

# Frictional Basalt-Reinforced Polymers Based on Polytetrafluoroethylene

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**Abstract**—The properties of basalt-reinforced polymers based on polytetrafluoroethylene are investigated as a function of the concentration of basalt fibers and their activation conditions. A high-speed planetary mill may effectively be used for the activation of the basalt fibers.

**Keywords:** polytetrafluoroethylene, polymer composites, friction, basalt fibers, reinforced polymers, wear resistance

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The production of polymers reinforced by strong thermally and chemically stable fibers of abundant and inexpensive materials is very promising. The use of basalt fibers to produce various composites and structural materials is of particular interest. Basalt-reinforced polymers expand the range of composites with special properties. Such polymers may be used at elevated temperature and humidity. They are employed in electrical and radio engineering, in the production of acoustic materials, in communication systems, in manufacturing, and in road building.

Polymers reinforced by carbon and glass fibers are promising for use in critical structures and in frictional components of machining equipment [1]. However, the high cost of the carbon fibers employed has slowed their adoption. Therefore, glass fibers are mainly used in reinforcement, although they cannot match the thermal stability and unit strength of carbon fibers. Therefore, fillers capable of replacing carbon and glass fibers are of great interest. One option is the use of basalt fibers, which are related to glass fibers and so have practically all the benefits of carbon and glass fibers. In addition, no special components are required in their production; they are made from inexpensive and readily accessible materials that are available in almost unlimited quantities. Recently, the production of basalt fibers has developed rapidly; their characteristics meet the requirements of most users of glass fibers [2].

In creating structural polymer composites containing reinforcing fibers, it is important to ensure bonding of the fibers with the polymer matrix so as to maximize the reinforcing effect [3]. Various methods increase the adhesion between the matrix and the fibers. Activation of the filler is the most common. Mechanical activation of the filler entails reducing the size of the

filler particles by a factor of 1.5–2 and increasing the reactivity of the surface by the formation of uncompensated bonds. That ensures the directed generation of a supermolecular composite structure. Consequently, the properties of the composite are modified: the wear resistance and elasticity are increased [4].

## EXPERIMENTAL METHOD AND MATERIALS

We investigate polytetrafluoroethylene (State Standard GOST 10007–80) and a polymer composite reinforced with basalt fibers (produced by OOO Zavod Bazal'tovykh Materialov, Pokrovsk). A continuous basalt fiber, obtained from magmatic rock, is an environmentally benign product. In comparison with glass fibers, it is characterized by a larger (by 10–20%) elastic modulus, elevated strength at high temperatures, and high resistance to alkalis and oxides. The thermal stability of basalt fibers matches that of asbestos fibers. Under the action of high contact stress and elevated temperatures (typically experienced by frictional components) basalt fibers do not split into carcinogenic microfibers [5].

For use as a filler in polytetrafluoroethylene, basalt fibers are pulverized in a Fritsch Pulverisette 15 mill, using a screen transmitting 0.25-mm particles. That ensures a mean fiber size of 30–90 µm (diameter 8–10 µm). To optimize the mechanical activation of basalt fibers, they are treated in different planetary mills: an AGO-2 mill (drum speed 3000 rpm, centrifugal acceleration 100 g); and a Fritsch Pulverisette 6 mill (drum speed 100–400 rpm; acceleration 20 g).

The composites are produced by dry mixing of weighed portions of the components in a high-speed mill, with subsequent cold pressing of samples from

