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Wear

ABRASIVE WEAR OF POLYMER COMPOSITE MATERIALS OBTAINED BY 3D PRINT TECHNOLOGY

PART II. COMPOSITE POLYMER MATERIALS

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ABSTRACT

The paper examines the parameters of abrasive wear and wear resistance of two types of composite polymer materials from different manufacturers – Steelfill and Carbonfil™, the samples of the materials were obtained by using a 3D technology. The materials were tested in four modes of friction – without and with lubricant grease Litol 24 and at two sliding speeds. Results and dependences for mass wear, wear rate, wear intensity and wear resistance of each material in the four friction modes were obtained. Carbonfil™ material was found out to have the best anti-wear properties during dry friction, at sliding speeds v = 0.25 m/s and v = 0.92 m/s; at limit lubrication with Litol grease 24 sliding speeds v = 0.25 m/s and v = 0.92 m/s, and Carbonfil™.

The results are original and have not been published in other editions.

Keywords: polymer materials, 3D print technology, tribology, abrasion wear, wear resistance

AIMS AND BACKGROUND

The grinding of various materials is an important industrial process. This process is extremely energy-intensive. Using manufacturing mills for laboratory experiments is an expensive process. This article focuses on materials from 3D printers to study the motion and interaction between grinding bodies and media. Determining the factors, optimizing the dimensions, and properly modeling the CAD mod-

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els and their tribological properties would help to enter accurate input data when creating simulations for laboratory and production mills. Research with innovative grinding media can reduce the time period to grind production and increase energy efficiency. Accurately creating simulations can reduce production costs[1–5].

Tribomaterial science is one of the main directions in modern tribology, which focuses on the research and development of materials and coatings with increased antifriction and antiwear properties[4,5,6]. Numerous efforts of researchers are focused on composite materials and coatings with metal matrix, modified with different in nature ceramic micro- and/or nanosized particles and applied by different technologies[9–15].

The use of 3D printing for single pieces, prototyping, use for castings and others leads to a reduction in production costs. Additive technology has several advantages in terms of building details. There are no operations that take time to make the details such as turning, milling, casting, etc.[16,17]. Basic materials are considered[18,19], used in 3D printing such as PLA (polylactic acid) and PETG (polyethylene terephthalate). Based on them are the materials studied in this article. Other varieties most often use PLA and ABS as a basis, varying the percentage of various impurities such as: carbon fiber, wood fiber, biodegradable materials, the presence of metal particles, the presence of cement particles, the presence of fluorescent particles[19]. Of great interest is the application of such materials in tribotechnical systems such as bushings for plain bearings, guides, gears and others. The widespread use of parts used for various applications requires a study of their tribological properties. Tribological studies of materials from 3D printers in the presence of biodegradable polymer materials are known[20].

The present work aims to study the characteristics of abrasive wear and wear resistance of two types of composite polymer materials based on PLA and PETG. For this purpose, 3D printed samples were tested in different modes of friction – without and with lubricant at two sliding speeds.

MATERIALS

Two types of composite polymer materials Steelfill (based on PLA material) and Carbonfil™ (based on PETG material) obtained by 3D print technology were studied. The details were 3D printed according to the manufacturers' recommendations, the filling is 100% at a layer height of 0.16 mm.

The designation and density of the test materials are described in Table 1.

Table 1. Sample number, designation and density of the tested materials

No sample	Designation	Type	Density кg/m^3
1	Steelfill	PLA with steinless steel powder aprox. w80%15	2801.127
2	Carbonfil™	PETG with carbon fibres	1082.25361

EXPERIMENTAL

The performed test of abrasive wear is done by sliding a cylindrical sample of the test material on a surface with fixed abrasive particles. A tribo tester with a kinematic scheme ‘Pin on disk’ with a functional scheme and methodology already described in the publication ‘Abrasive wear of polymer composite materials obtained with 3D print technology, Part I. Polymer Materials’ is used. The tested samples have a diameter of 10 mm and a height of 20 mm. The samples are fixed in the holder. The abrasive surface is modeled using impregnated corundum Corundum P 320 with a hardness of 9.0 on the Mohs scale, which meets the requirement of the standard for at least 60% higher hardness of the abrasive material than the hardness of the tested material.

