Research Article

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Tribological characteristics of polymer materials used for slide bearings

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Abstract: The automotive industry uses a variety of technologies and construction materials in production process. Knowledge of the characteristics of tribological material pairs cooperating with each other is useful for their selection from the safety point of view sliding pairs, in means of transport, and other machines. The aim of the contribution is the analysis of the characteristics of tribological ball-on-disc wear of polymeric materials used as sliding bearings. Tribological tests were carried out under dry friction for a polymer–metal pair of three types of materials. Among all three groups of the tested materials statistically significant differences ($p < 0.05$ in Student's t -test) in wear were observed. The wear rate and friction coefficient of the sample were tested, and the signs of wear were submitted to SEM observations.

Keywords: technical safety, coefficient of friction, slide bearings, polymers, ball-on-disc test, wear

1 Introduction

The automotive industry is the one of the constantly developing sectors. This development is dictated by the constantly growing requirements of consumers, the developing technology and manufacturing processes, and increasing attention to the protection of the natural environment. Ecological requirements in the automotive sector favor the development of propulsion systems, research on energy flow in a vehicle [1–5], and research in the field of

construction materials [6–11] as well as the manufacturing processes [12–14].

The automotive industry uses a variety of technologies and construction materials in the production process of various components and parts. Various types of construction materials are used in automotive industries, which include polymers [15–18], composite materials [2,19–21], steel and aluminum [13,22,23], and titanium alloys [24]. The polymeric materials and their composites have recently been increasingly used in various industrial applications in which their abrasion resistance makes them preferred for the elements of sliding pairs [17,25–27]. Each slide bearing is a tribosystem which is thermodynamically open, i.e., it exchanges energy and mass with the environment [28]. At the design stage of construction, the acceptability level of polymer materials to work in conditions of abrasive wear to a large extent depends on their mechanical load and wear level, which in turn translates into safety and durability of machine parts [26,29,30]. Friction is a very important parameter that determines the choice of materials for slide bearings, because many variables have an impact on them, e.g., working conditions of the contact elements, the ability to create a polymer film (transfer of material) or generate heat, etc. [31]. In tribology of polymers, a wide relationship can be found between friction and wear phenomena [21]. The fact of accurately characterizing the friction in the contact pair is a key factor for reproducing in a correct way the wear phenomena in the contact pair [32]. Knowledge of the characteristics of tribological materials pairs cooperating with each other is useful for their selection from the point of safe slide bearings in agricultural equipment and machinery and in means of transport.

Many researchers [26,33,34] reported that the resistance to wear depends on not only the mechanical and structural properties of the materials used but also the technique of testing [35,36]. In fact, the manufacturer Igus GmbH provides information in its catalogs about the values of the friction coefficient of the materials offered but by working in other friction pairs, e.g., roll-shaft. There is no wear and friction information for the ball-on-disc friction pair association. Therefore, this work

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deals with tribological characteristics using ball-on-disc test, and materials working as a sliding pair of polymer and metal under technical dry friction.

2 Materials and methods

Polymer samples used for the sliding nodes by Igus®, with trade names iglidur A180, iglidur P210, and iglidur X have been applied for the tests. Table 1 presents the characteristics of physical and mechanical properties according to the manufacturer's data. The specimens used for tribological tests have been made as the discs with diameter of Ø 30 mm and thickness of 5 mm. The discs have been subjected to grinding by means of water abrasive papers with grain size of 220, 600, and 1,200 correspondingly. Then the samples have been subjected to mechanical polishing by means of suspending diamond particles (3 µm) and oxide particles (0.05 µm), washing with acetone, and drying after the polishing process.

In this study, the wear tests were conducted on a “ball-on-disc” tribotester by CSM instruments, under technical dry friction at constant room temperature conditions of 22°C. As countersamples (ball) the balls with diameter of Ø 6 mm made of steel 100Cr6 (manufactured by CSM Instruments) have been used. The tests were carried out under the load of 10 N with linear speed of 0.05 m/s on the radius of 5 mm. The total test distance was equal to 500 m and was used to record the friction coefficient change. The wear measure was equal to the volumetric loss of the sample, which occurred as a trace

of abrasion as a result of sample and ball mating. The surface area of sample abrasion was measured along the sample circumference by means of Dektak 150 contact profile meter manufactured by Veeco Instruments (at 12 locations). Nose radius of the measuring needle was equal to 2 µm. A volumetric wear was set as the product of average value of the wear field of sample and circumference of a circle of wear track resulting in ball-on-disc test. Then the so-called wear factor K was determined, which next to volumetric wear took into account the load and the distance used during the test:

$$K = \frac{\text{Volumetric wear}}{\text{Loading force} \times \text{Road test (distance)}} \quad (1)$$

[mm³ N⁻¹ m⁻¹]

The surface of the wear tracks of materials tested after carrying out the tribological tests was assessed using scanning electron microscope Phenom G2 pro (Phenom Word).

