

A Comparative Study of Tribological Behavior of Moglice and DK-6(PT) Composites

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ABSTRACT

Authors have produced new polymer-based composite material DK-6(PT) for substitution of Moglice (Diamant) polymer. We manufactured and used sliding-friction test apparatus (pin-on-disc) capable of testing three specimens simultaneously, much reducing time for the test. The monitoring of the material curing process and the Shore hardness test indicate minor difference from reference material. Measurements were carried out during the curing period, since it is important to know change in this parameter over time. The wear test proved that DK-6(PT) composite in the long-time test has good wear resistance: over 80 km of the friction path, the wear loss of both materials is approximately the same. Furthermore, the friction factor of DK-6(PT) is 5–10% less than that of Moglice. Thus, the studied new polymeric composite may compete with well-known material Moglice and significantly cut the expenses for reconditioning of worn slide ways of metal working equipment.

Keywords: polymer matrix composites, friction coefficient, wear, tribometer, hardness, wear.

INTRODUCTION

A large number of materials that are used for friction applications are known. Among these materials, the most effective and promising are polymers and polymer-based compositions. Such materials can significantly increase machines' reliability and service life, reduce their weight and overall dimensions, and save expensive alloy steels and non-ferrous metals. In many cases, this also reduces the labor expenses and simplifies the design [1–4].

It is especially advisable to use polymer matrix composite materials for aircraft structures [5–7] to reduce weight. This is because they have high physical and mechanical characteristics.

The wear resistance and other tribotechnical characteristics of such parts' friction surfaces are comparable to those for metallic friction couples [8, 9]. Recently, technologies or restoration of worn or damaged friction surfaces using two-component composite materials [10] are getting more comprehensive applications. Their use in repair practices and subsequent operation requires studying the characteristics of these materials. In particular, such parameters as the sliding friction coefficient, wear resistance, and lubricants' effect should be studied.

One example of using composite polymer-based material is the repair of metal-cutting machine slideways worn surfaces using a composite polymer material Moglice (Diamant)

[11–13]. Moglice is a two-component, cold-curing antifriction polymeric material used to rebuild and restore all types of sliding surfaces. Moglice may be used for the repair of any sliding system. It is widely used in the manufacture of new machines to cover the guides and for their repair and repair of localized damage. Moglice is characterized by chemical resistance to water, oils, alkaline solutions, emulsions, kerosene, gasoline, etc.

Tribotechnical studies of the polymeric material Moglice indicated positive results and confirmed the characteristics declared by the “Diamant” [10–13]. However, the use of polymer material Moglice is associated with high financial costs. Its relatively high cost limits the use of Moglice material to repair worn-out surfaces in the industry. Therefore, it is good to find material with at least the same mechanical and tribological performance for industrial use but with a lower price. To replace the Moglice material, we researched the antifriction properties of a set of composite polymer-based materials with lower cost. One of these materials is a composite polymer material DK-6(PT). It has relatively high hardness and is promising to fulfill research requirements. The material DK-6(PT) was fabricated based on a polymer matrix with various fillers containing molybdenum disulfide, graphite, etc. This composite is a development of Pryazovsky State Technical University, Mariupol, Ukraine.

OBJECTIVES AND PROBLEM STATEMENT

The objective of this work is to study the properties of newly developed new polymer-based composite material DK-6(PT) and to compare them with the material Moglice, as well as to create an experimental laboratory setup and methods for determining the physical characteristics and antifriction indicators of composite polymer materials – friction coefficient and wear rate. Based on the analysis of the known friction test layouts and test methods for polymeric materials, [14–16], it is possible to figure out the basic requirements for the friction unit of the tribometer:

- ensuring the constancy of the nominal contact area between the sample and counterpart during wear test;
- possibility to variate friction parameters of studied friction surfaces;
- the minimum use of expensive polymer materials for fabrication of test samples.

To study the tribotechnical properties of polymers, we used a pin-on-disc layout, as far as it satisfies all listed above requirements. Explained below tribometer was designed and manufactured for this study (Figure 1, 2) [17].