The experimental study parameters of the samples are represented in Table 2.

Table 2. Parameters of the experiment

No	Parameter	Value
1	Normal load	4.9 N = const
2	Nominal contact area	78.5 x 10^{6} m^2
3	Nominal contact pressure	6.2 x 10^{4} N/m^2 = const
4	Sliding speeds	V = 0.25 m/s; V = 0.92 m/s
5	Abrasive surface	Corundum P 320
6	Lubricant	Grease Litol 24
7	Environmental temperature	22^{o} C

The investigated two types of materials are tested in four modes of friction:

- Dry friction at sliding speed of 0.25 m/s;
- Dry friction at sliding speed of 0.92 m/s;
- Friction using grease Litol 24 with sliding speed 0.25 m/s;
- Friction using grease Litol 24 with sliding speed 0.92 m/s;

RESULTS AND DISCUSSION

The used methodology in the publication ‘Abrasive wear of polymer composite materials obtained with 3D print technology, Part I. Polymer Materials’[21] results are obtained for the wear characteristics of the tested materials. The results are represented below in tabular and graphical form for each material separately.

Examination of Steelfill material – Sample No 1

The results for the wear characteristics and wear resistance of Steelfill in dry mode and when lubricated mode for both sliding speeds are represented in Tables 3 and 4.

Table 3. Wear characteristics of Steelfill material in friction modes without and with lubricant at a sliding speed of 0.25 m/s

Sample No 1 – Steelfill Dry friction, V=0.25 m/s				
Number of cycles (N)	200	400	600	800
Sliding distance, m	50	100	150	200
Sliding time, min	3.3	6.6	9.9	13.2
Mass loss, mg	37.5	52.7	78.7	88.3
Wear speed, mg/min	11.4	8.0	8.0	6.7
Wear intensity	$3.38x10^{-6}$	$2.37x10^{-6}$	$2.36x10^{-6}$	$1.99x10^{-6}$
Wear resistance	$0.3x10^{6}$	$0.42x10^{6}$	$0.42x10^{6}$	$0.5x10^{6}$
Sample No 1 – Steelfill With Litol 24, V = 0.25 m/s				
Mass loss, mg	65.5	98.2	166.7	227.5
Wear speed, mg/min	19.9	14.9	16.8	17.2
Wear intensity	$5.9x10^{-6}$	$4.4x10^{-6}$	$5.0x10^{-6}$	$5.1x10^{-6}$
Wear resistance	$0.17x10^{6}$	$0.23x10^{6}$	$0.2x10^{6}$	$0.2x10^{6}$

Table 4. Wear characteristics of Steelfill material in friction modes without and with lubricant at a sliding speed of 0.92 m/s

Sample No 1 – Steelfill Dry friction, V=0.92 m/s				
Number of cycles (N)	200	400	600	800
Sliding distance, m	50	100	150	200
Sliding time, min	3.3	6.6	9.9	13.2
Mass loss, mg	148.9	184.0	197.0	218.3
Wear speed, mg/min	163.6	101.1	72.16	60.0
Wear intensity	$13.4x10^{-6}$	$8.28x10^{-6}$	$5.91x10^{-6}$	$4.91x10^{-6}$
Wear resistance	$0.07x10^{6}$	$0.12x10^{6}$	$0.17x10^{6}$	$0.20x10^{6}$
Sample No 1 – Steelfill With Litol 24, V=0.92 m/s				
Mass loss, mg	92.3	150.7	200.6	269.9
Wear speed, mg/min	101.4	82.8	73.5	74.2
Wear intensity	$8.31x10^{-6}$	$6.78x10^{-6}$	$6.0x10^{-6}$	$6.07x10^{-6}$
Wear resistance	$0.12x10^{6}$	$0.15x10^{6}$	$0.17x10^{6}$	$0.16x10^{6}$

As the data in Tables 3 and 4 show, the wear degree of the Steelfill material is much greater than the wear of the materials tested so far. Figures 1, 2, 3 and 4 show the dependence of mass wear on the sliding path in different modes – dry friction and when lubricated for both sliding speeds.

