



Tribotechnical Tests of Layered Polymers

S.N. Sharifullin^a, V.A. Denisov^b, R.N. Zadorozhny^b, E.Yu. Kudryashova^b, E.O. Reschikov^{b,*},
A.I. Izikaeva^b

^aKazan (Volga Region) Federal University, 420008, Kazan, street Kremlin, Russia,

^bFederal State Budgetary Institution "Federal Scientific Agro-Engineering Center VIM", 109428, Moscow, 1st Institute Passage, 5, Russia.

Keywords:

Tests
Pump blades
Polymers
Wear resistance
Laminates
Reinforcing fibers

* Corresponding author:

E.O. Reschikov 
E-mail: gosniti8@mail.ru

Received: 21 July 2019

Revised: 03 October 2019

Accepted: 12 December 2019

ABSTRACT

The article presents the results of comparative accelerated bench tests for production capacity, carrying capacity and wear resistance of materials: CT textile, Rusar and Oxafen textile. These materials are proposed for the manufacture of vacuum pump blades used in animal husbandry complexes for milking machines. From the vacuum pump depends on the performance of the milking machine, its reliability and noise level. In turn, the reliability of the pump is largely determined by the wear resistance of its blades. Therefore, the problem of choosing a lightweight, durable and wear-resistant material for the blades is crucial in their design and production. The study of the wear process under friction is associated with the need to reduce losses caused by the wear process itself. As well as with the development of effective methods for predicting the durability of friction units, ensuring their reliable operation, especially under extreme conditions. Innovative development of materials based on polymer resins with the addition of carbon, glass, fabric and other reinforcing fibers have already found wide application in aircraft manufacturing, shipbuilding, construction, and electrical engineering. Such materials have high strength and low weight, which explains the interest in their use in the production, strengthening and repair of agricultural machinery parts. The research results presented in the article provide a comparative assessment of layered plastics based on polymeric binders with the addition of reinforcing threads that have unique properties: they have high physical and mechanical properties, are resistant to long-term variable loads, to wear.

© 2020Published by Faculty of Engineering

1. INTRODUCTION

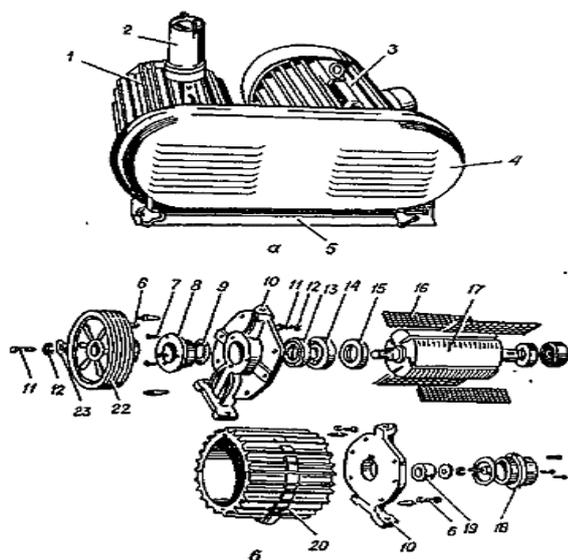
Tribological studies are important due to the need to reduce losses caused by the wear process, to develop effective methods for predicting the durability of friction units, to ensure their reliable operation, especially in extreme conditions.

Polymers are widely used in the creation of antifriction composite materials. Special fillers are introduced to improve the tribological properties, for example, graphite, or to reinforce, for example, different synthetic and natural fibers [1,2].

Polymeric composite materials are used in the manufacture of rotary vacuum pump (RVP) blades. The advantages of such pumps include smooth operation, low vibration, uniform air evacuation, and high speed. RVP is widely used in various industries and in agriculture due to these advantages [3,4].

However, a significant disadvantage of RVP is the high sensitivity to violation of nominal clearances. The low overhaul resource leads to a relatively low reliability of vacuum systems equipped with this unit. On livestock farms, up to 47 % of failures occur in vacuum systems. At the same time, a significant part of vacuum installations operates with reduced productivity [4,5].

The device RVP on the example of the vacuum unit UVU-60/45 is shown in Fig. 1.