The friction coefficient is calculated using values of friction moment measured by an inductive sensor according to the deflection angle of the carriage rocker arm 15 fixed to the casing of tribometer carriage 4 (Figure 2). The frame of the inductive sensor is connected to calibrated springs, which create a moment on the L arm,

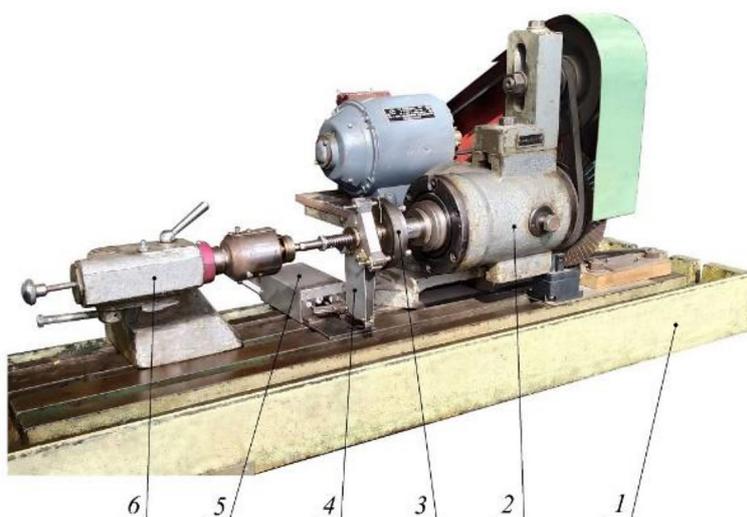


Fig. 1. Tribometer

1 – tribometer bed; 2–headstock; 3 – counterpart; 4 – tribometer carriage with specimens; 5 – friction moment sensor; 6 – tailstock

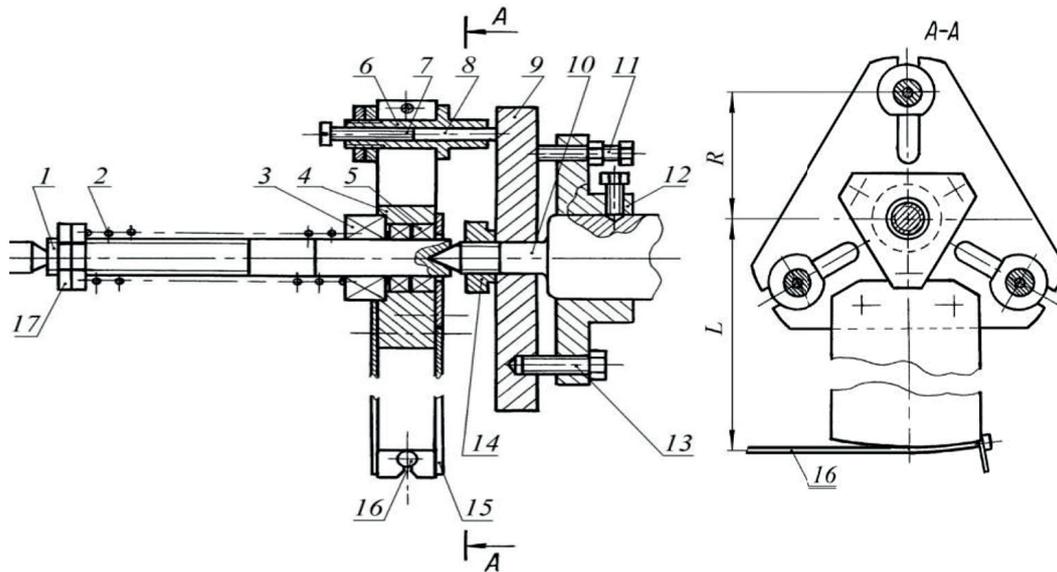


Fig. 2. The layout of the tribometer carriage

1 – axis; 2 – spring; 3 – thrust bearing; 4 – carriage casing; 5 – bearings; 6 – bush; 7 – adjustment bolt; 8 – specimen; 9 – disc-shaped counterpart; 10 – running center; 11 – tree screws to adjust specimen position; 12 – leading flange; 13 – leading driver; 14 – nut; 15 – carriage rocker arm; 16 – metallic cable connecting carriage and inductive sensor measuring casing 4 angular displacement; 17 – spring stops

counteracting the friction moment on the R arm. The samples are cylindrical pins made of DK-6 (PT) and Moglice polymers, diameter 3 mm, length 10–15 mm. A counterpart is a disc whose rotation speed can be adjusted in a range of m 10–2500 rpm. The rotational speed is controlled by digital tachometer.