From Fig. 1 it can be seen that during dry friction the greatest wear occurs at the high sliding speed – 0.92 m/s. It is almost three times higher than the wear at 3.68 times the sliding speed. The data in Tables 7 and 8 for the wear intensity

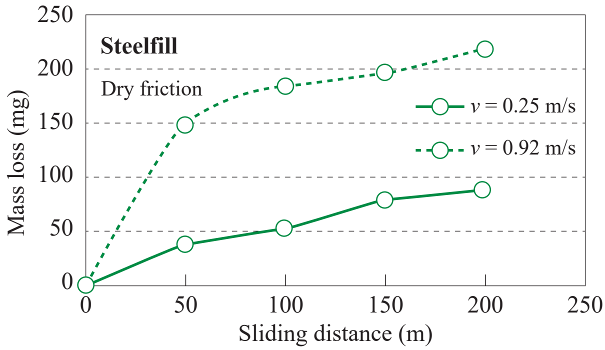

Fig. 1. Dependence of wear on the sliding path in friction without lubrication at two speeds

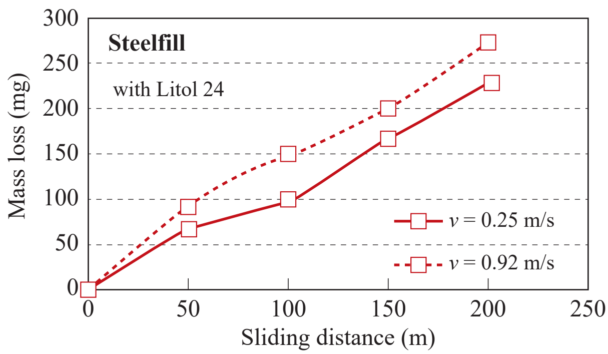

Fig. 2. Dependence of wear on the sliding path in friction with grease Litol 24 at two speeds

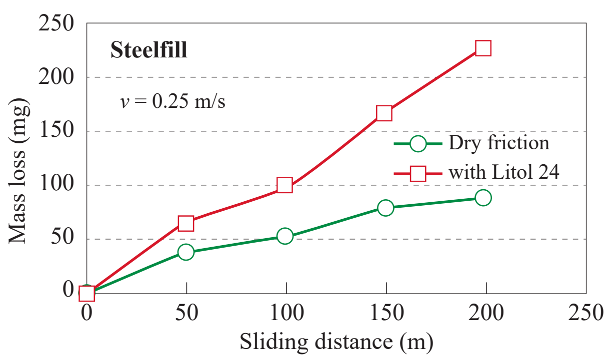

Fig. 3. Dependence of wear on the sliding path without and with lubricant Litol 24 at $v = 0.25$ m/s

clearly show that at low sliding speeds the wear intensity decreases insignificantly – it remains almost constant, while at high speeds it decreases exponentially.

When lubricated, the wear values are much higher than in case of dry friction. The wear kinetics curves shown in Fig. 2 are almost straight lines. The wear

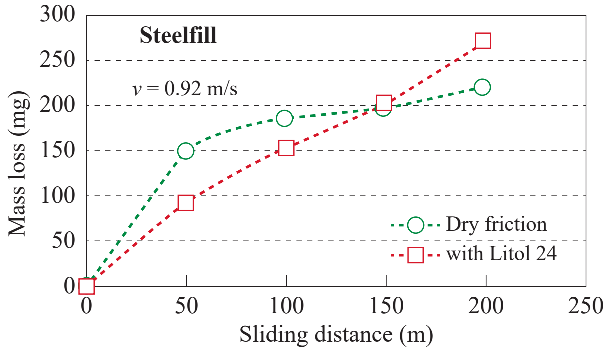

Fig. 4. Dependence of wear on the sliding path without and with lubricant Litol 24 at $v = 0.92$ m/s