1 - pump; 2 - oiler; 3 - electric motor; 4 - protective casing of the V-belt transmission; 5 - slide; 6 - key; 7 - screw; 8,10 - cover; 9 - gasket; 11 - a bolt; 12,15 - washer; 13 - cup; 14 - ball bearing; 16 - blade; 17 - the rotor; 18 - cap; 19 - sleeve; 20 - housing; 21 - pin; 22 - pulley; 23 - washer.

Fig. 1. Vacuum unit UVU-60/45: a - a general view of the installation; b - disassembled vacuum pump.

Vacuum is used for machine milking of cows, for transporting milk through the milk line, for driving the metering valves for dispensing concentrates, opening and closing doors, etc., on livestock farms. [6-8].

The main reason for the wear of individual parts of the RVP is the gradual surface destruction of the material of the parts, accompanied by the

separation of particles, changes in size, geometric shape and properties of the surface layers of the material [6,7].

The most wear parts of a vacuum pump are rotor blades. Worn of blades is more than 0.2 mm on the end surface. And then worn of blades more than 0.1 mm on the outer surface, there is a decrease in performance by more than 25 %. And the pump must be repaired [5].

RVP blades are made of textile, graphite, and also of composite materials. The blades are lubricated with oil continuously supplied from an oiler [6].

The high wear rate of the blades, as well as their decisive influence on the reliability of the entire pump, determines the search for new materials that provide high wear resistance of the blade mating - the vacuum pump body. Currently, the possibilities of manufacturing RVP blades from layered polymers with the addition of reinforcing fibers, as well as fluoroplastic, modified textile (with the addition of graphite), impregnated graphite, etc., research work in progress [4,5,9-11].

Layered polymers with the addition of reinforcing binders are approximately at the same level in terms of bearing capacity and workability [12].

In the presented work, the tribotechnical properties of pump blades made of constructive textile, constructive textile called organotextolite with aramid fibers Rusar NT [13], layered polymer material "Oxafen" [14] and graphite were studied.

2. MATERIALS AND METHODS

The samples for the study were rectangular plates of 50x50x6 mm, cut from RVP blades, made of the following materials.

Sample 1 – Rusar – organotextolite made of aramid fibers Rusar NT (vendor code 86-130-02H) textile and polymer epoxy resin EDT 69N (Specifications TU 1-595-12-584-2006), which is commercially available at All-Russian Scientific Research Institute of Aviation Materials (<https://viam.ru/>) [15,16].

Sample 2 – top grade constructive textile (CT) GOST 5-78 is an extruded material based on cotton fabric impregnated with a thermosetting binder.

Sample 3 – Oxafen (Specifications TU 22.29.29-014-56821720-2017) is a trademark of an antifriction isotropic polymeric structural material of dry friction, which is produced on the basis of a mixture of polymer resins, polyoxadiazole synthetic fibers and cellulose fibers [14].

Sample 4 Graphite – RVP blade is isostatic pressing produced [17] from carbon constructive material AG-600 (Specifications TU 48-4802-4-97) commercially available at Graphitel – Moscow Electrode Plant (<http://www.graphitel.ru/>).

Some of the physical, mechanical and operational properties are given in Table 1, the others are available at [13,16,18,19]. There are a lack of information about Rusar sample due to the fact the material is a new one and is now being investigated.

Table 1. Investigated samples properties.

Properties	Rusar	CT	Oxafen	Graphite
Density, kg/m ³	1380-1390	1300-1400	1300-1400	1700
Tensile strength, MPa	930	90	90	-
Compressive strength, MPa	210	230	180	57
Young's modulus, GPa	42	3.9-6.4	5.9-9.8	-
Hardness	-	275 HB	150 HB	32-36 HRC
Coefficient of thermal expansion, (1/K)*10 ⁻⁶	-	0.2-0.41	0.24-0.39	5
Thermal conductivity, W·m ⁻¹ ·K ⁻¹		0.23-0.34	0.2	58.1
Working temperature, C ⁰		-40 to 105	-60 to 250	2500 max
Water absorption, %	1.3	2-3	5	-

The wear resistance of the samples was evaluated in accordance with ASTM G99. This standard provides for the determination of wear of materials during their relative movement (sliding) according to the pin-disk scheme under non-abrasive wear conditions.

