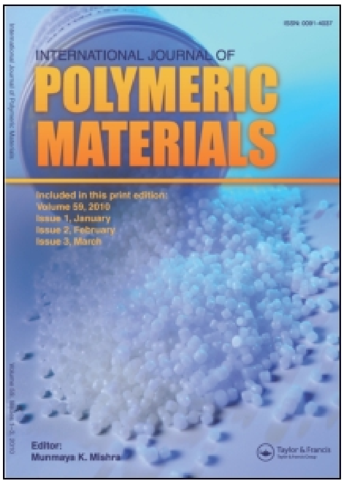

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Influence of the Composition of Carbon-fiber Phenolformaldehyde Composite Materials on Their Tribological Characteristics

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Carbon-fiber phenolformaldehyde composite materials have been obtained by two technological methods—prepreg and dry mixing of components. The tribological properties of the composite materials are investigated. As such tribological characteristics are used friction factor and the intensity of wear as a criterion for the wear stability of the material. Influence of some dispersion fillers-bentonite clay, talc, kaolin and boron carbide is investigated to the tribological characteristics. The influence of loading and the speed of sliding over the friction factor and the wear hardness is determined too.

The tribological properties of the obtained composite materials help them join the best materials working in conditions of dry friction and ensure manufacturability of their obtaining and processing and high reliability in operation.

KEY WORDS: Carbon-fiber phenolformaldehyde composite materials, tribological properties, friction factor, intensity of wear, antifriction materials.

INTRODUCTION

The needs for materials, able to work in assemblies of friction without or with a limited quantity of lubricant and in contact with agggressive agents, increase constantly. One of the effective ways of solving this problem is the production of self-lubricating polymeric composite materials.[1]

Filling of the polymeric materials with carbon fibers, studying their functional properties and using them for production of various parts with an antifriction design are developing intensely in recent years. This is determined by the appropriate properties of carbon fibers and by the good prospects of the technologies for obtaining fiber reinforced composites.

Dispersion fillers, that help to control in broad limits the friction factor and

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especially their wear hardness, are also used together with the use of carbon fibers in polymeric composite materials in production of antifriction parts.

All the materials designed for antifriction (AFM) must comply with the requirements for friction factors within the limits from 0.01 to 0.30, intensity of wear within the limits from 1×10^{-9} to 1×10^{-17} m^3/N m, and at the same time to be economically advantageous.[2]

EXPERIMENTAL

The present work is devoted to surveying the tribological characteristics of carbon-fibrous phenolformaldehyde composite materials (CFPFCM). Tribological characteristics are determined by friction factor, intensity of wear as a criterion for the wear resistance of the material, as well as by the variation of the friction factor with load and speed of sliding.

Two technological methods were used for producing CFPFCM. The first one is carried out by prepreg and the second one by dry mixing of the components.[3] Phenolformaldehyde oligomers—of novolak and resol types, produced by Chemical Plant "P. Volov"—Shoumen, were as a polymeric matrix. Carbon non-woven fabric materials and cut cellulose carbon fibers were used as the reinforcing component. Fillers were also used such as bentonite clay, talc, kaolin, boron carbide.

RESULTS AND DISCUSSIONS

The characteristics of the CFPFCM, obtained by prepreg, are shown in Table I.

It becomes obvious from the quoted data, that the type of phenolformaldehyde oligomer and the amount of the dispersion fillers exert influence on the friction factor. As for the two types of oligomers, carbon-fiber composite materials without a filler and based on a resol oligomer show lower values for the friction factor, in comparison with those based on a novolak oligomer.

It was found that depending on the type and the concentration of the filler, their influence on the friction factor is expressed in a different way. For example, for kaolin filler with filling of 2 and 5%, the friction factor is greater or commesurable to a composition without a filler; while for bentonite clay and talc with concentration of filler of about 5% the antifriction properties of the material are rather markedly improved. Undoubtedly, the structure of the filler exerts a substantial influence on the antifriction properties of the composite material. Bentonite clay, whose basic mineral is montmorillonite, is a typical laminar aluminum silicate that has the ability to "pulsate" under the influence of moisture. The bentonite clay desorbs the water during the friction process and as a result of the amount of liberated heat, improving thereby the friction characteristics of the composition.

Talc, similar to bentonite clay, has a trilaminar structure with an inner layer of $MgO.H_2O$ and an outer layer of SiO_2.[4] These layers are weakly connected by van