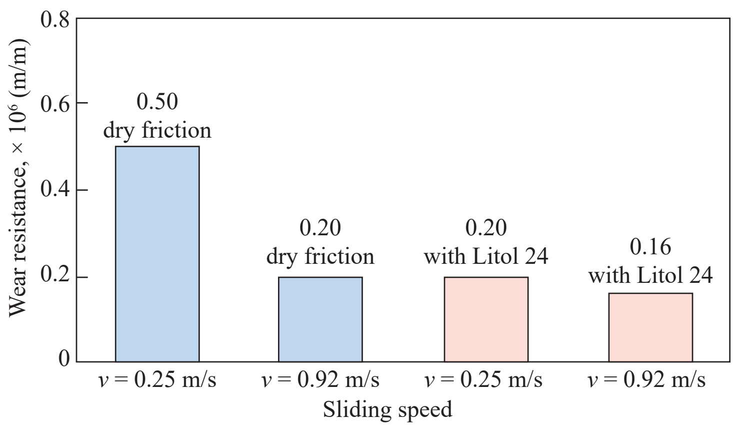

Fig. 5. Wear resistance diagram of Steelfill material at two sliding speeds in dry friction and lubrication with Litol 24 at friction path length 200 m

values at the two sliding speeds do not differ significantly. Wear values at high sliding speeds is greater than at low speeds.

Figures 3 and 4 show the dry wear and when lubricated wear curves for the low sliding speed of 0.25 m/s and for the almost 4 times higher sliding speed of 0.92 m/s, respectively. The results show that this material has better anti-wear properties in dry friction conditions and at low sliding speeds. The abrasion resistance diagram of the material shown in Fig. 5 confirms this statement.

Examination of Carbonfil™ material – Sample No 2

The results for the wear characteristics and wear resistance of Carbonfil™ material under different friction regimes are represented in Tables 5 and 6.

The analysis of the character of the wear curves in dry friction mode and when lubricated (Figs 6 and 7) shows that in dry friction mode low wear is ob-

Table 5. Wear characteristics of Carbonfil™ material in friction modes without and with lubricant at a sliding speed of 0.25 m/s

Sample No 2 – Carbonfil™ Dry friction, V=0.25 m/s				
Number of cycles (N)	200	400	600	800
Sliding distance, m	50	100	150	200
Sliding time, min	3.3	6.6	9.9	13.2
Mass loss, mg	13.6	21.6	26.5	29.7
Wear speed, mg/min	4.1	3.3	2.7	2.3
Wear intensity	3.18×10^{-6}	2.52×10^{-6}	2.07×10^{-6}	1.74×10^{-6}
Wear resistance	0.31×10^{6}	0.40×10^{6}	0.48×10^{6}	0.57×10^{6}
Sample No 2 – Carbonfil™ With Litol 24, V=0.25 m/s				
Mass loss, mg	29.6	48.0	67.0	81.8
Wear speed, mg/min	9.0	7.3	6.8	6.2
Wear intensity	6.93×10^{-6}	5.62×10^{-6}	5.23×10^{-6}	4.78×10^{-6}
Wear resistance	0.14×10^{6}	0.18×10^{6}	0.19×10^{6}	0.21×10^{6}

Table 6. Wear characteristics of Carbonfil™ material in friction modes without and with lubricant at sliding speed 0.92 m/s