Two interacting samples were used according to the pin-disk scheme test. The first - a pin with a rounded end (counter sample) was placed perpendicular to the second - the test sample. A ball with a diameter of 6 mm made of steel 100Cr6 is rigidly fixed at the end of the pin.

Before the test and measurement, the sample and the counter sample were cleaned by wiping with a rag soaked in acetone and dried in air.

The tests were carried out using the tribometer TRB-S-DE-0000 by CSM Instruments.

Prints were made on the test sample on Rockwell's hardness tester, model TK-14-250, GOST 23677-79, so that the slip path was located between the prints in accordance with the recommendations of GOST 23.224-86 for determining the wear by the method of profilography.

Samples were profilographed using a Surtronic 25 ml 12/3522-01 profilograph-profilometer in such a way that the lowest points of the prints lay on the profilography route. The surface of the sample on the plot with prints was photographed at 50-fold magnification using an Olympus GX51 microscope. The distance between the prints was measured. The surface of the sample with the prints of the hardness tester before the test looked as shown in Fig. 2. The surface roughness according to ISO 4287 measured before tribotechnical tests are given in Table 2.



Fig. 2. The surface of the sample "CT" before testing, x50.

The sample and counter sample were reliably placed in the holders. They were adjusted so that they were perpendicular during the test to ensure the necessary contact conditions.

Table 2. Samples surface roughness before tests.

Sample	Surface roughness, μm	
	Ra	Rz
Rusar	0,4	1,9
CT	0,2	1,1
Oxsaphen	0,4	2,5
Graphite	1,9	13,2

The pin was pressed to the surface of the plate with a load that was provided by a system of weights. The testing machine provided the sample to rotate relative to its center. The sliding trajectory was a circle on the sample surface. The flat surface of the plate is horizontal.

The tests were carried out with a load of 20 N, relative slip speed - 0.30 m/s, at a distance of 4500 m, humidity - 45-50 % and ambient air temperature - 23-25 °C. The coefficient of friction and the depth of penetration of the counter sample into the sample body are continuously measured during the test.

At the end of the test, the samples were removed and cleaned of wear products by washing in acetone and dried in air. Samples were profilographed after the test, the section of the trajectory lying between the prints, and the contact patch on the surface of the counter sample were photographed at 50- and 100-fold magnification, the width of the trajectory, the distance to the prints, the area of the contact patch were measured.

Sample wear was defined as the loss of material volume in mm^3 . The wear of the counter sample was qualitatively evaluated by the size of the contact patch.

The amount of wear was determined using the TriboX CSM Instruments software package after profiling by measuring the sectional area of the wear surface.

3. RESULTS AND DISCUSSION

In the study of profilograms obtained after testing received the following results.

The wear surface of the «Rusar» and «Oxafen» samples did not change significantly.

The surface of the graphite sample (Fig. 3) as a result of wear has a smaller roughness, that close

to the parameters of the counter sample. And on the contrary on the surface of the CT sample (Fig. 4) is seen an increase in roughness. We assume that this is due to the nature of the wear of this material in conjunction with the material of the counter body. Analysis of the wear surface of the sample and the counter body indicates in favor of the assumption of the transfer of a harder material of the counter-tile to the soft surface of the textile sample "CT". This statement is also confirmed by the increase in roughness according to the given profilogram (Fig. 4). It should be noted that the roughness of the sample "Graphite" before testing was higher than that of other samples.

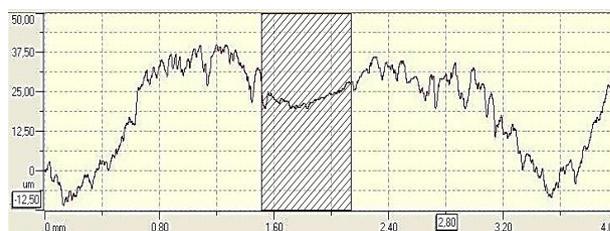


Fig. 3. The cross-sectional area of the path of wear of the sample «Graphite».