Tribometer carriage consists of axis 1 (Fig. 2) fixed in the centers. Spring 2 through thrust bearing three clamps casing 4. Casing 4 rocking on bearings 5 may slide along axis 1 with the minimum clearance Z_1 between the inner ring and axis 1. Casing 4 has radial slideways (radial pitch is 120° between neighboring slideways) with 3 bushings 6 inserted into them. Radial slideways are used to adjust the location of bushings 6. Bolts 7 are used to fix pins 8, which contact with counterpart 9. The clamping force on the samples is determined by measuring the length of the compressed pre-calibrated spring 2 (Fig. 2). Because the distance L from the rocking axis of the housing 4 to the axis of the inductive sensor is significantly greater than distance R from rotational axes to samples 8, the accuracy of friction torque measuring increases.

The possible force on each sample is up to 40 N. Using 3 mm diameter specimens, the developed contact pressure between each specimen and counterpart was 5.6 MPa. Before starting the experiment, the clamping spring 2 is calibrated, and the

return springs of the friction torque measuring unit are connected to the rocker arm of the carriage 15.

The friction coefficient is calculated using the formulas:

$$f = \frac{F_{fr}}{N_1} \quad (1)$$

where: F_{fr} – friction force developed on one specimen; N_1 – clamping force applied to one specimen.

$$F_{fr} = \frac{1}{3} F_s \frac{L}{R} \quad (2)$$

$$N_1 = \frac{1}{3} N F_{fr} \quad (3)$$

where: F_s – the calibrated force of inductive sensor springs; N – clamping force; L and R – arms of tribometer (explained in Figure 2).

The samples' linear wear is determined by measuring their length using a lever bracket and a fixture (Figure 3). The fixture ensures the parallelism of the specimen axis and the axis of the clamp measuring rod. Wear measurement accuracy is 2 μm . It was not suitable to use weight loss to characterize specimens wear, as far as they have significantly different densities (Table 3), chemical composition, and friction-induced oxygen gain.

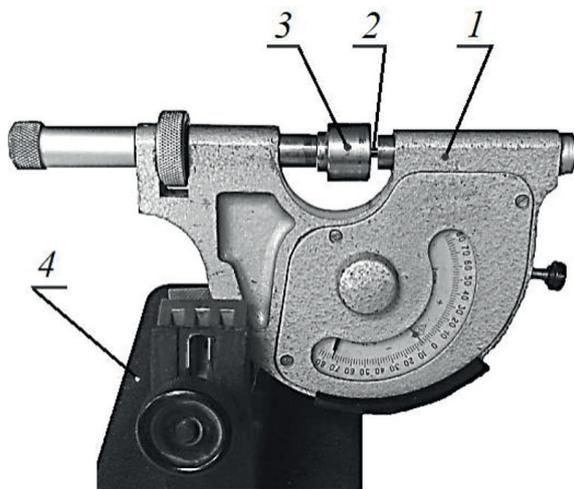


Fig. 3. Measuring linear wear. 1 - lever bracket; 2 - measured sample; 3 - fixture; 4 - staple stand

Preparation of specimens

The samples were made from a paste-like material Moglice, type P, and the other samples were made of developed DK-6(PT) material. First, the required amounts of resin and the hardener are mixed in a ratio of 5:1 (parts by weight). After mixing, the mixture is poured with a syringe into the sleeve-type calibrated-size molds. A hardener covers Pre-calibrated molds inside the hole to avoid sticking the solidified polymer to the mound surface. On one side, the opening in the mold is closed. The curing duration is 24 hours. After curing, the specimens are easily knocked out of the mound with a metal rod. Before wear testing, samples' ends were ground using fine sandpaper in a fixture to ensure the perpendicularity of the end face and axis of the sample. The same roughness was ensured for the samples made of Moglice and DK-6(PT) samples. Counter-part disc is fabricated of cast-iron SCh20 (ISO/ASTM 200).