3 Results and discussion

The values of the recorded friction coefficients are presented in Table 2 and graphical interpretation vs distance is illustrated in Figure 1. Comparative analysis of the coefficients of friction pointed out that the lowest coefficient of friction was observed for steam iglidur P210 – steel 100Cr6. For this pair obtained the maximum standard deviation of ±0.05. Whereas the largest coefficient of friction is obtained for steam iglidur X – steel 100Cr6. In general, less friction coefficient corresponds

Table 1: Summary of physical and mechanical properties of the researched polymer materials [37]

Properties	Unit	igidur® A180	igidur® P210	igidur® X
Density	g/cm ³	1.46	1.40	1.44
Color	—	White	Yellow	Black
The maximum moisture absorption at 23°C/50% r.h.	% weight	0.2	0.3	0.1
The maximum water absorption	% weight	1.3	0.5	0.5
Modulus of elasticity	MPa	2,300	2,500	8,100
Tensile strength at temperature 20°C	MPa	88	70	170
Compressive strength	MPa	78	50	100
The maximum surface pressure at 20°C	MPa	28	50	150
Shore hardness	°Sh D	76	75	85
The maximum operating temperature in a longtime	°C	+90	+100	+250
The maximum operating temperature in a short time	°C	+110	+160	+315
The minimum operating temperature	°C	−50	−40	−100
Thermal conductivity	W/m K	0.25	0.25	0.6
The coefficient of thermal expansion at 23°C	K ⁻¹ × 10 ⁻⁵	11	8	5

Table 2: Summary of the values of the coefficients of friction of the tested materials

Materials	The average coefficient of friction	Standard deviation
iglidur A180	0.139	0.023
iglidur X	0.189	0.035
iglidur P210	0.124	0.050

Figure 1: Charts of changes in coefficient of friction recorded on a ball-on-disc stand at a distance of 500 m in technical dry friction conditions, respectively, for materials: (a) iglidur A180, (b) iglidur X, and (c) iglidur P210.

to a polymer with a smaller hardness (see Table 1 – Shore hardness). To change the coefficient of friction in the distance function in all the studied cases, a small increasing tendency of coefficient of friction was observed, which smoothly increases along with the increasing contact field between the mating surfaces. Sometimes the products of wear get to the track of the direct cooperation of sample and countersample and then the momentary increase in coefficient of friction was observed. Moreover, the slight upward trend of the friction coefficient is influenced by the morphology of the wear track surface, i.e., inequalities related to delamination and fatigue microcracks.

The analyses of results (Figure 2) demonstrated that the iglidur A180 material showed the most resistant to wear in the friction of technically dry environment. But by far the biggest wear was recorded for iglidur P210 material, which has been characterized by the lowest coefficient of friction.

In order to verify whether the changes are indeed statistically significant, an analysis using STATISTICA software was performed along with the parametric tests for independent trials. Statistical analysis using Shapiro–Wilk test of volumetric wear measurement showed that the results obtained have a normal distribution ($p > 0.05$; assuming $\alpha = 0.05$). For the material iglidur A180, X, and P210, it was $p = 0.345$, $p = 0.947$, and $p = 0.801$, respectively; therefore, $p > \alpha$, and there is no reason to reject a hypothesis of normal distribution of the tested characteristics. This can provide quite homogeneous structure of the tested polymeric materials. In addition, severe Student's t -test (for $\alpha = 0.05$) showed that the differences in wear are statistically significant ($p < 0.05$) between all groups of the tested materials.

Figure 2: A graph of the values of wear coefficients K .

The values of determined wear coefficients K are shown in Figure 2.

Figure 3 shows the wear profile obtained during the ball-on-disc test.

Deepest wear track (Figure 3) has been reported for material iglidur P210, and it is on average about 3× deeper with respect to the least wearable iglidur A180.

The representative SEM structures of wear tracks after tribological tests under conditions of technically dry frictions of the testing materials are shown in Figure 4.

Based on the analysis of wear profiles (Figure 3) and wear track surface (Figure 4), we can notice that the abrasive wear mechanism is dominant. Whereas micro-cutting is an intensifying factor, whose traces are then found along the wear track in form of continuous scratches. The observed microcracks are the result of low cycle wear resulting from multiple counterbody swelling of the same volume of material. Cracks are the result of tensile stresses behind the countersample generated in the top layer of the sample. In addition, adhesive phenomena are determined by increase in local temperature as a result of friction. There has been a transfer of polymer material on metal surface of the countersample (Figure 5). After the tribological tests, it was noted that polymer particles adhered to the steel countersamples 100Cr6. As shown in the literature [16,29,31,38], during tribological processes after a given period of time the polymer-metal pair goes in cooperation with polymer-polymer, thereby creating a polymer film.

Recognition of wear processes in the mechanical systems is extremely important from the perspective of the

Figure 3: Representative profiles show the sign of wear after the ball-on-disc test.

Figure 4: Representative SEM structures of wear tracks after tribological tests under conditions of technically dry frictions of the following materials: (a) iglidur A180, (b) iglidur X, and (c) iglidur P210.

Figure 5: Photographs of surface of countersample.

final product due to its durability and reliability. It is extremely important in the operation of means of transport, where the first signs of wear are diagnostic information. In the transport sector are many diagnostic methods, widely described in the literature [34,35,39–43], which can be used in other machines and technical devices.

4 Conclusion

This contribution presents a comparative analysis of the coefficients of friction of three polymeric materials used in the construction of slide bearings in the automotive industry. The analysis of coefficients of friction pointed out that the material iglidur X ($\mu = 0.189$) possesses the highest coefficient, followed by lower iglidur A180 ($\mu = 0.139$) and iglidur P210 ($\mu = 0.124$). In addition, among all three groups of the tested materials statistically significant differences ($p < 0.05$ in Student's t -test) were observed in wear. However, the greatest resistance to wear was recorded for the material iglidur A180 in the ball-on-disc test. Essentially, the destruction mechanism of the tested polymers had an abrasive nature. In addition, adhesive phenomena associated with the transfer of polymer material on the surface of steel 100Cr6 were observed. Moreover, it has also been observed that in terms of technically dry friction, the most wearable material was iglidur P210, which recorded the lowest coefficient of friction in the test.

Knowledge of tribological characteristics and identification of polymer material wear allows to develop in the future comprehensive criteria for their selection in the design of slide bearings in means of transport and various types of machineries.

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