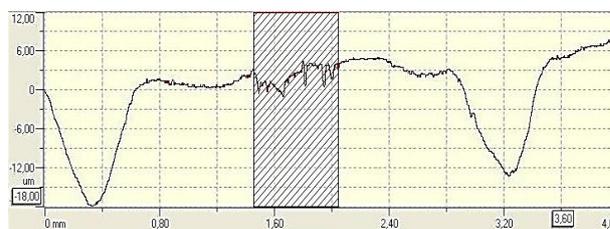
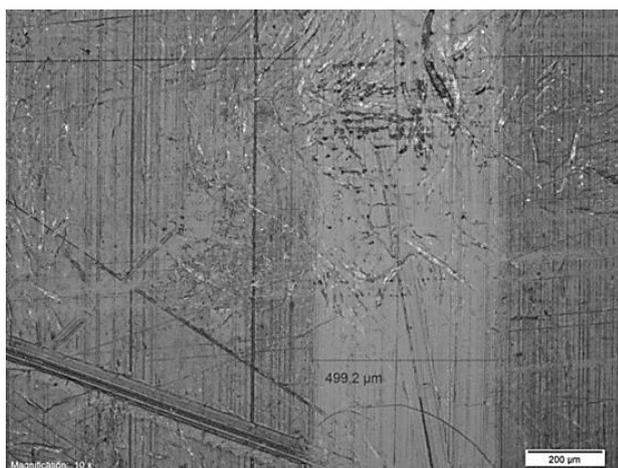


Fig. 4. The cross-sectional area of the path of wear of the sample "CT".

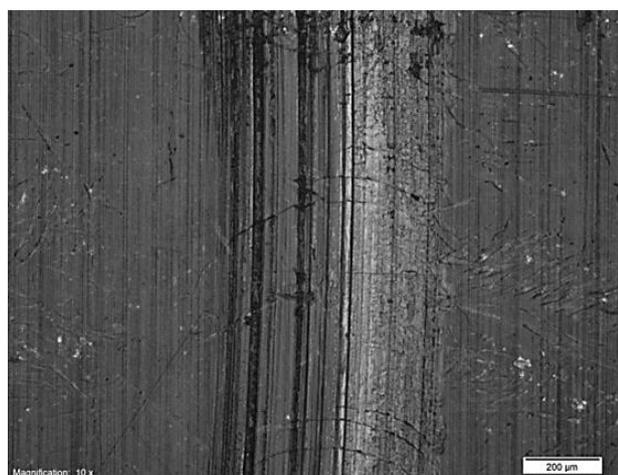
On profilograms, deep depressions, the dimensions of which considerably exceed the profile parameters, correspond to the prints on the hardness tester, as described in the section "Materials and Methods", and the wear trajectory is located between them. Zero ordinates on profilograms correspond to the initial position of the profilometer probe.

The wear surface of the «Rusar», «Oxafen» and «Graphite» samples is a slip band without noticeable surface defects (Fig. 5a). The graphite sample (Fig. 5b) has a deeper slip mark.

Traces of elliptical shape without visible defects, on the surface of which a layer of wear products and transferred sample material formed, are visible on the surface of the counter sample working in conjunction with the "Rusar", "Oxafen" and "Graphite" samples (Fig. 6a).

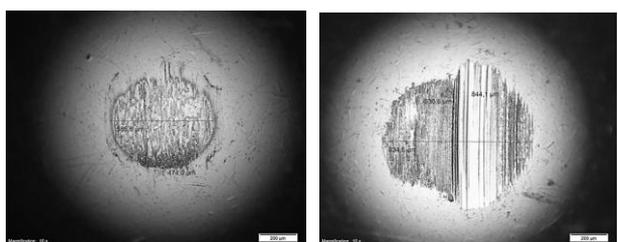


a)



b)

Fig. 5. The wear surface of the sample "Oxafen" (a) and "CT" (b), x50.



a)

b)

Fig. 6. The wear surface of the counter sample in conjugation with the sample "Rusar" (a) and sample "CT" (b), x50.

The counter sample interacting with the "CT" sample has friction on an elliptical surface containing wear products and particles of the sample material, deep scratches in the direction of sliding (Fig. 6b).

