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FORMING USAGE PROPERTIES OF LUBRICANTS BY THE FUNCTIONAL ADDITIVES

KSZTAŁTOWANIE WŁAŚCIWOŚCI UŻYTKOWYCH ŚRODKA SMAROWEGO POPRZEZ ZASTOSOWANIE DODATKÓW FUNKCJONALNYCH

Key words:

lubricants, wear resistance, anti-seizure properties, additives, wear, scuffing

Słowa kluczowe:

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Summary

The article presents the results of analysis of improvement possibilities of lubricating properties by the modification of lubricants with the use of functional additives that improve resistance to the wear and scuffing of frictional couple. The research encompasses different base oils. Mineral oil and the synthetic oils, i.e. ester oil and hydrocarbon oil, were investigated. Tribological investigations were conducted with the use of a four ball apparatus. The research results were analysed with particular consideration of simultaneous effects of two types of additives, i.e. anti-wear and anti-scuffing. As the result of research, the possibilities of forming a lubricant's anti-wear and

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anti-scuffing properties have been demonstrated through the selection of the percentage of additives. The limitation of simultaneous improvement of both resistance to wear and scuffing was also demonstrated. This limitation is due to the additives' interactions.

INTRODUCTION

Ensuring the proper conditions of the friction process in accordance with working conditions is the main condition of the machines durability and reliability.

High demands, especially concerning the reduction of the effects of friction that causes damage of friction elements, determine, inter alia, research on the development of lubricants adapted to working conditions related to friction.

The properties of the lubricant should provide a reduction of the negative effects of the friction process under operating conditions. Research in this area includes, inter alia, an analysis of the relationship between the physicochemical and tribological lubricants properties **[L. 1]**. A wide range of research has been devoted to the influence of additives for improving the functional properties of lubricants **[L. 2–7]**, and the effect of the antiwear additive geometry has been analysed in **[L. 8]**. The authors found that the size of the nanoparticles fullorene-like MoS2 had no effect on reducing friction and wear; however shape had a significant influence, and the benefits of using spherical nanoparticles, such as IF-MoS2, has been clearly shown. Publications have presented the results of numerous studies on the effects of various additives on lubrication efficiency **[L. 9]**, and these have been analysed for the effects of additives to improve the anti-wear properties and antiseizure of biodegradable industrial oils **[L. 10]** and the life extension of the greases through the use of appropriate antioxidative additives **[L. 11**, **12]**.

Lubricant additives can perform various functions, including increased resistance to corrosion and wear, improved oxidative stability **[L. 13]**, and ensuring adequate wetting during operation. When selecting the additives, it is necessary to take into account the working conditions, including high temperatures. The positive impact of nanotubes, as an additive for silicone lubricants, has been observed on the thermal properties that have a particular importance in applications for electronic devices with high power **[L. 14]**. Significant research is needed for the identification of the impact of the composition of lubricants to counteract the dominant forms of the destruction of friction elements. The results of the impact of functional additives on fatigue wear are presented in **[L. 15**, **16]**. The relationship between the concentration of additives and resistance to scuffing are presented in **[L. 17]**, and the authors have designated optimal additive content for scuffing resistance. The exhaustion of the content of additives in the lubricant composition has a significant impact on the effectiveness of the resistance to scuffing **[L. 18]**. In practice, the additives are usually introduced into in packages containing ingredients that meet a variety of functions. Often, antiwear and/or antiseizure additive packages are added to the base oil to improve tribological properties. However, simultaneous application of these two types of additives does not provide the effect of improving both antiwear and antiscuffing properties of lubricant **[L. 19**, **20]**.

The results of the research presented in this paper were the identification of influence on tribological properties of simultaneous addition of antiwear and antiseizure additives to different kinds of oil – mineral and synthetic. The different percentage contents of additives were investigated. The aim of the research was primarily the analysis of the ability to maximize the improving effect of both the anti-wear and antiseizure properties simultaneously by a proper selection of the percentage of AW and EP additives in lubricating compositions.