Sample No 2 – Carbonfil™ Dry friction, V=0.92 m/s				
Number of cycles (N)	200	400	600	800
Sliding distance, m	50	100	150	200
Sliding time, min	3.3	6.6	9.9	13.2
Mass loss, mg	11.7	34.9	57.9	67.5
Wear speed, mg/min	12.9	19.2	24.4	18.5
Wear intensity	2.74×10^{-6}	4.08×10^{-6}	4.52×10^{-6}	3.95×10^{-6}
Wear resistance	0.36×10^{6}	0.24×10^{6}	0.22×10^{6}	0.25×10^{6}
Sample No 2 – Carbonfil™ With Litol 24, V=0.92 m/s				
Mass loss, mg	13.4	20.3	27.6	33.5
Wear speed, mg/min	14.7	11.2	11.6	9.2
Wear intensity	3.13×10^{-6}	2.37×10^{-6}	2.15×10^{-6}	1.96×10^{-6}
Wear resistance	0.32×10^{6}	0.42×10^{6}	0.46×10^{6}	0.51×10^{6}

served at low sliding speeds of 0.25 m/s, and when lubricated – at high sliding speed 0.92 m/s.

In the dry friction mode the kinetic curves have a nonlinear character, and when in lubricated mode – almost direct proportionality. This is confirmed by the change in the values of wear intensity. Figure 8 shows that at low sliding speeds (0.25 m/s) in dry friction mode the wear is 2.7 times less than the wear

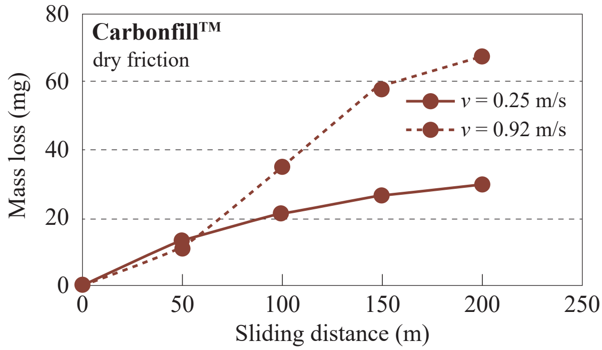

Fig. 6. Dependence of wear on the sliding path in friction without lubrication at two speeds

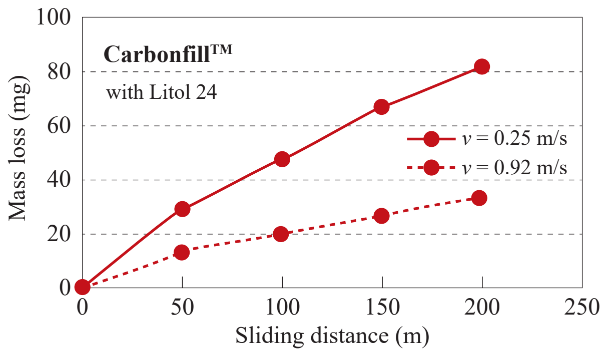

Fig. 7. Dependence of wear on the sliding path in friction with grease Litol 24 at two speeds

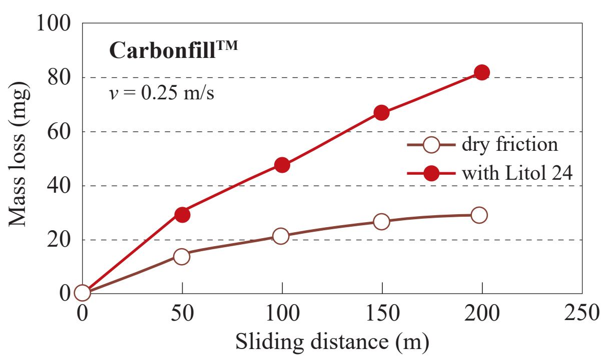

Fig. 8. Dependence of wear on the sliding path without and with lubricant Litol 24 at $v = 0.25$ m/s

when lubricated. From Fig. 9 it is clear that at high sliding speeds (0.92 m/s) in the limit lubrication mode the wear is about 2 times less than the wear in dry friction mode.