Wear loss and friction factor test results

The polymeric materials Moglice and DK-6(PT) were tested for wear at sliding friction as a lubricant industrial oil I-20 was used. The rotation speed of the counterpart was 20 rpm. At these rpm's, the sliding velocity was 4.71 m/min. The contact pressure was 1.6 MPa. These speed and pressure values are typical for most sliding friction units using polymeric antifriction materials. The results of polymeric materials Moglice and DK-6(PT) wear tests are in Figure 4. Tables 1 and 2 and contain information about wear

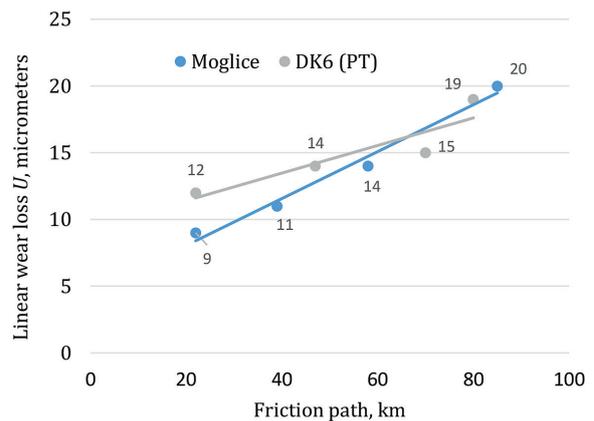


Fig. 4. linear wear loss of tested materials

measurement details. Before starting the wear test, the length of each of the three samples was measured using a lever clamp. The bracket was adjusted using pin-type calipers. Average wear loss after friction time T was determined as average length difference before and after the test period based on three sample measurements.

Photographs of friction surfaces were obtained using light microscope MBS-1. Wear surface profiles were constructed using profilometer MOD-201 with control of R_a parameter. Wear path was calculated using formula 4:

$$l = \frac{60\pi Dn}{10^6} \times T \quad (4)$$

where: D – average diameter of wear groove; $D = 75$ mm; n – rotational speed of counterpart, $n = 20$ rpm; T – wear test duration between length measurements, h .

Figures 5–9 show wear tracks character and wear track roughness profiles of specimens and counterpart.

During wear tests, the friction torque was periodically monitored and the friction coefficient was calculated using formula (1). The average values of the friction coefficient for both Moglice and DK-6(PT) coupled with cast-iron, was in the range of 0.06–0.8; and for composites coupled with steel friction coefficient ranged from 0.08 to 0.12. Owing to the tribometer's high sensitivity, we registered fluctuations of the friction coefficient caused by different factors. These fluctuations may be caused by replacing lubricating oil, changing air temperature or the operating time of the tribometer before stop (it was stopped periodically to measure the wear loss), inaccuracies in the position of test samples, etc. Measured values of friction coefficients for the polymeric material Moglice correspond to those declared by

Table 1. Wear measurement details for Moglice polymeric material (pin-on-disc unidirectional sliding, lubricated by I-20 oil)

No.	Wear test duration, h	Wear path, km	No. of specimen	Specimen length after wear path l, mm	Average length, mm	Accumulated wear loss, U, μm
1	0	–	1	18.237	18.876	–
			2	18.307		
			3	20.084		
2	83	23.54	1	18.235	18.867	9
			2	18.292		
			3	20.075		
3	135	38.41	1	18.234	18.865	11
			2	18.288		
			3	20.074		
4	206.5	58.62	1	18.232	18.862	14
			2	18.284		
			3	20.070		
5	299.5	85.02	1	18.232	18.856	20
			2	18.280		
			3	20.055		

Table 2. Wear measurement details for DK-6(PT) composite material (pin-on-disc unidirectional sliding, lubricated by I-20 oil)