**Table 1.** Properties of polytetrafluoroethylene reinforced by basalt fibers (BF)

Material	Activation of BF (min)	Drum speed, rpm	$\sigma_d$ , MPa	$\varepsilon_d$ , %
PTFE + 0.1% BF	Yes (2)	—	20	300
		3000	22	356
		400	18	302
		300	17	302
		200	17	310
		100	17	190
	No	—	18	327
	Yes (2)	3000	24	370
		400	18	372
		300	18	327
		200	19	328
		100	14	387
	No	—	18	310
PTFE + 1.0% BF	Yes (2)	3000	22	327
		400	17	341
		300	17	380
		200	18	321
		100	17	199
	No	—	21	320
	Yes (2)	3000	24	371
		400	18	328
		300	17	367
		200	17	354
		100	14	177
	No	—	20.5	318
PTFE + 5.0% BF	Yes (2)	3000	18	343
		400	15	387
		300	14	331
		200	15	362
		100	16	235
	No	—	21	294

the mixture. The samples are roasted in a muffle furnace at 380°C and calibrated for correction of their shape and the elimination of the consequences of the thermal shrinkage on sintering.

The relative elongation and fracture strength of the samples are determined in accordance with State Standard GOST 11262–80 on an Autograf test machine (Shimadzu, Japan), at normal temperature, with a mobile-clamp speed of 100 mm/min (five samples in each test). Type-II blades are investigated.

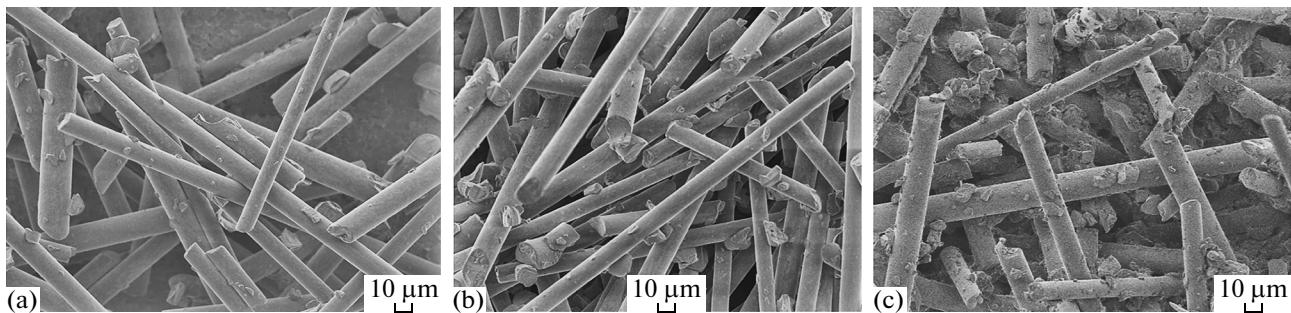
The specific surface of the basalt fibers is determined as a function of the activation conditions on a Sorbtometer-M instrument.

IR spectra in the range 400–4000 cm<sup>-1</sup> are obtained by means of a Varian FTIR 7000 spectrome-

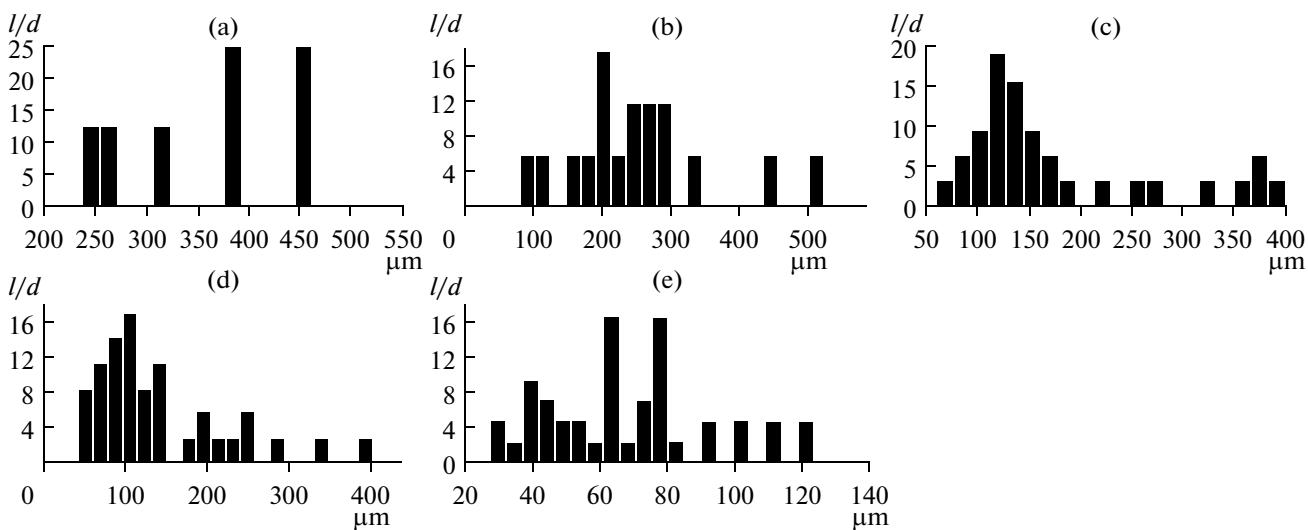
ter with an attachment for disrupted complete internal reflection, such that spectra may be obtained from samples of practically any shape. The structure of the basalt fibers is studied on a JEOL JSM-6480 LV scanning electron microscope and an Olympus BX-140 optical microscope.

