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## THE EFFECT OF THE EXPOSURE-IN-OIL ON THE CONTACT ANGLE OF THE POLYMERS FORMING SLIDING LAYERS IN HYDRODYNAMIC BEARINGS

### WPLYW EKSPOZYCJI W OLEJU NA KĄT ZWILŻANIA POLIMERÓW STOSOWANYCH NA WARSTWY ŚLIZGOWE W ŁOŻYSKACH HYDRODYNAMICZNYCH

#### Key words:

hydrodynamic thrust bearings, polymer-sliding layers, contact angle, wetting

#### Słowa kluczowe:

łożyska hydrodynamiczne wzdłużne, polimerowe warstwy ślizgowe, kąt zwilżania, zwilżanie

#### Abstract

Polymers used as the sliding layers of hydrodynamic thrust bearings are typically thermoplastics characterized by relatively high values of contact angles when compared with metals.

Metals, including Babbitt, or other bearing alloys, are characterized by low values of the contact angles. The lower the angle, the better the surface is wetted.

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Plastics used in tribological pairs to ensure a lower coefficient of friction, that is, for example, polytetrafluoroethylene (PTFE) or its composites, have several times higher contact angles compared to the bearing alloys. The research described below shows the effect of the exposure-in-oil contact angle of the polymer layer applied on a hydrodynamic sliding bearing. The conducted study showed the beneficial effects of oil on the reduction of the contact angle.

## INTRODUCTION

Plastics, especially thermoplastic polymers and the composites based on them, are increasingly used as sliding layers of hydrodynamic thrust bearings. Due to numerous advantages, polymers are also used in many other types of tribological pairs in various conditions. Despite their frequent industrial applications, the processes that occur at the interface of fluid film – polymer are not fully known. It is commonly believed that polymers are insensitive to lubricants – including oil.

The presented results are part of a broader study aimed at understanding both: opportunities and limitations of polymers working in the conditions of high temperature and high pressure of oil.

Polymers used as the sliding layer of the hydrodynamic thrust bearings are typically thermoplastics having relatively high values of contact angles when compared with metals.

Metals, including Babbitt, or other bearing alloys, are characterized by low values of the contact angles. The lower the angle, the better the surface is wetted. Good wetting of the surface is essential for the creation of an appropriate lubricating film. In the study, samples made of PEEK (polyetheretherketone), PTFE, and PEEK composite with PTFE were used. In addition, two types of oils were used: mineral turbine oil of ISO VG-32 viscosity, and a synthetic one, based on esters, Turwada Synth of similar viscosity grade.

The results of the research showed that exposure of polymers to oil have a certain impact on the contact angle. It was observed that the immersing of polymers in oil at elevated temperature resulted in reducing the contact angle in comparison with the clean polymers sample.

The reduction of the contact angle of polymers compensates to some extent for the deterioration of mechanical properties, such as the storage modulus, under the conditions of oil film in the hydrodynamic thrust bearings.

## POLYMERS USED FOR THE SLIDING LAYER

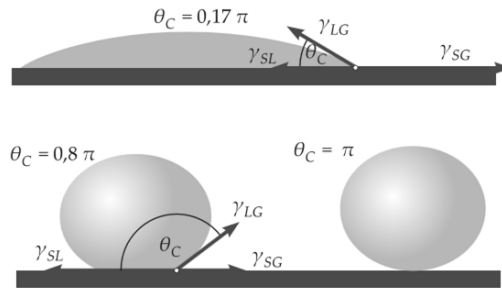
The polymers used for the sliding layer in hydrodynamic thrust bearings are mainly characterized by low friction, good thermal stability, low thermal conductivity, and a relatively high modulus compared to other thermoplastic



materials. The most commonly used polymers are PTFE, and its composites, and PEEK together with its composites.

## THE CONTACT ANGLE: DEFINITION AND RELATIONSHIPS

Contact angle is the angle between the surface wetting a solid surface and the tangent to the liquid at the point of contact with the solid. The value of the contact angle is directly related to the surface tension between liquid, gas, and solid phases. This parameter allows one to characterize the ability of wetting the surface to determine whether the surface layer of the lubricating film will be formed to provide adequate durability of the surface in sliding contact.