Analysis of the friction coefficient change diagrams during the test shows that the wear process is stable for the "Rusar", "Oxafen" and "Graphite" samples (Fig. 7).



Fig. 7. Diagram of changes in the coefficient of friction and the depth of introduction of the counter sample when testing "Rusar" sample.

The diagram in red shows the coefficient of friction, and the green - the depth of the introduction of the sample.

At the beginning of the test, during the running-in process, the friction coefficient decreases. The running-in distance matches to the moment at which a further decrease in the friction coefficient does not occur. The run-in distance of the samples is given in Table 1.

After the break-in, there is a section where the value of the friction coefficient remains almost unchanged and which matches to its minimum value, after which the parameter increases and the output goes to normal operation. The main test time occurs in this mode.

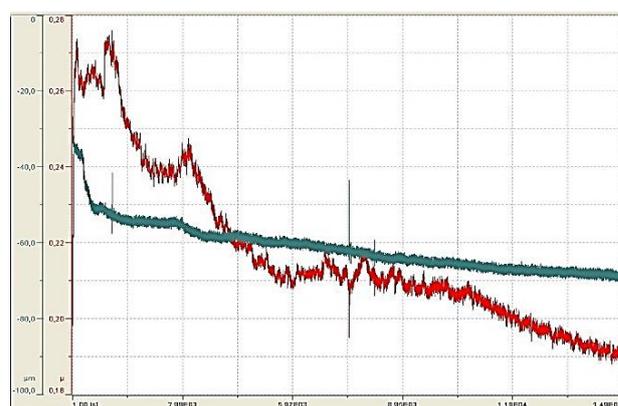


Fig. 8. Diagram of changes in the coefficient of friction and the depth of introduction of the counter sample when testing the sample "CT".

A change in the friction coefficient (Fig. 8) indicates unsteady wear mode for the "CT" sample. After the run-in stage, similar to the testing of other samples, there is a sharp increase, and then a decrease in the friction coefficient. This situation is repeated during the

test several times. At the end of each cycle of growth and reduction of the studied parameter, its value is less than at the beginning. The minimum coefficient of friction during the test was not achieved. According to the form of the curve it is possible to suggest that if the test is continued, the coefficient of friction would continue to decrease.

Presumably, this change in the friction coefficient is explained as follows. The increase in the parameter matches to the setting, which results in the transfer of material from one of the interacting surfaces or the destruction of sections of the setting with the release of wear products, contributing to a decrease in the parameter.

The analysis of the surface of sample wear and the counter sample testifies in favor of the assumption that the more rigid material of the counter sample is transferred to the soft surface of the textile sample "CT". Scratches form on the harder surface as a result of the scratching effect of the transferred metal, which is in the state hardening.

Wear products can reduce the friction coefficient due to the adsorption of lubricant particles, reduction of electrostatic tension, intensification of heat transfer, separation of their leveling surfaces. And the formed particles have such an effect if their size does not exceed 5 microns.

The separation and transfer of particles of the material of the interacting materials is also fixed on the graph of the change in the depth of introduction of the counter sample in the form of single increases.

The tribological parameters of the samples, determined as a result of the tests, are given in Table 3.

Table 3. Tribological parameters of samples.

Sample	Break-in distance, m	Friction coefficient		
		min	max	average in normal operation
Rusar	310	0,24	0,28	0,27
Oxafen	240	0,14	0,15	0,145
CT	55	0,19	0,28	0,23
Graphite	110	0,20	0,24	0,23

Note: The tribological parameters of the "CT" sample are determined approximately, taking into account the unstable change in the friction coefficient.

The shortest run-in distance, with the exception of the "CT" sample, was found in a graphite sample, which has a good workability due to the properties of the material.

The running-in distance of the "Rusar" and "Oxafen" samples are higher. And strength of these materials is higher in comparison with graphite.

The "Oxafen" sample has the smallest friction coefficient throughout the entire test period. The friction coefficient when testing other samples is approximately at the same level. The friction coefficient obtained values is similar to which is observed in [18].

The friction coefficient during Graphite sample test differs from analogical tribotechnical test [9] due to the different experimental conditions (temperature, load value etc.).

The results of tests for wear resistance are shown in Table 4.