## EXPERIMENTAL RESULTS

Table 1 presents some characteristics of the basalt-reinforced polymers as a function of the activation conditions and the concentration of basalt fibers. The optimal properties are obtained when using an AGO-2 mill at a drum speed of 3000 rpm. After such treatment, the specific surface of the basalt



**Fig. 1.** Microphotographs of basalt fibers before (a) and after mechanical activation in Fritsch Pulverisette (b) and AGO-2 (c) mills.



**Fig. 2.** Relative length  $l/d$  of activated basalt fibers at drum speeds of 100 (a), 200 (b), 300 (c), 400 (d), and 3000 (e) rpm.

fibers is 4–6 times that of fibers produced in a Pulverisette 6 mill and 23 times that of chopped fibers (Table 2). The increase in the specific surface on activation is associated not only with dispersion but also with significant modification of the filler's microtopography: defects that increase the roughness appear on the fiber surface (Fig. 1). That increases the fiber adhesion at the polymer matrix and hence the strength of the polymer composite.

After mechanical activation, the fiber length is practically unchanged, but the surface is looser. In other words, the ratio  $l/d$  is more than one, where  $l$  is the length and  $d$  is the diameter. That leads to anisotropy, which is responsible for the effectiveness of chopped and activated basalt fibers as reinforcement in polytetrafluoroethylene [3].

Optimal properties are obtained with 2 wt % of basalt fibers in the polytetrafluoroethylene. In that case, the tensile strength is 10–25% greater than for unactivated fibers; the relative elongation at failure is greater by a factor of 1.2, on average. Significant increase in the relative elongation at failure on reinforcement by activated basalt fibers indicates greater

anisotropy in terms of the relative elongation. On filling with chopper fibers, no such anisotropy is seen. That flattens out the benefits of the composite system due to the fibers introduced.

Table 3 presents the wear resistance of the polymer composite as a function of the concentration of basalt fibers and their conditions of activation. The wear resistance of the polymer composite increases with increase in concentration of the basalt fibers and in the drum speed on activation, on account of the high degree of dispersion: most of the activated basalt fibers are no larger than 100  $\mu\text{m}$  (Fig. 2). In addition, as shown by electron-microscope data, the fiber surface becomes active as a result of defect initiation. Most of

**Table 2.** Specific surface of basalt fibers produced by different methods

Drum speed, rpm	100	200	300	400
Specific surface of basalt fibers, $\text{m}^2/\text{g}$	0.165	0.176	0.188	0.224

The specific surface is 0.04  $\text{m}^2/\text{g}$  for chopped basalt fibers and 0.939  $\text{m}^2/\text{g}$  after mechanical activation in an AGO-2 mill.