**Fig. 1. Contact angle interpretation for good wetting, poor wetting, and no wetting [L. 1]**

Rys. 1. Kąt zwilżania dla dobrego zwilżania, słabego i całkowitego braku zwilżania [L. 1]

The polymers have a much lower surface tension than the commonly used metals in bearings. Furthermore, as shown by Kalin and Polajnar [L. 2], certain materials may have greater contact angles with certain oils, but smaller with the others, and the differences between the oils (the same material) are also large. This suggests that both the chemical structure and viscosity of the oil may play key roles in determining the wetting properties of oils in contact with various materials. Furthermore, a reduction of the contact angle of polymers exposed to oil in the actual friction in a running hydrodynamic bearing may be associated with the Rebinder effect or the adsorption of surfactants to oil. This leads to significant changes on the polymer surface due to the increase of pressure within the oil gap as a result of high loads in friction contact [L. 3]. In case of polymers, this effect primarily depends on the adsorption changes in the dislocations near the surface. This effect does not depend on a reduction in the surface energy of the thermoplastic [L. 4]. Moreover, as indicated by Plaza et al [L. 5], adsorption plays a dominant role not only in the process of wetting, but above all in creating a boundary layer.

## DESCRIPTION OF TESTS

Basically plastics, including thermoplastics are considered to be chemically stable and impervious to the oils. Nevertheless, lubricants, both synthetic and mineral, can significantly modify the properties of polymers. In the study described below, the samples made of PEEK, PTFE, and the composite were treated with a lubricant by immersion in oil at 100° C for 100 hours. Two types of oils, mineral turbine oil of ISO VG-32 viscosity and a synthetic ester-based Turwada Synth, were used. The conditions of high temperature, exceeding 100°C occur in the oil film. Therefore, temperature was applied to the conditioning of samples.

The measurement of contact angle was performed on Kruss goniometer, model DSA 10HS, using data analysis software Drop Shape Analysis System DSA 10 14k2. The study was conducted at room temperature, i.e. of 23°C. All measurements were done for the same drop volume equal to 1µl. As a measurement liquid, the same types of oil as for conditioning were used: TU-32 and Turwada Synth. The samples were dried and conditioned before each measurement using a paper towel to remove any additional substance. In order to degrease the surface, no other chemical substance was used to avoid any chemical modification of the polymer surface layer. For each material, at least 20 measurements were carried out. The surface roughnesses of samples were similar (**Table 1**).

**Table 1. Surface roughnesses (Ra) of the test samples**

Tabela 1. Chropowatość powierzchni (Ra) badanych próbek

Material	Surface roughness Ra [µm]
<b>PEEK</b>	0.85
<b>TECAPEEK PVX</b>	1.1
<b>PTFE</b>	0.6

## RESULTS

The results obtained in the measurements of contact angle of thermoplastic polymers, PEEK, PTFE or their composites, are summarized in **Tables 2** and **3**. The results obtained are compared with the results obtained for high tin bearing alloy (Babbitt).

**Table 2. The contact angle for the samples unexposed to oil**

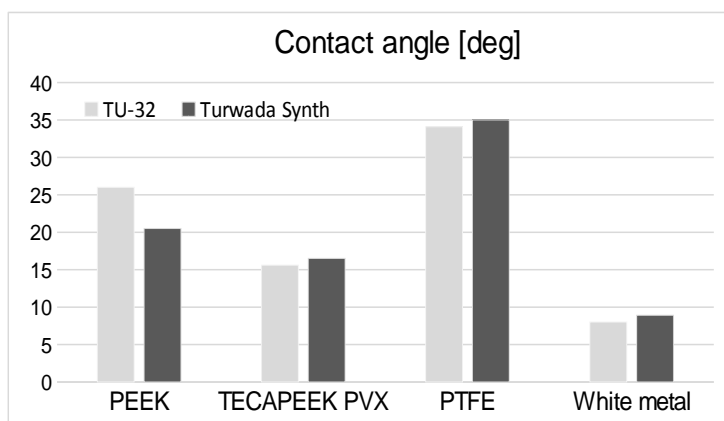
Tabela 2. Wartość kąta zwilżania dla próbek nieeksponowanych w oleju

Oil	Material			
	<b>PEEK</b>	<b>TECAPEEK PVX</b>	<b>PTFE</b>	<b>Babbitt</b>
<b>TU-32</b>	26.0	15.6	34.1	8.0
<b>Turwada Synth</b>	20.5	16.5	35.0	8.9

**Table 3. The contact angle for the samples exposed to oil at 100°C**

Tabela 3. Wartość kąta zwilżania dla próbek ekspozowanych w oleju w temperaturze 100°C