No.	Wear test duration, h	Wear path, km	No. of specimen	Specimen length after wear path l, mm	Average length, mm	Accumulated wear loss, U, μm
1	0	–	1	22.682	22.022	–
			2	22.154		
			3	21.230		
2	83	23.48	1	22.662	22.010	12
			2	22.143		
			3	21.225		
3	168	47.6	1	22.663	22.008	14
			2	22.135		
			3	21.227		
4	251	71.1	1	22.666	22.007	15
			2	22.134		
			3	21.222		
5	281	79.7	1	22.663	22.003	19
			2	22.129		
			3	21.219		

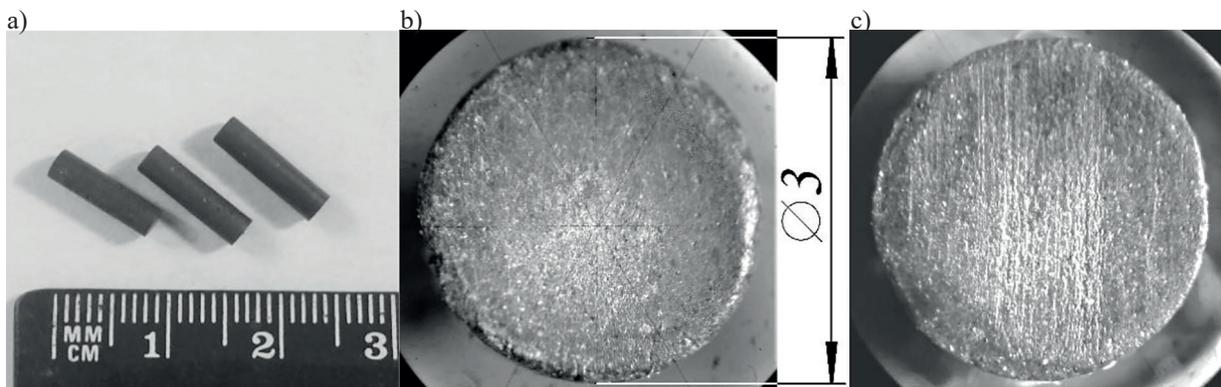


Fig. 5. The studied specimens and wear surface of “Moglice” pins, $\text{Ø} 3 \text{ mm}$: (a) specimens of polymeric materials, (b) initial surface, (c) wear track on Moglice surface

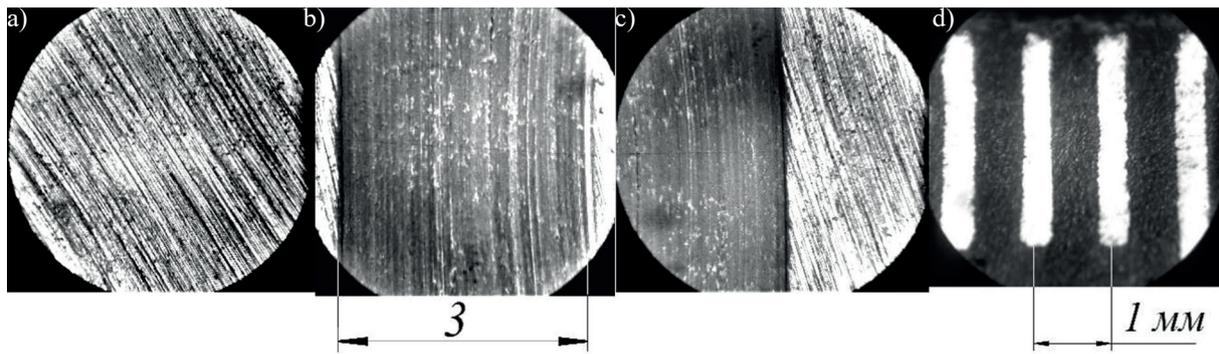


Fig. 6. Wear track of cast-iron counterpart after Moglice testing: (a) initial surface, wear track boundary from the left (b), and right (c) sides, (d) microscope magnification scale