LUBRICATING COMPOSITION AND RESEARCH METHOD

The study involved lubricating compositions were based on synthetic oils, ester (Priolube) and hydrocarbon (PAO4), and mineral oil (SN400). The tested lubricating compositions contained various percentages of additives of anti-wear (AW) and antiseizure (EP). Both types of additives were added simultaneously. We examined 18 different compositions that varied by percentage content of additive packages AW and EP.

Ranges changes in the content of additives, AW at the level of 3-8% by weight and the EP on the level of 1-4%, were determined based on the results of previous studies on the effects of individual packages of additives on tribological properties **[L. 21]**.

Table 1 shows the percentage of the additives in the developed compositions determined by the plan of the experiment developed for mixtures. The contents of the additives in mineral oil planned for the experiment.

Table 1. Composition of developed lubricants
Tabela 1. Skład opracowanych środków smarowych

	additive AW [%]	additive EP [%]
1	3	1
2	8	1
3	3	4
4	8	4
5	3	2.5
6	8	2.5
7	5.5	1
8	5.5	4
9	5.5	8

Testing of anti-wear and antiseizure lubricant compositions were performed on a four ball apparatus. The balls were made of bearing steel 100Cr6 (H 15), and their diameter was approx. 12.7 mm, with a surface roughness of $R_a = 0.32$ μm, and a hardness of 60-65 HRC (in accordance with the PN-75/M-86452 standard). As a measure of anti-wear properties, wear-limiting load (G_{oz}) was assumed, and the measure for antiseizure properties were the limiting pressure of seizure (p_{oz}).

The wear limiting load (G_{oz}) values were determined in accordance with the PN-75/C-041447 standard. They were estimated base on the scar diameter, after 60-seconds of four-ball friction tests in the presence of lubricant, with a constant load (P = 1500 N) under stable conditions. The wear scars (d**[**mm**]**) were calculated as the average value of diameters of scars formed on the three stationary balls.

G_{oz} was calculated as follows:

$$G_{oz} = 0{,}52 \frac{P}{d^2}$$

The limiting pressure of seizure (p_{oz}) was determined in accordance with a method developed in ITeE – PIB in Radom **[L. 22]**. It is based on analysis of the course and consequences of the mashing process in conditions of continuous load increase. The limiting pressure of seizure is determined in the process of the friction of the four-balls in the presents of the lubricant under continuously increasing load until seizure. During this process the friction torque (resistance to motion) is continuously registered. In this case, seizure is meant as exceeding the limit of friction torque – 10 Nm. This value is defined because of the durability of upper ball's holder in the four-ball apparatus. The friction process parameters are presented in **Table 2**.

Table 2. Parametry procesu wyznaczania granicznego nacisku zatarcia
Tabela 2. Process parameters of the measurement of limiting pressure of seizure

Start load [N]	Rotation [min^{-1}]	Velocity [m/s]	Velocity of load increase [N/s]	Temperature [°C]
0	500±20	0.19	409	20±5

Limiting the pressure of seizure p_{oz}, equal to the nominal pressure at the surface trace of wear, which takes place at seizure or at the end of the run (when the seizure does not occur), is calculated from the following equation:

$$p_{oz} = 0{,}52 \frac{P_{oz}}{d^2}$$

where: d – average diameter of balls wear scare,
P_{oz} – limiting scuffing load

Measurements for each of the lubricant compositions produced were repeated three times. The determination value was calculated as a mean. To eliminate outliers, a Q-Dixon test was used.

ANALYSIS OF RESULTS

After tests, we calculated the average values of p_{oz} and G_{oz} for each of lubricating compositions.

Values of the coefficient of the variability of results were calculated based on three test repetitions as the quotient of the difference of measured and average values. Mean values of coefficients calculated for investigated lubricant compositions are shown in **Table 3**.

Tabela 3. Average values of the coefficient of results variability
Tabela 3. Średnie wartości współczynników zmienności pomiarów charakterystyk tribologicznych

	Priolube		PAO		SN400	
	p_{oz}	G_{oz}	p_{oz}	G_{oz}	p_{oz}	G_{oz}
variability	6%	10%	5%	9%	4%	6%

Tribological studies of tested oils without additives showed significant differences in anti-wear properties (**Fig. 1**).