Table 4. Results of the wear test.

Sample	Sample wear path width, mm	Cross-sectional area of wear, mm ²	Sample wear, mm ³	The largest size of the contact patch of the counter sample, mm
Rusar	0,522	2,970·10 ⁻⁴	0,0318	0,585
Oxafen	0,539	5,330·10 ⁻⁴	0,0517	0,658
CT	0,650	8,980·10 ⁻⁴	0,0849	0,844
Graphite	0,649	3,354·10 ⁻³	0,3173	0,661

It is noticed, that the most wear is on the "Graphite" sample, which exceeds the wear of the "Rusar", "Oksafen" and "CT" samples, respectively, in 10; in 6.1; and 3.7 times.

The amount of wear of samples from polymeric materials increases with increasing width of the wear path. While, despite the significantly larger amount of wear of the "Graphite" sample, its width of the friction track does not exceed the value of the parameter of the "CT" sample. It is explained by the fact that the roughness of the "Graphite" sample before the test was higher than that of the other samples. The

volume of material enclosed on a given width of the friction track is higher than that of samples with a lower roughness.

The wear of the counter sample, assessed qualitatively by the size of the contact patch, is approximately at the same level for all materials. And it is maximum when tested with the "CT" sample. That is associated with the scratching effect of abrasive particles of wear products. Tribological studies have shown that the wear of polymeric materials is predominantly adhesive and the main factors of wear are the setting and abrasive action of the counter body particles, which corresponds to referential knowledge [2] and to the previous investigations made by authors [12].

4. CONCLUSION

1. The best wear resistance has a composite polymer material with Ruser fibers. In this case, the sample "Ruser" is characterized by the smallest amount of wear, both the sample and working with it in a pair of counterbody.
2. According the test, the lowest values of the friction coefficient belongs to the material "Oxafen".
3. The anti-friction properties of graphite provide it with good workability and a low coefficient of friction even with relatively high roughness. At the same time, the wear of the counterbody when tested in tandem with the "Graphite" sample is also on par with the composite polymers.
4. The relatively low wear resistance of graphite blades RVP is compensated by the high tribological properties of the material and the relatively low wear of materials used in combination with graphite. Thus, the replacement of the blades allows you to quickly restore the efficiency of the RVP and increase the life of the remaining parts of the interface (rotor, housing, etc.).
5. Textile sample "CT" has a much better wear resistance compared to the sample "Graphite". The high wear value of the counterbody, as well as the abrasive nature of the wear make the textile the least reliable material for the manufacture of RVN blades from the studied.
6. Polymer materials with reinforcing fibers ("Ruser" and "Oksafen") have better tribological properties compared to materials traditionally used for the manufacture of vacuum pump blades (textile, represented by the sample "CT" and graphite).