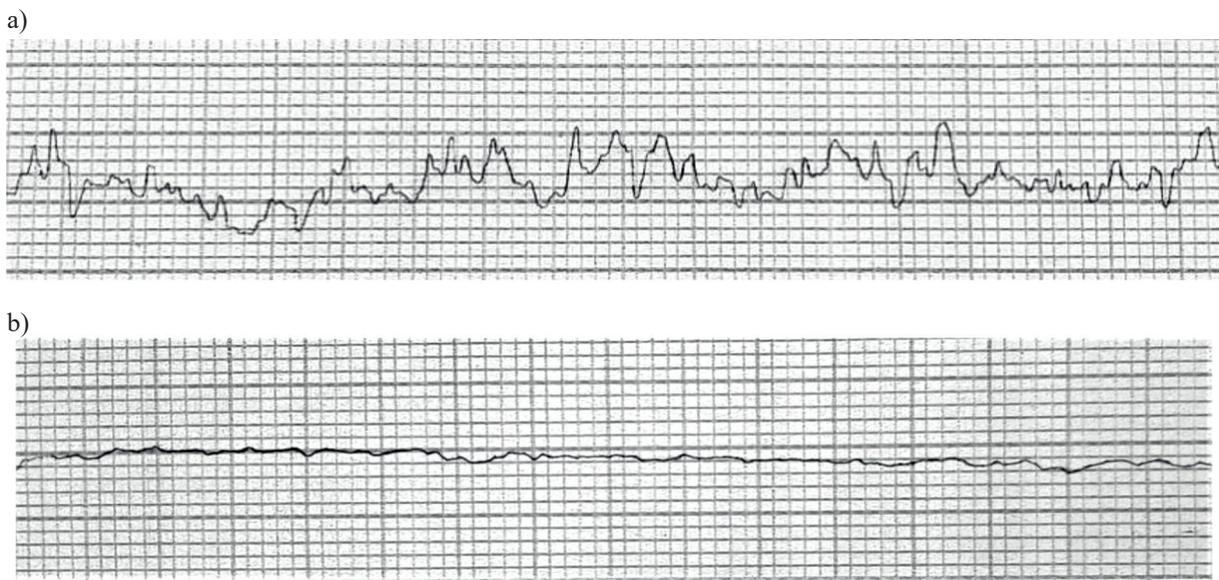


Fig. 7. Wear track profiles of cast-iron counterpart after wear test coupled with Moglice: horizontal magnification $HM = 200$, vertical magnification $VM = 1000$, grid distance on profilogram is 2×2 mm initial counterpart roughness (a), $Ra = 0,12 \dots 0,18 \mu m$, wear track roughness (b), $Ra = 0,03 \dots 0,04 \mu m$