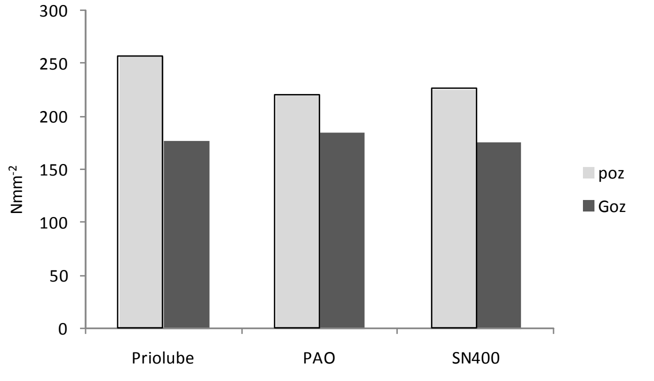

Fig. 1. Average values of wear limiting load (G_{oz}) and limiting pressure of seizure (p_{oz}) for oils without additives
Rys. 1. Średnie wartości graniczne obciążenia zużycia (G_{oz}) oraz granicznego nacisku zatarcia (p_{oz}) przy smarowaniu olejami bez dodatków

The tested synthetic oils and mineral oils exhibit similar tribological characteristics in respect to the prevention of wear and seizure. Synthetic ester oil was characterized by the best properties.

Another study involved the analysis of tribological test results for the lubricating compositions of tested oils and various percentage contents of additives AW and EP.

Figures 2, 3, and **4** present the average values of research results on changes of antiwear and antiseizure properties of the lubricating compositions in relation to the percentage content of additives AW and EP in tested oils.

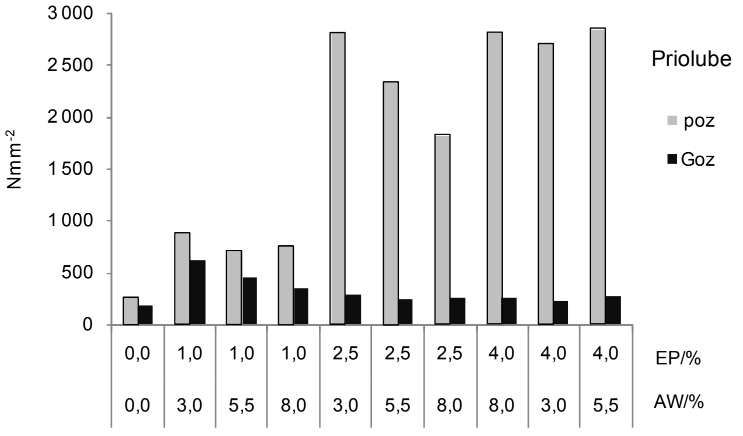

Fig. 2. Average values of wear limiting load (G_{oz}) and limiting pressure of seizure (p_{oz}) for Priolube oil with additives

Rys. 2. Średnie wartości graniczne obciążenia zużycia (G_{oz}) oraz granicznego nacisku zatarcia (p_{oz}) przy smarowaniu olejem Priolube z dodatkami

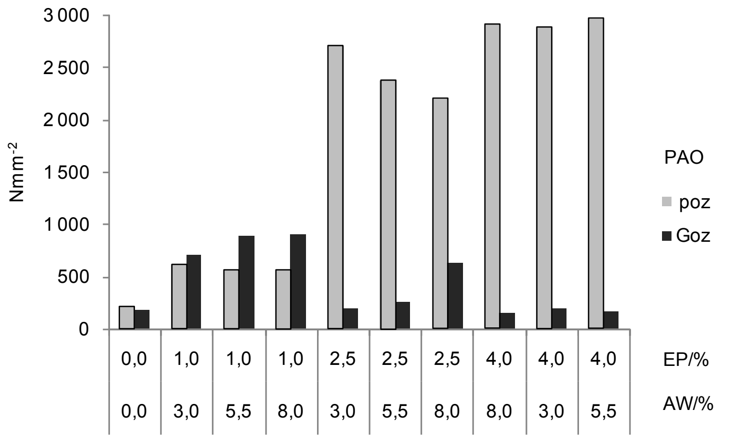

Fig. 3. Average values of wear limiting load (G_{oz}) and limiting pressure of seizure (p_{oz}) for PAO oil with additives