Oil	Material		
	PEEK	TECAPEEK PVX	PTFE
TU-32	11.2	11.8	32.7
Turwada Synth	12.2	12.3	39.6

**Fig. 2. Results of contact angle measurements for TU-32 and Turwada Synth oils**

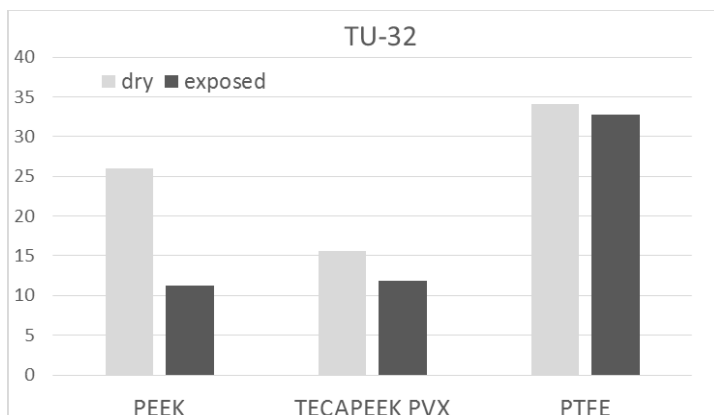
Rys. 2. Wyniki pomiarów kąta zwilżania dla olejów TU-32 i Turwada Synth

As can be seen from the data in **Tables 2** and **3**, in almost all cases, except for PTFE, exposure to oil causes a decrease of the contact angle. The most pronounced decrease of the contact angle was observed for pure PEEK. For this material, after exposure to oil, both mineral and synthetic, the results were similar to those obtained for the bearing alloy. The biggest change in the contact angle was observed for PEEK after exposure to mineral oil – it was 57%. In the case of the composites based on PEEK, TECAPEEK PVX a reduction in the contact angle was also observed, but this change was not as big as in the case of pure PEEK. The smallest effect of soaking in oil was observed for the samples made of PTFE. Furthermore, for this material as opposed to the others, in the case of soaking in synthetic oil, there was an increase in contact angle. Furthermore, the contact angle of the material is three times higher than that of PEEK and more than four times higher than that of the bearing metal. It seems to confirm the opinion that the desirability of the use of this material is only in tribological pairs with dry running, i.e., without the use of additional lubricants.

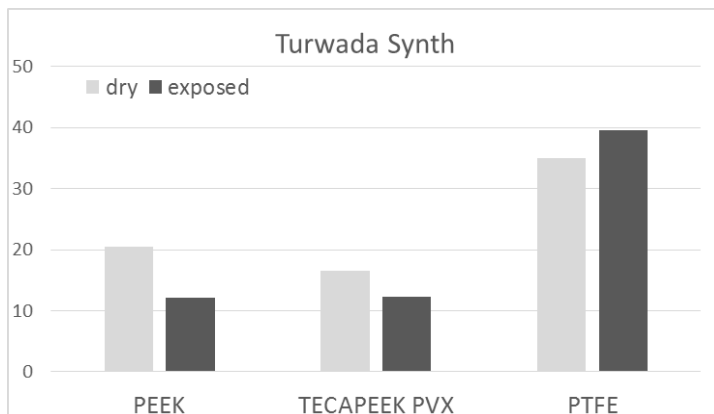
Samples of various materials after exposure were also weighed to determine the absorption of oil. The average weight gain of the samples after



soaking in both types of oil at 100° is shown in **Table 4**. These results show little effect of the oil type on the absorption and a substantial effect of the polymer type. PTFE shows the lowest absorption rate.



**Fig. 3. Results of contact angle measurements for dry samples and exposed to oil**  
Rys. 3. Wyniki pomiarów kąta zwilżania dla próbek suchych i poddanych działaniu oleju



