosystems present in many branches of industry.

It is advisable to conduct further research on the mechanism of such effective tribological properties of vegetable oils, modified with amorphous silica as a thickener.

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Streszczenie

W artykule przedstawiono wyniki badania wpływu roślinnych baz olejowych na właściwości smarne wybranych kompozycji smarów plastycznych. Do wytworzenia środków smarowych użyto czterech olejów roślinnych: rzepakowego, słonecznikowego, sojowego oraz rycynowego, które następnie zagęszczono modyfikowaną krzemionką typu Aerosil®.

Wykonano badania właściwości tribologicznych objęte normą dla smarów plastycznych, a uzyskane wyniki porównano ze sobą i oceniono, który z olejów roślinnych zastosowanych jako baza olejowa smarów plastycznych wpływa najkorzystniej na wartości badanych parametrów. Do oceny właściwości tribologicznych wykorzystano wyniki badań granicznego obciążenia zużycia, obciążenia zespawania, obciążenia

zacierającego, granicznego obciążenia zatarcia oraz granicznego nacisku zatarcia.

Na podstawie wyników badań tribologicznych stwierdzono, że najkorzystniej na właściwości przeciwzużyciowe wpływa kompozycja, w której jako fazę dyspergującą zastosowano olej rzepakowy, natomiast najskuteczniejszą ochronę przeciwzatarciową pełni kompozycja, w której fazą dyspergującą był olej rycynowy.