Rys. 3 Średnie wartości graniczne obciążenia zużycia (G_{oz}) oraz granicznego nacisku zatarcia (p_{oz}) przy smarowaniu olejem PAO z dodatkami

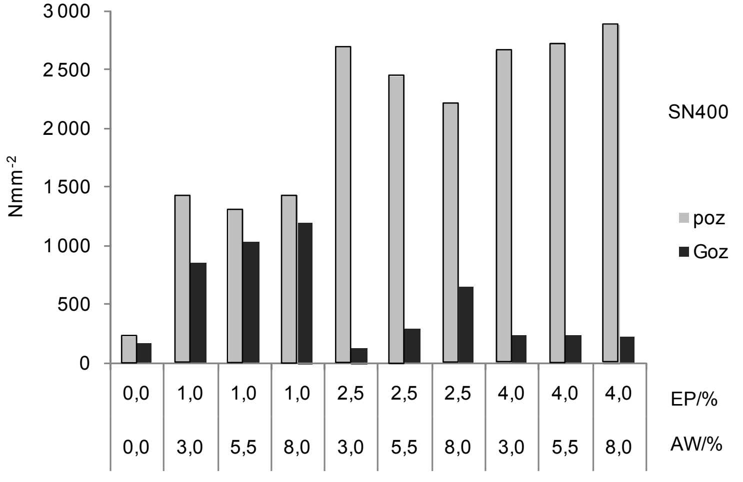

Fig. 4. Average values of wear limiting load (G_{oz}) and limiting pressure of seizure (p_{oz}) for SN400 oil with additives

Rys. 4 Średnie wartości graniczne obciążenia zużycia (G_{oz}) oraz granicznego nacisku zatarcia (p_{oz}) przy smarowaniu olejem SN400 z dodatkami

Conducted research findings have shown that the additives AW and EP, in all tested oils, cause similar changes in the investigated tribological properties. Simultaneous use of additives for antiwear and antiseizure did not result in the expected simultaneous improvement of these characteristics. Increasing the content of EP additive is beneficial for improving antiseizure properties; however, it simultaneously lowers anti-wear properties. In the case of application of 1% EP additive and AW additive, we observed an improvement over the oil without additives in both anti-wear properties and antiseizure properties for all the tested lubricant compositions. However, while increasing the value of EP additives up to 2.5% and above, there was a significant decrease in antiwear properties, which were values similar to oil without additives. Only for mineral oil and synthetic ester oil was partial levelling of the adverse effects observed by increasing the AW additive content. Increasing the EP additive content in the lubricating composition even further almost completely eliminated the beneficial effect of the antiwear additive (AW). A change in the percentage content of AW additive does not significantly influence the antiseizure properties of the lubricating composition. However in the case of 2.5% of the EP additive, antiseizure properties worsened with an increase in the percentage of the AW additive. These changes occurred for all investigated base oils, and properties deteriorated the most in the case of synthetic ester oils. The lubricating compositions with a high content of EP additive (4%), regardless of the percentage of AW additive and the type of base oil, have virtually the same antiseizure properties. The analysis of the results of research shows that proper selection of the percentage content of additives in the studied oils enables over a 10-fold improvement in antiseizure properties. In the case of anti-wear properties, we obtained 3-fold improvement for the synthetic ester oil, a 5-fold for the synthetic hydrocarbon oil, and a 7-fold improvement for mineral oil. As we demonstrated in the results of the research, the type of oil, if EP was added, had no significant effect on the prevention of seizure (**Fig. 5**).

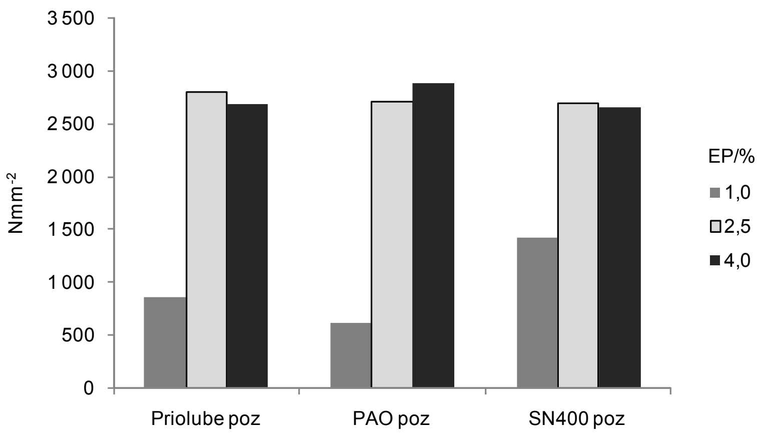

Fig. 5. Influence of oil and percentage content of EP additive on antiseizure properties, in the case of 3% content of AW additive