REFERENCES

- [1] L.I. Bondaletova, V.G. Bondaletov, *Polymer composite materials (part 1): study guide*. Tomsk: Publishing House of Tomsk Polytechnic University, 2013. (in Russian)
- [2] K. Friedrich, L. Chang, F. Hauptert, *Current and Future Applications of Polymer Composites in the Field of Tribology*, in L. Nicolais, M. Meo, E. Milella, *Composite Materials*. Springer, London, pp. 129-167, 2011, doi: [10.1007/978-0-85729-166-0](https://doi.org/10.1007/978-0-85729-166-0)
- [3] T.S. Mesogitis, A.A. Skordos, A.C. Long, *Uncertainty in the Manufacturing of Fibrous Thermosetting Composites: A Review*, *Composites Part A: Applied Science and Manufacturing*, vol. 57, pp. 67-75, 2014, doi: [10.1016/j.compositesa.2013.11.004](https://doi.org/10.1016/j.compositesa.2013.11.004)
- [4] V. Bria, D. Dima, G. Andrei, I.-G. Birsan, A. Circiumaru, *Tribological and Wear Properties of Multi-Layered Materials*, *Tribology in Industry*, vol. 33, no. 3, pp. 104-109, 2011.
- [5] N.M. Antonov, V. A. Borozdin, Yu. V. Bobylev, *The reliability of the vacuum system of the milking plant*, *Bulletin KrasGAU*, no. 12, pp. 184-188, 2009. (in Russian)
- [6] M.G. Bader, *Selection of Composite Materials and Manufacturing Routes for Cost-Effective Performance*, *Composites Part A: Applied Science and Manufacturing*, vol. 33, iss. 7, pp. 913-934, 2002, doi: [10.1016/S1359-835X\(02\)00044-1](https://doi.org/10.1016/S1359-835X(02)00044-1)
- [7] S. Maurice, *Surface Production Operations, Volume IV - Pump and Compressor Systems: Mechanical Design and Specification, 1st Edition*. Gulf Professional Publishing, 2018.
- [8] U. Strobel, S. Rose-Meierhofer, H. Oz, R. Brunsch, *Development of a Control System for the Teat-End Vacuum in Individual Quarter Milking Systems*, *Sensors*, vol. 13, iss. 6, pp. 7633-7651, 2013, doi: [10.3390/s130607633](https://doi.org/10.3390/s130607633)
- [9] U. Sachs, R. Akkerman, K. Fetfatsidis, E. Vidal-Salle, J. Schumacher, G. Ziegmann, S. Allaoui, G. Hivet, B. Maron, K. Vanclooster, S.V. Lomov, *Characterization of the Dynamic Friction of Woven Fabrics: Experimental Methods and Benchmark Results*, *Composites Part A: Applied Science and Manufacturing*, vol. 67, pp. 289-298, 2014, doi: [10.1016/j.compositesa.2014.08.026](https://doi.org/10.1016/j.compositesa.2014.08.026)

- [10] W. Umrath, H. Adam, A. Bolz, H. Boy, H. Dohmen, K. Gogol, *Fundamentals of Vacuum Technology*, Cologne, 2007.
- [11] B.B. Difallah, M. Kharrat, M. Dammak, G. Monteil, *Mechanical and tribological response of ABS polymer matrix filled with graphite powder*, *Materials & Design*, vol. 34, pp. 782-787, 2012, doi: [10.1016/j.matdes.2011.07.001](https://doi.org/10.1016/j.matdes.2011.07.001)
- [12] V.A. Denisov, E.Yu. Kudryashova, I.V. Romanov, E.O. Reschikov, *Comparative tests on wear resistance of layered polymers with the addition of reinforcing fibers*, Moscow: Technical service of machines, vol. 132, pp. 164-175, 2018. (in Russian)
- [13] Ye. N. Kablov, G.F. Zhelezina, G.S. Kulagina, *Prepreg*, Patent RF, no. 2687926, 2019. (in Russian)
- [14] V.V. Mokhov, I.V. Asanov, A.Yu. Belousov, V.A. Bugayev, *Composite polymer fiber material with antifriction properties*, Patent RF, no. 2270845, 2006. (in Russian)
- [15] G.F. Zhelezina, I.V. Tikhonov, V.G. Bova, T.E. Chernykh, S.I. Voinov, *Third generation aramid fibers Rusar NT for reinforcing organotextiles for aviation purposes*, *Plasticheskie massy*, vol. 2019, no. 3-4, pp. 43-46, 2019, doi: [10.35164/0554-2901-2019-3-4-43-46](https://doi.org/10.35164/0554-2901-2019-3-4-43-46) (in Russian)
- [16] M.I. Valueva, G.F. Zhelezina *Polymer Composites Based on Aramid Fibers with Increased Shear Strength for Aircraft Engineering Products*, *Inorganic Materials: Applied Research*, vol. 10, iss. 1, pp. 70-73, 2019, doi: [10.1134/S2075113319010362](https://doi.org/10.1134/S2075113319010362)
- [17] M. Inagaki, F. Kang, M. Toyoda, H. Konno, *Advanced Materials Science and Engineering of Carbon*. Butterworth-Heinemann, 2014, doi: [10.1016/C2012-0-03601-0](https://doi.org/10.1016/C2012-0-03601-0)
- [18] OXAFEN OPM-94, available at: <http://oxafen.ru/oksafen-opm-94/> (accessed 18.07.2019).
- [19] Antifriction materials Graphite El-MEZ, available at: <http://tt.kiev.ua/pages/305/Grafit.pdf> (accessed 18.07.2019).