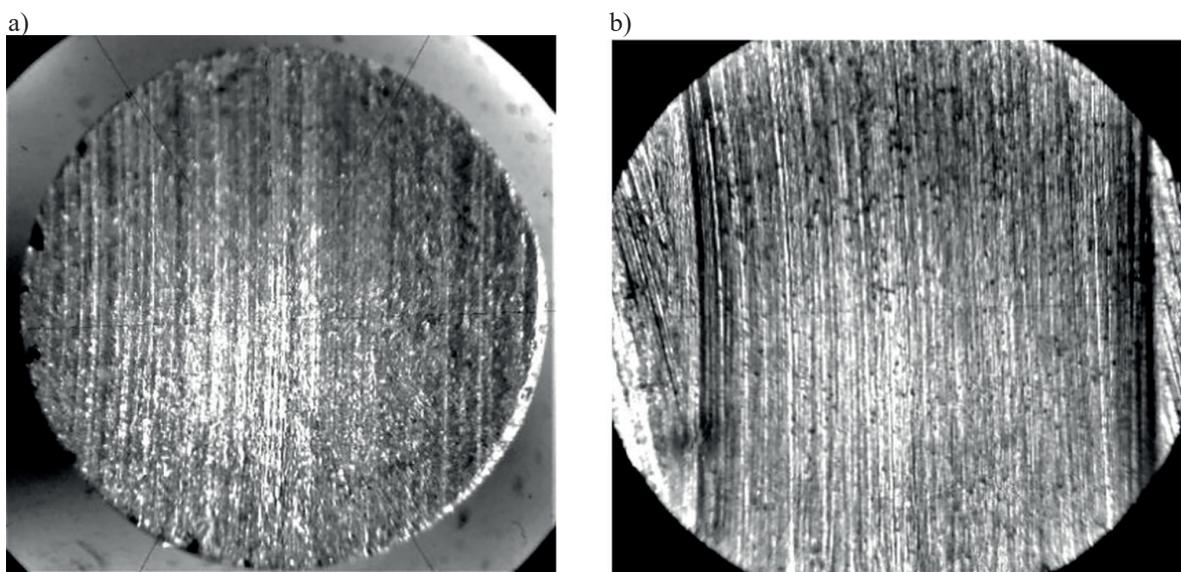


Fig. 8. DK-6(PT) wear track surface, pin diameter $\varnothing 3$ mm, initial surface (a) and wear track surface (b)

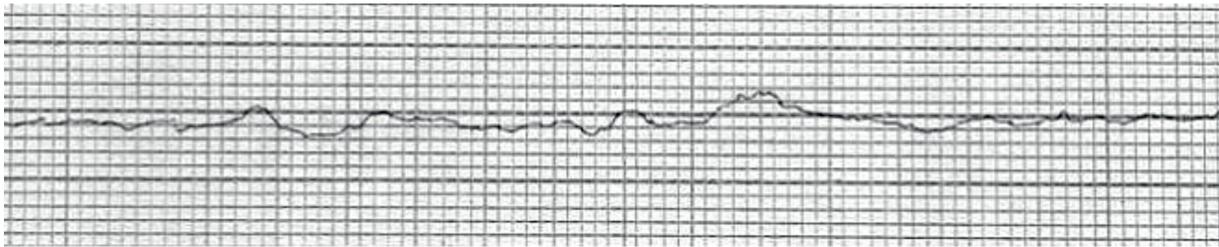


Fig. 9. Wear track profile of counterpart surface after testing DK-6(PT) material horizontal magnification HM=200, vertical magnification VM=1000, grid distance on profilogram is 2×2 mm, Ra = 0.08...0.12 μm

Diamant. The friction coefficients' average values for the developed new polymeric material DK-6(PT) are close (even lower) to the values of the friction coefficients for Moglice.

Comparative study of Moglice and LK6(PT) mechanical properties

One of the important mechanical characteristics of the polymers Moglice and DK-6(PT) is their hardness. In this case, the value of the final hardness after curing change in this parameter

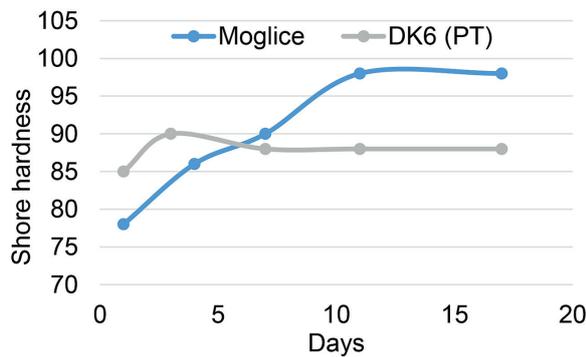


Fig. 10. The change of hardness of studied materials

Table 3. Physical characteristics of Moglice and DK6(PT)

Property	Moglice	DK-6(PT))
Density, g/cm ³	1.7	2.0
Thermal stability, °C:		
- short time	-40 ÷ +125	-
- long time	-20 ÷ +60	-20 ÷ +90
Pot life at 20 °C, min	50	40
Full curing time, h	18	24
Elasticity module, MPa	10400	6500
Compression strength	120	150
Bending strength, MPa	64	60
I-20 lubricated friction factor (coupled with steel)	0.08–0.95	0.06–0.08
Shore hardness	90	90

over time is important. Thus, in machining a surface made of Moglice or DK-6(PT) material, for example, scraping or the formation of lubricating grooves, it seems expedient to perform these operations after complete final polymerization of the material. Therefore, we carried out measurements of the Shore hardness of samples made from the studied polymeric materials. For this, samples with a thickness of 2.4 mm were fabricated. Hardness measurements were carried out using a dynamic hardness tester TD-32M, which has a measurement range on the Shore scale (HSD) of 40–100 with the accuracy of ±5%. Hardness measurements were done after 1, 4, 7, 11, and 17 days for Moglice and after 1, 3, 7, 11, and 17 days for DK-6(PT) (Figure 10).