Rys. 5. Wpływ rodzaju oleju i zawartości dodatku EP na właściwości przeciwzatarciowe przy 3% zawartości dodatku AW

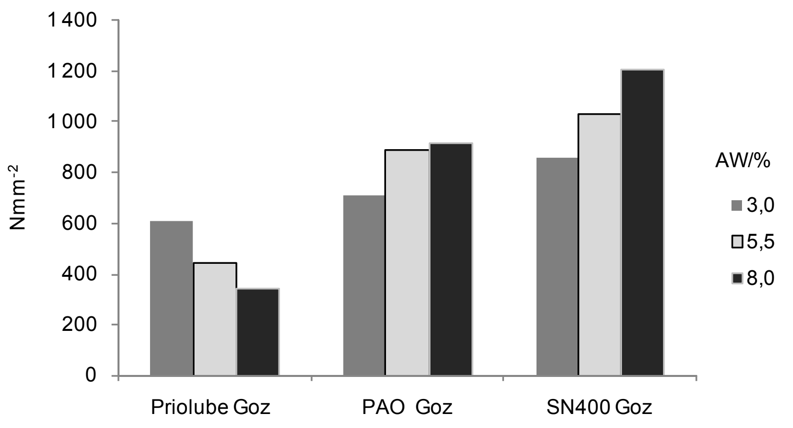

Fig. 6. The influence of the type of oil and percentage content AW additive on anti-wear properties if percentage of EP additive is 1%

Rys. 6. Wpływ rodzaju oleju i zawartości dodatku AW na właściwości przeciwzatarciowe przy 1% zawartości dodatku EP

Only with small (1%) amount of antiseizure additive did the type of oil affect the value of the antiseizure properties of the lubricating composition. In this case, the best qualities were found in the lubricating compositions based on mineral oil and the worst were based on synthetic hydrocarbon oil.

In the case of antiwear properties, the G_{oz} value depends on the type of base oil and on the content of the AW additive (**Fig. 6**). The research results indicate that the best anti-ear properties have compositions based on mineral oil.

The analyses found that it is not possible to simultaneously ensure the highest level of anti-wear and antiseizure properties of a lubricant based on tested oils by simultaneously adding functional additives AW and EP.

Figure 7 illustrates the relationship between anti-wear properties and antiseizure properties of the tested lubricant compositions.

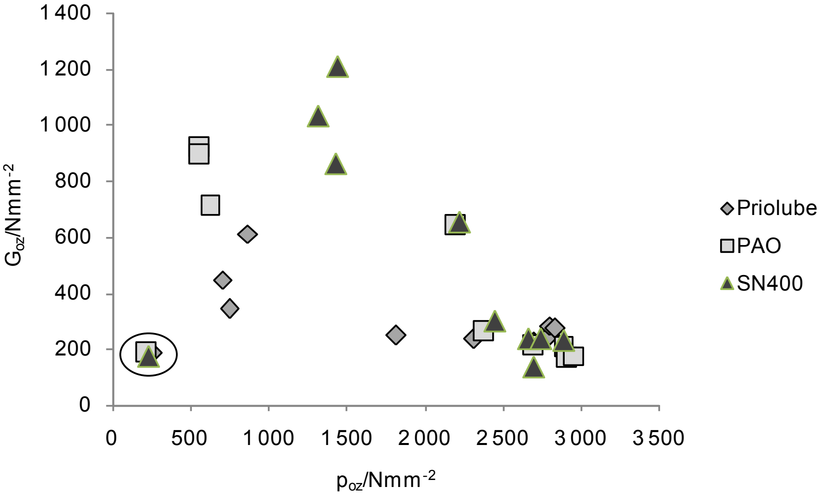

Fig. 7. Relationship between anti-wear properties and antiseizure properties of tested lubricant compositions. Oval surrounded points characterizing the properties of oils without additives