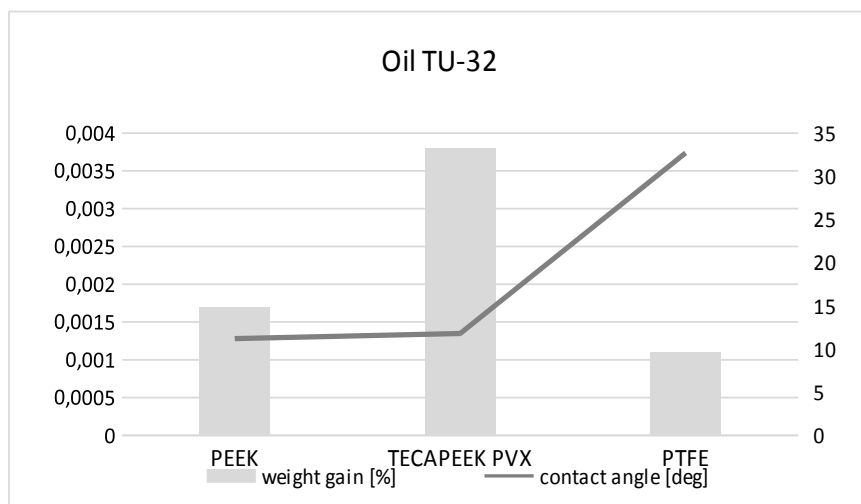
**Fig. 4. Results of contact angle measurements for dry samples and those exposed to oil**  
Rys. 4. Wyniki pomiarów kąta zwilżania dla próbek suchych i poddanych działaniu oleju

**Table 4. The average weight gain for the samples exposed in oil at 100°C**  
Tabela 4. Średni przyrost masy dla próbek eksponowanych w oleju w temperaturze 100°C

Material	Oil	
	TU-32	Turwada Synth
PTFE	0.11%	0.12%
PEEK	0.17%	0.15%
TECAPEEK PVX	0.38%	0.40%



Even a small increase in weight due to soaking the samples in oil significantly influenced the change of the contact angle. However, there is not a clear correlation between weight gain and the wetting angle (**Figure 5**). PTFE has the greatest wetting angle and the lowest absorbency.



**Fig. 5. The correlation between weight gain and the contact angle**

Rys. 5. Zależność pomiędzy przyrostem masy a kątem zwilżania

Undoubtedly, it is the impact of the structure of polymers. In the case of plastics, there is no homogeneity of the material. The outer layers of polymers, due to the nature of these materials, often vary considerably from the layers inside the sample. Above all, this is related to the fact that the group with the lowest Gibbs energy, including monomer units and segments, especially localize in the external surface or on the verge of its contact with other surfaces [L. 6]. Moreover, the structure of the polymer surface may be susceptible to chemical changes due to external factors, in this case, the exposure to oil at elevated temperatures. In addition, the previously described adsorption may have an impact on this.

## CONCLUSIONS

Based on these results, one can discard the conclusion that long-term exposure to oil can significantly reduce the contact angle and thus improve the tribological properties of the lubricating layer. Polymers exposed to oil at elevated temperatures, in particular PEEK, and a composite based on a matrix of PEEK show significantly lower values of contact angles compared to the materials not soaked. Moreover, the value of the contact angles for both



materials was similar to the contact angles for bearing alloys. Furthermore, slightly lower values of contact angles were determined for the mineral oil TU-32. Improving the tribological properties of the polymer in contact lubricated after exposure should be confirmed in further tribological tests, which are planned.

The exposure to oil appears to have no detrimental effect on the polymers used for the sliding layer. The reduction in contact angle after exposure to oil compensates, to some extent, for the deterioration of mechanical properties, namely a reduction in the elastic modulus or Young's modulus, which is observed for polymers exposed to the oil at elevated temperatures or elevated temperatures without oil [L. 7]. The previous studies [L. 8] showed a negative impact of oil exposure on mechanical properties of polymers. The research described in this paper shows the effects of complex processes taking place in the outer layers of polymers in the course of exposure in oil. The explanation of these phenomena may be crucial to a full understanding of the process of lubricating surfaces made of plastic.

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## Streszczenie

**Polimery stosowane jako warstwy ślizgowe w hydrodynamicznych łożyskach wzdluznych to zazwyczaj tworzywa termoplastyczne charakteryzujące się relatywnie wysokimi wartościami kątów zwilżania w porównaniu z metalami.**





Metale, w tym również Babbitt czy inne stopy łożyskowe, cechują niskie wartości kątów zwilżania. Im niższy kąt, tym powierzchnia lepiej się zwilża.

Tworzywa sztuczne wykorzystywane w węzłach tribologicznych mających zapewnić jak niższy współczynnik tarcia, czyli na przykład politetrafluoroetylen lub jego kompozyty cechują kilkukrotnie wyższe wartości kątów zwilżania w porównaniu ze stopami łożyskowymi. W opisanym poniżej badaniu przedstawiono wpływ ekspozycji w oleju na kąt zwilżania polimerów stosowanych na warstwy ślizgowe w łożyskach hydrodynamicznych. Przeprowadzone badanie pokazało korzystny wpływ oleju na obniżenie kąta zwilżania.