TABLE I
Friction factor in relation to pressure

Type of the sample		Friction factor, Pressure, MPa 0.2	0.6	0.8	1.0	1.2	1.4	1.5
Novolak matrix								
Without filler		0.23	0.22	0.22	0.22	0.22	0.22	0.22
Kaolin, %	2	0.25	0.27	0.27	0.27	0.26	0.25	0.25
	5	0.23	0.23	0.22	0.22	0.21	0.21	0.20
	10	0.19	0.21	0.21	0.21	0.21	0.20	0.19
Bentonite clay, %	2	0.23	0.23	0.23	0.21	0.21	0.21	0.21
	5	0.14	0.14	0.14	0.14	0.14	0.13	0.13
	10	0.19	0.20	0.18	0.18	0.18	0.19	0.18
Talc, %	2	0.22	0.22	0.21	0.20	0.20	0.20	0.20
	5	0.19	0.16	0.16	0.16	0.16	0.16	0.15
	10	0.20	0.20	0.19	0.19	0.18	0.18	0.18
Resol matrix								
Without filler		0.22	0.19	0.19	0.19	0.19	0.19	0.19
Kaolin, %	2	0.23	0.22	0.22	0.21	0.22	0.21	0.22
	5	0.19	0.20	0.21	0.21	0.19	0.18	0.18
	10	0.19	0.19	0.20	0.20	0.19	0.19	0.19
Bentonite clay, %	2	0.23	0.23	0.25	0.27	0.27	0.27	0.26
	5	0.20	0.20	0.20	0.20	0.18	0.18	0.18
	10	0.19	0.19	0.18	0.17	0.17	0.17	0.17
Talc, %	2	0.22	0.21	0.21	0.21	0.21	0.20	0.20
	5	0.19	0.17	0.18	0.16	0.16	0.16	0.15
	10	0.20	0.20	0.19	0.19	0.17	0.17	0.17

der Waals forces that determine the good self-lubricating properties of the CFPFCM based on it. With it, as with bentonite clay, the lowest values of the friction factor are also observed at filler content of 5%.

The higher values of the friction factor for CFPFCM based on kaolin can be accounted for by the tendency of kaolin particles to aggregate, impeding thereby their dispersion and uniform distribution in the phenolformaldehyde matrix. The increased friction factor at 2 and 5% filler content can be attributed to aggregation which is observed with both novolak and resol types of oligomers.

The influence of pressure on the friction factor is negligible for the range of pressure values from 0.2 to 1.5 MPa.

Bentonite clay and talc fillers appeared to be the best for composition based on novolak matrix according to their degree of influence on the friction factor.

Further on, researches were conducted on specifying the influence of the compositions on the tribological treatments of CFPFCM with cut cellulose carbon fibers obtained by dry mixing of the components (Table II).

Minimum of the friction factor is observed in compositions without dispersion filler, especially in compositions II-C and III-C. The intensity of wear alters analogically.

Introduction of mineral dispersion fillers in the contents of the compositions

TABLE II

Tribological characteristics of CFPFCM based on short carbon fibers

Type of sample	Novolak type PFO content, %	Carbon fibres content, %	Filler content %	Friction factor	Intensity of wear $m^3/N\ m \times 10^{14}$
I-C-O	20	80	0	0.25	12.7
I-C-2-B	20	78	2	0.23	10.4
I-C-5-B	20	75	5	0.22	8.7
I-C-10-B	20	70	10	0.24	8.5
I-C-15-B	20	65	15	0.25	8.5
I-C-2-T	20	78	2	0.22	10.0
I-C-5-T	20	75	5	0.21	9.3
I-C-10-T	20	70	10	0.23	10.4
I-C-15-T	20	65	15	0.23	10.2
II-C-O	30	70	0	0.24	11.0
II-C-2-B	30	68	2	0.22	6.2
II-C-5-B	30	65	5	0.18	4.6
II-C-10-B	30	60	10	0.19	5.3
II-C-15-B	30	55	15	0.19	5.6
II-C-2-T	30	68	2	0.20	4.7
II-C-5-T	30	65	5	0.15	0.8
II-C-10-T	30	60	10	0.17	4.1
II-C-15-T	30	55	15	0.17	4.2
III-C-O	40	60	0	0.24	13.0
III-C-2-B	40	58	2	0.23	10.2
III-C-5-B	40	55	5	0.21	9.1
III-C-10-B	40	50	10	0.22	9.7
III-C-15-B	40	45	15	0.23	9.9
III-C-2-T	40	58	2	0.22	9.7
III-C-5-T	40	55	5	0.20	8.8
III-C-10-T	40	50	10	0.21	8.5
III-C-15-T	40	45	15	0.22	9.5

B—bentonite clay, T—talc.

leads to an alteration of the antifriction characteristics. Friction factor decreases but remains within acceptable limits.

The dependence of the friction factor on the amount of the filler has a well defined minimum. The compositions comprising talc have relatively lower values for the friction factor. In broad outlines, both fillers: talc and bentonite clay are equivalent. Advantage can be granted to mixture II-C which achieves a friction factor of 0.15 with talc as dispersion filler. These compositions possess the lowest intensity of wear—$0.8 \times 10^{-14}\ m^3/N\ m$.