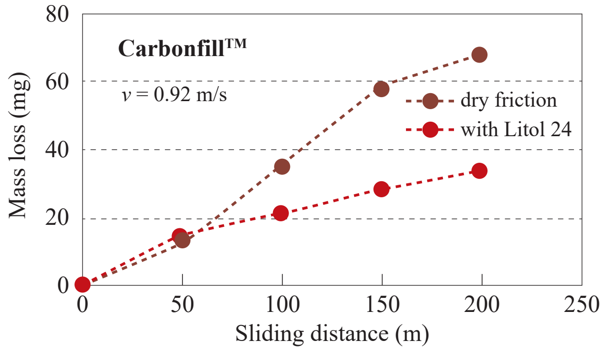

Fig. 9. Dependence of wear on the sliding path without and with lubricant Litol 24 at **v** = 0.92 m/s

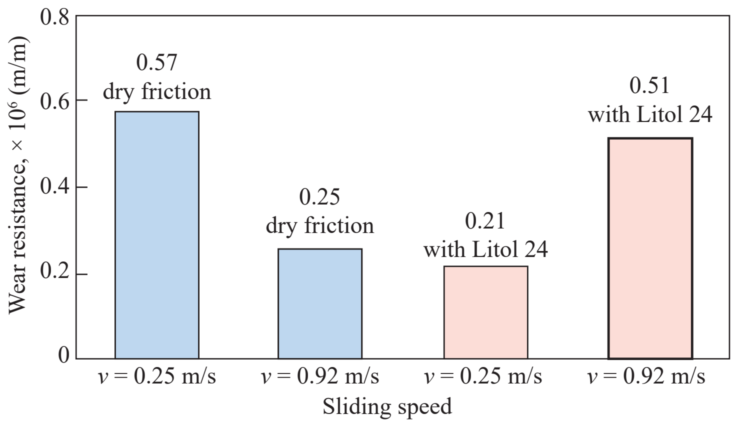

Fig. 10. Wear resistance diagram of Carbonfil™ material at two sliding speeds in dry friction and lubrication with Litol 24 at friction path length 200 m

Figure 10 shows a diagram of the wear resistance of a composite material Carbonfil™ in different abrasive friction modes. High abrasion resistance of Carbonfil™ is observed in two modes of friction – dry mode and when lubricated, but at different speeds. The highest is the wear resistance in dry friction mode at low sliding speeds – ($I_r = 0.57 \times 10^6$) and when lubricated it is at a higher sliding speed ($I_r = 0.51 \times 10^6$).

Comparative results for the wear resistance of the tested materials

Table 7 represents data on the wear resistance of the tested composite materials for all modes of friction – dry and when lubricated at two sliding speeds at the same sliding path length $L = 200$ m.

On Fig. 11 is shown a diagram of the wear resistance of materials in dry friction mode, and Fig. 12 – a diagram of wear resistance in lubricated mode at two sliding speeds.

Table 7. Wear resistance of the tested materials in dry friction mode and when lubricated with Litol 24 grease at two sliding speeds

Sample No	Name of the material	Wear resistance at v = 0.25 m/s; L = 200 m		Wear resistance at v = 0.92 m/s; L = 200 m	
		Dry friction	With grease Litol 24	Dry friction	With grease Litol 24
1	Steelfill	0.5 x 10^6	0.20 x 10^6	0.20 x 10^6	0.16 x 10^6
2	CarbonfilTM	0.57 x 10^6	0.21 x 10^6	0.25 x 10^6	0.51 x 10^6

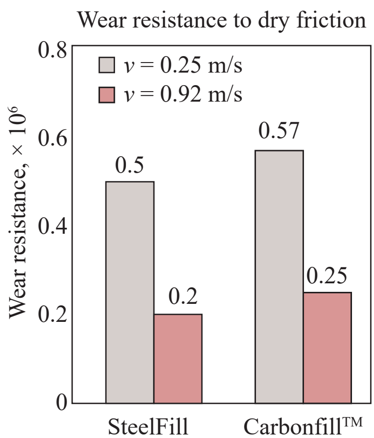

Fig. 11. Diagram of the wear resistance of the test materials in dry friction mode at two sliding speeds with a friction path length of 200 m