Rys. 7. Właściwości przeciwzużyciowe i przeciwzatarciowe badanych kompozycji smarowych

The relationships shown in **Fig. 7** enable one to evaluate of the ability to provide the required properties of a lubricant composition through an appropriate selection of the EP and AW additives for given working conditions. The best antiwear properties are found using mineral oil as the base oil. As we have shown, the lubricant of the highest value G_{oz} provides about 50% of the possibilities of improving antiseizure properties. However, this is a significant improvement (more than 6-fold) relative to oil without additives.

The maximum level of resistance to seizure, obtained in as the research results, was about thirteen-fold higher in relation to oil without additives; however, in this case, the value of the wear limiting load was on the level similar to oil without additives. The study shows that the composition of oil with additives, as compared to oils without additives, simultaneously ensures both the highest possible resistance to scuffing (10-fold) and resistance to wear (4-fold). However, this is approx. 75% improvement in p_{oz} and approx. 54% improvement in G_{oz}, if one takes into account the maximization of only one criteria namely resistance to scuffing or wear.

CONCLUSIONS

Based on the study and analysis of the results, it was demonstrated that the simultaneous use of additives for antiseizure and antiwear might adversely affect the indicators characterizing a particular type of tribological wear. Therefore, an important issue is the selection of the suitable percentage of additives due to the expected type of dominating wear mechanism of the friction contact.

The proposed graph ($G_{oz} – p_{oz}$) illustrates the possible level of the values of properties anti-wear and antiseizure can be simultaneously obtained.

The results can be summarized in the following conclusions:

- Determined based on research results, and illustrated in the graphs, properties anti-wear and antiseizure of the lubricating compositions with additives AW and EP clearly demonstrated the impossibility of simultaneously obtaining the maximum of indicators G_{oz} and p_{oz}, which characterize the properties of antiwear and antiseizure. This applies to all of the compositions tested, regardless of the used oil base.
- Antiseizure additive EP causes deterioration of anti-wear properties. Up to a certain percentage of the addition of EP, this adverse effect can be offset by increasing the antiwear additive content.
- In the case of base oils, the antiwear properties can be improved of hydrocarbon synthetic oil or mineral oil to a certain extent with a specific content of the EP additive (in the above studies, no more than 2.5%). In the case of the ester synthetic oil, the EP additive content has less of an effect (not to exceed 1%).
- The ability to improve antiwear properties depends on the type of base oil, and the largest improvement was obtained using mineral oil, and there was much less improvement using ester synthetic oil.
- The application of EP additive can provide radical improvement (approx. 10-fold) in antiseizure properties, compared to oil without additives, regardless of the base oil.
- The antiseizure properties of lubricant compositions depend mainly on the applied additives, and the type of oil does not practically matter. The antiwear properties depend on both the additives and on the type of oil.

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Streszczenie

W artykule przedstawiono wyniki analizy dotyczącej możliwości poprawy tribologicznych właściwości środka smarowego, którego skład modyfikowano z użyciem różnej zawartości dodatków funkcjonalnych poprawiających przeciwdziałanie zacieraniu i zużyciu węzłów trących. Badania przeprowadzono dla kompozycji smarowych wytworzonych na różnych olejach bazowych. W badaniach uwzględniono oleje syntetyczne: estrowy i węglowodorowy oraz olej mineralny. Uzyskane wyniki z badań na aparacie czterokulowym poddano analizom ze szczególnym uwzględnieniem jednoczesnego wpływu zestawu dodatków na właściwości przeciwzużyciowe i przeciwzatarciowe opracowanych kompozycji. W wyniku przeprowadzonych badań wykazano możliwość kształtowania tych właściwości poprzez dobór procentowej zawartości dodatków. Wykazano również ograniczenia jednoczesnej poprawy analizowanych właściwości użytkowych wynikające ze wzajemnego oddziaływania dodatków funkcjonalnych.