For samples II-C-5-T that showed the lowest friction factor, its fluctuation was studied at different values for $P_a \cdot V$ (where P_a is the relative load and V is the sliding speed). On Figure 1 the friction factor is shown in relation to variable P_a; and on Figure 2 to variable V. It can be seen that in both cases the plot is nearly a straight line that shows very good stability of the composite materials in relation to their antifriction characteristics. The results from conducted researches proved the possibility of producing antifriction phenolformaldehyde composite materials

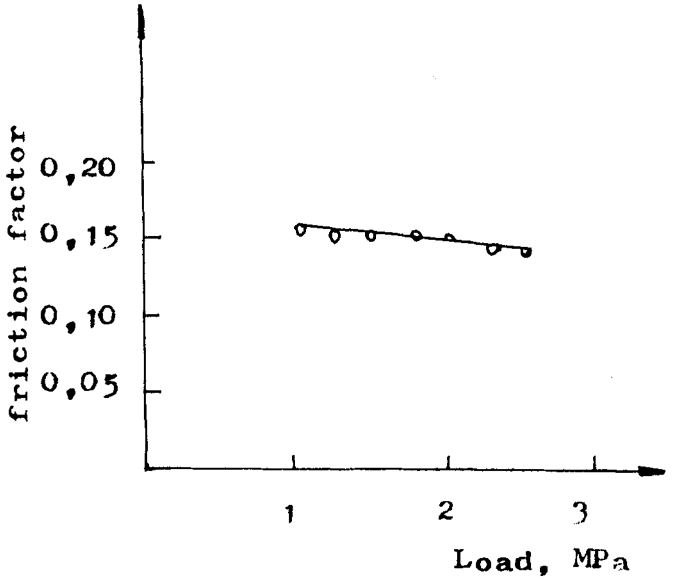

FIGURE 1 Dependence of friction factor on the load.

on the basis of cut cellulose carbon fibers, having a friction factor within the limits from 0.15 to 0.25 and intensity of wear within the limits from 1×10^{-14} to 13×10^{-14} $m^3/N\,m$.

Additional studies were made on the composition that showed the best antifriction characteristics (CFPFCM with 5% bentonite clay and based on novolak oligomer), that were aimed at determination of the composite material intensity of wear. The influence of boron carbide filler in an amount from 0.1 to

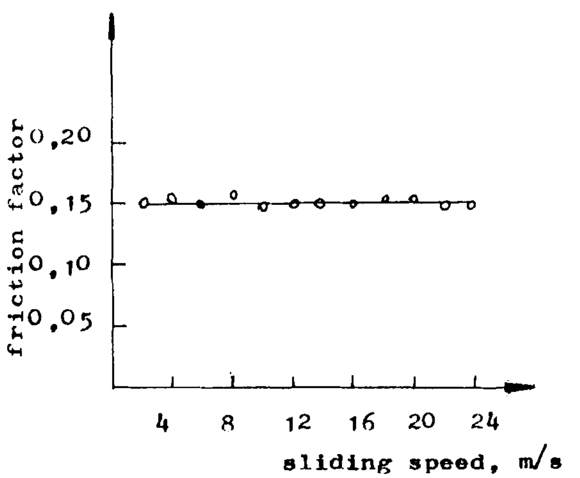

FIGURE 2 Dependence of friction factor on the sliding speed.

TABLE III

Influence of bentonite clay and boron carbide fillers on the tribological characteristics of composite material based on Novolak phenolformaldehyde oligomer and carbon not-woven fabric

Filler		Friction factor	Intensity of wear, $m^3/N\,m$
Without filler		0.22	6.7×10^{-13}
Filler 5% BG		0.14	3.7×10^{-13}
Filler BC, %	1	0.35	11.2×10^{-14}
	3	0.37	6.4×10^{-14}
	5	0.40	7.8×10^{-14}
Filler 5% BG and filler BC, %	0.1	0.30	8.9×10^{-14}
	1	0.33	6.4×10^{-14}
	3	0.35	6.0×10^{-14}
	5	0.36	5.8×10^{-14}
	7	0.37	15.0×10^{-14}

BG—bentonite clay, BC—boron carbide.

7% on the intensity of wear and on the friction factor of this composite material was studied.

It becomes obvious from the data classified in Table III that the composition with bentonite clay shows lowest friction factor (0.14) and, moreover, intensity of wear nearly twice as low as that of the composition without a filler. Undoubtedly, bentonite clay is a filler that leads to increases in hardness of the polymeric mixtures as well as in their wear hardness.[5]

Introduction of different amounts of boron carbide in concentrations from 0.1 to 7% exerts a substantial influence on the tribological characteristics of CFPFCM.

As for compositions containining boron carbide as the dispersion filler, their friction factor is varying in the limits from 0.35 to 0.40 and the material obtains friction characteristics from the antifriction properties.

Mixtures of bentonite clay and boron carbide show lower friction factor from 0.30 to 0.37. Obviously, boron carbide worsens the antifriction properties and at the same time substantially improves the wear hardness of the obtained composite materials of one order therefore addition of boron carbide to the composite materials is not expedient from the point of view of their antifriction characteristics and mainly, of the friction factor. These materials would have been of a certain interest with respect to their relatively high friction factor as well as their very good wear hardness, in their quality of friction materials.

On the basis of presented data, we conclude that the friction materials described in this study exhibit:

1) high values of intensity of wear which are comparable or superior to those of materials described in the technical literature,[2]

2) low friction factor values (0.13 to 0.25).

Because of these favorable characteristics, these materials should be regarded as potential candidates for technological use.

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