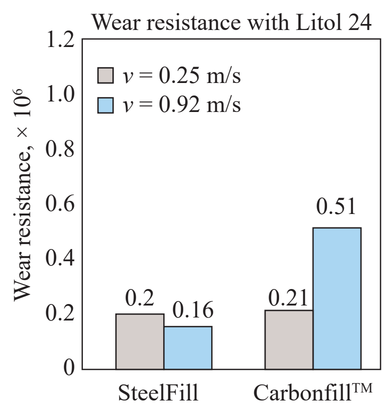

Fig. 12. Diagram of the wear resistance of the test materials when lubricated with Litol 24 at two sliding speeds with a friction path length of 200 m

The diagram in Fig. 12 shows that in the dry friction mode the highest abrasion resistance is Carbonfil™ material – at a sliding speed of 0.25 m/s. At the same sliding speed, Steelfill – Ir = 0.57x10^6 materials have close values of wear resistance. The material has the lowest abrasion resistance in dry friction mode and Steelfill – I_r = 0.2 x 10^6 at a speed of 0.92 m/s.

In the when lubricated with Litol 24 mode, the highest abrasion resistance is for the Carbinfil™ at a high sliding speed of 0.92 m/s (Ir = 0.51 x 10^6), and the lowest is the wear resistance of Steelfill (Ir = 0.16 x 10^6) at the same sliding speed – Fig. 12.

Figures 13 and 14 represent comparative results of the abrasion resistance of the materials under dry friction and when lubricated friction at the same sliding speed 0.25 m/s (Fig. 13) and 0.92 m/s, respectively (Fig. 14).

From the analysis, it can be concluded that among the tested materials in the four abrasive friction modes Carbonfil™ has the best anti-wear properties in dry friction conditions at low sliding speeds v = 0.25 m/s and when lubricated with grease Litol 24 at high sliding speeds v = 0.92 m/s.

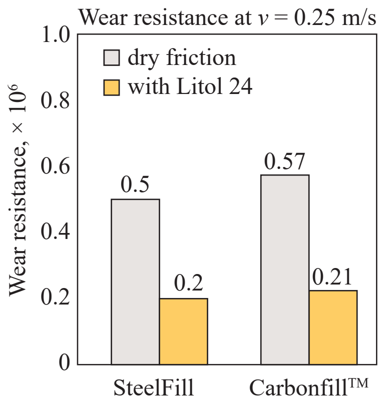

Fig. 13. Diagram of the wear resistance of the tested materials in the dry friction mode and in lubrication with Litol 24 at a sliding speed v = 0.25 m / s and a friction path length of 200 m

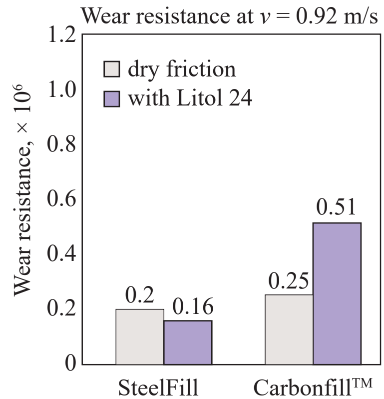

Fig. 14. Diagram of the wear resistance of the tested materials in the dry friction mode and in lubrication with Litol 24 at a sliding speed v = 0.92 m / s and a friction path length of 200 m

CONCLUSIONS

This publication represents results on the abrasive wear characteristics of two types of composite polymer materials – Steelfill and Carbonfil™, obtained by 3D print technology. The materials were tested in four modes of friction – without and with lubricant grease Litol 24 at two sliding speeds – v = 0.25 m/s and v = 0.92 m/s.

Results and graphical dependences for mass wear, wear rate, wear intensity and wear resistance of the two materials in the four friction modes were obtained.

It was found out that the influence of the presence of lubricant and the magnitude of the sliding speed has a different nature on the obtained dependences and on the absolute values of the wear parameters for individual materials.

Comparative diagrams for the wear resistance of the tested materials in the four modes of friction are represented.

The material Carbonfil™ has been found out to have the best anti-wear properties:

– in dry friction mode at sliding speed v = 0.25 m/s;

– when lubricated with grease Litol 24 mode at sliding speed v = 0.92 m/s.

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