Table 3 shows polymeric composite materials' physical and mechanical characteristics: P-type Moglice and DK-6(PT) (according to materials manufacturers' catalog data).

DISCUSSION

For 80 km of the friction path, both polymer composite materials' wear is approximately the same. The increased wear rate in the area up to 20 km can be explained by the samples' insufficient running-in, which was carried out before the test. The friction coefficients are also close in their values. These studies have proved that polymer composite materials Moglice and DK-6(PT) are equivalent in their tribotechnical characteristics. Using a cheaper polymer DK-6(PT) to manufacture and repair sliding friction couples to replace the Moglice material looks very promising.

The initial roughness of the cast-iron counterparts is identical since they were polished simultaneously. Micrographs and profilograms were obtained after 80 km of friction path. Micrographs and profilograms of samples and counterparts friction surfaces indicate that DK-6(PT)

after friction have higher roughness than Moglice. This may be explained by the fact that during friction DK-6(PT), there is a sizeable adhesive component of friction. Wear products are not removed from the friction zone but again adhere to the friction surface. Besides, the modulus of elasticity for the Moglice material is 1.6 times higher than for DK-6(PT). Moglice is tougher than DK-6(PT). This explanation is also supported by the lower actual hardness of DK-6(PT) compared to the polymer Moglice. The authors experimentally determined that actual hardness (Table 3) differs from that declared by the manufacturer. From Figure 10, one may see that the hardness of DK-6(PT) becomes constant on 7th day after curing, and the hardness of Moglice stops increasing on 11th day after curing. Moglice has the highest hardness on the 11th day after curing and the material DK-6(PT) on day 3. After three days, DK-6(PT)'s hardness decreases, but this will not affect surface machining quality.

The data for Moglice are derived from manufacturer's specifications. The manufacturer of the material obtained the characteristics of the material DK-6(PT). Mechanical characteristics are similar in their values, except for the modulus of elasticity. The friction coefficients are also close in their values, although for DK-6(PT), the friction coefficient is slightly higher than for Moglice. These studies have proved that polymer composite materials Moglice and DK-6(PT) are equivalent in their tribotechnical characteristics. Using a cheaper polymer DK-6(PT) to manufacture and repair sliding friction couples can make it possible to replace the material Moglice. DK-6(PT) is approximately eight times cheaper than Moglice [18, 19].

The developed tribometer allows the constancy of the nominal contact area of the rubbing surfaces during the test. It makes it possible to provide technological support and vary the studied friction surfaces' quality parameters and the possibility of using a minimum amount of expensive polymeric materials for manufacturing purposes. To create and recover sliding friction couples, it is advised to use polymer materials, which significantly simplifies the process of equipment repair. For the manufacture and repair of sliding friction couples, it is advisable to use a cheaper composite polymer DK-6(PT), which can be used as a substitute for the Moglice.

CONCLUSIONS

The two examined materials (Moglice and DK-6(PT) polymer-based composite material) have similar tribological characteristics. Both materials may be used for permanent or temporary repairs of sliding friction couples, especially used in metal working machine tools. Moglice has 10 minutes longer pot life and 6 hours shorter full curing time: this extends the time of material application to the slide ways, and reduces the wait time before reconditioned equipment may turn back to operation. According to our test, DK-6(PT) material has higher hardness after five days curing (Figure 11). The wear intensity of Moglice is less during the first 60 km of wear path, but it becomes higher after this threshold. Also, DK-6(PT) has higher long-term temperature stability. Being eight times cheaper and having close tribological performance, DK-6(PT) may be successfully used as a substitute for Moglice.

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