**Table 3.** Wear rate, mg/h, of polymer composites with different concentrations of basalt fibers activated at different drum speeds

Fiber concentration, %	Drum speed, rpm				
	100	200	300	400	3000
0.1	52.59	11.75	8.40	2.77	—
0.5	9.05	8.57	4.92	4.67	4.13
1	5.93	4.89	4.47	4.29	3.84
2	3.13	2.54	2.28	2.84	2.10
5	2.23	1.86	1.47	1.25	0.69

the activated fibers interact with macromolecules of the matrix, forming PTFE structures that are resistant to friction.

With increase in the drum speed, the length of the basalt fibers declines (Fig. 2). In activation by means of an AGO-2 mill with a drum speed of 3000 rpm, the fibers are not only shortened, but the spread in the length increases. That facilitates denser packing in the polymer.

The improvement in properties of the polymer composite when using activated basalt fibers may be explained in that mechanical activation increases the bulk reinforcement of the polymer.

In Fig. 3, we show IR spectra of chopped and activated basalt fibers. Peaks at 2926, 2850, and 1460  $\text{cm}^{-1}$  correspond to valence and deformational vibrations of the  $\text{CH}_2$  group; peaks of moderate intensity at 1650  $\text{cm}^{-1}$  correspond to structural vibrations of the  $\text{C}=\text{C}$  bond [6]. This may be explained in that the lubri-

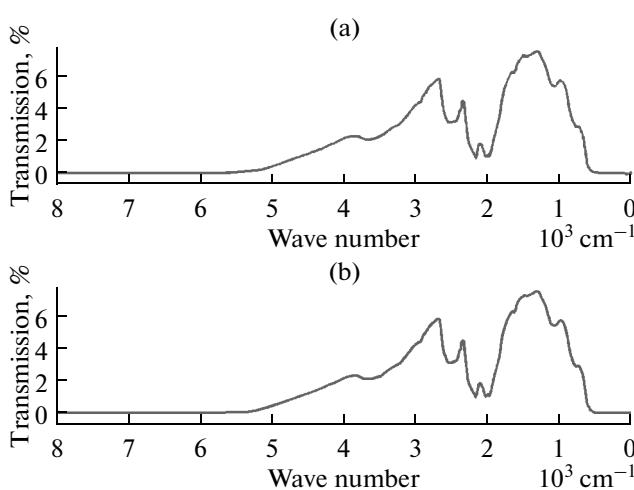
cant used in the production of basalt fibers contains turpentine, which is a polymerization product of terpene hydrocarbons.

Thus, basalt fibers may expediently be used as a filler of polytetrafluoroethylene in the production of frictional polymers. Such fibers are inexpensive and readily available. The AGO-2 high-speed planetary mill may be used for the activation of the fibers. As a result, the polymer–filler interaction is improved, as are the properties of the composite produced.

## ACKNOWLEDGMENTS

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## REFERENCES



**Fig. 3.** IR spectra of the surfaces of activated (a) and chopped (b) basalt fibers produced by the Sakhabazal't plant.

- Startsev, O.V., *Macromolecular compounds*, *Vysokomol. Soedin.*, 1983, vol. 25 no. 11, pp. 2267–2270.
- Perepelkin, K.E., *Armiruyushchie volokna i voloknistye polimernye kompozity* (The Reinforced Fibers and Fibrous Polymer Composites), St. Petersburg: Nauchnye Osnovy i Tekhnologii, 2009.
- Mikhailin, Yu.A., *Konstruktionskiye polimernye kompozitsionnye materialy* (Construction Polymeric Composites), Moscow: Nauchnye Osnovy i Tekhnologii, 2008.
- Baramboim, N.K., *Mekhanokhimiya vysokomolekularnykh soedinenii* (Mechanic Chemistry of Macromolecular Compounds), Moscow: Knimiya, 1978.
- Okhlopkova, A.A., Physical-chemical principles of development of tribotechnical materials based on polytetrafluoroethylene and ultrafine ceramics, *Doctoral (Tech.) Dissertation*, Gomel, 2000.
- Dechant, J., *Ultrarotspektroskopische Untersuchungen an Polymeren*, Berlin: Akademie-Verlag, 1972.

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