BALKANTRIB'O5
5th INTERNATIONAL CONFERENCE ON TRIBOLOGY
JUNE.15-18. 2005
Kragujevac, Serbia and Montenegro

ASBESTOS-FREE FRICTIONAL MATERIALS WITH A POLYMER MATRIX: RESEARCH DIRECTIONS AND SOLVED TASKS

V.P. Sergeinko, I.I. Zlotnikov, A.V. Kupreev, O.S. Yarosh
V.A. Belyi Metal-Polymer Research Institute of National Academy of Sciences, Gomel, Belarus

Abstract
General information on frictional materials is reported, actual problems of frictional materials science are described, and results of fundamental studies and practical applications of the frictional materials with a polymer matrix developed at the V.A. Belyi Metal-Polymer Research Institute of the National Academy of Sciences of Belarus are presented. The ecological aspects of the manufacturing and operation of the materials are discussed.

Key words: *frictional materials, friction, wear, properties, machine-building*

Modern science and such branches like materials science, tribology and mechanical engineering, on the first place, are unimaginable without the research and design of frictional materials (FM). The present investigation is aimed at creation of artificial materials with strong capability of dissipating mechanical energy. The dissipation mechanism involves transformation of the energy into the frictional heat and its dissipation in the ambient space [1]. A reverse problem is solved in engineering by using FM as well, namely the kinetic energy transfer from the source to the actuating units. FM are employed for brake elements, clutch lining, frictional inserts and dampers used in vehicles, rolling stock, aircraft construction, engineering facilities of oil-and-gas producing enterprises, railways, transport systems, technological equipment and numerous other machines and mechanisms. FM are subjected to unfavorable operation factors, including high, sign-variable temperature and dynamic loads, extreme sliding velocities, intensive wear and very often to the effect of hostile media (salt solutions, oil products, acids, and so on).

The transport industry and mechanical engineering have adopted for today three classes of FM: composites on organic matrix base, metal-ceramic and carbon ones [2]. Each of named class has a wide range of different formulations for the FM that are in agreement with certain requirements and operation conditions. The chief criterion for choosing one or another class of materials is the heat regime of the friction pair operation. The use of FM with the organic matrix is restricted by the volume temperature ϑ_v=(570-620) K and the mean friction surface temperature ϑ_s= (670-695) K. The cermet FM are mainly used under heat regimes, where ϑ_v=(870-970) K and ϑ_s=(1070-1270) K are prevailing. Notice, however, that with rising temperature frictional efficiency of cermet materials impairs considerably. For operation in severe heat regimes under ϑ_v=(1270-1770) K and ϑ_s=(1770-2270) K the carbon FM have been elaborated operating with the like counterpart materials. The carbon FM are ineffective at low temperatures (ϑ_s<400 K) [3]. In the recent years a stable tendency has been preserved of the growth of production output and utilizing of the FM with the organic matrix. Their effective application is attributed largely to their unique properties, such as strength, frictional and vibroacoustic characteristics, reliability and comfort during operation.

The present work deals with a series of fundamental and applied aspects of designing fric tional materials with a polymer matrix, which is connected with a largest volume of demand of this class of materials in Belarus.

From the viewpoint of their structure, FM with the polymer matrix represent composite materials consisting of various multiphase systems, among which some organic polymer or a blend of polymers serves as a continuous phase (matrix). The quality of FM depends on their thermal resistance and thermomechanical strength of the matrix polymer. To strengthen their polymer matrix, frictional composites contain reinforcing fillers, which are, as a rule, highly strong high-modular fibers. They also include the components for improving thermal properties, first of all, heat capacity and thermal conductivity. The dispersed microsize friction modifiers are added to reach the needed tribological characteristics, structural plasticizers are introduced to lower stiffness of the polymer matrix. Besides, the frictional composites may contain corrosion inhibitors, antiscoring and some other target additives. In commercial production of FM about a hundred types of mineral, organic, synthetic and metal-containing substances are used. Modern FM are complex heterogeneous systems involving about 12-25 components to ensure a complex of unique properties for their application in threshold operation conditions [4-5].

Within a more than 80-year's period of the development of frictional materials science, asbestos was a primary filling agent for the frictional polymer compositions and some types of cermet FM. From the standpoint of frictional materials science, this natural material possesses such a combination of unique properties that no other known for today natural or synthetic material has. The term 'asbestos' unites six noticeably differed in composition, structural and morphological, and physical-chemical properties silicate fibrous minerals (crocidolite, anthophyllite, actinolite, amosite, tremolite and chrysotile). For manufacture of FM commonly chrysotile is employed, which is related to the group of magnesia hyrdrosilicates (the theoretical formula $3MgO \cdot 2SiO_2 \cdot 2H_2O$). Numerous investigations have proved that the fibrous particles incorporated in asbestos are 5-8 μm in length and 3 μm wide, they are biologically active substances with expressed carcinogenic effect. Their hazard is redoubled because the latent period between the start of the asbestos fibers affect and clinical signs of the disease makes up 30 years [6].

A "Consolidated list of products forbidden for consumption or/and production, withdrawn, strictly bounded or not certified by the governments" was published by the decision of the General Assembly of UNO in 1982 [7]. The complete group of asbestos was referred to as particularly dangerous for human health. In fact all kinds of utilizing asbestos were prohibited in the course of 1982-1990 in Western Europe, USA and many other countries. Its usage in frictional joints is specifically harmful since the finest wear debris of FM are accumulated in great amounts in the air, especially round the city transport arteries and in closed industrial workshops.

The fundamental and applied investigations performed at V.A. Belyi Metal-Polymer Research Institute of NASB have promoted the solution of a number of actual problems in materials science. Based on these solutions, physical-chemical and technological principles of creating asbestos-free frictional materials with a polymer matrix have been worked out. A priority has been given to the development of the polymer FM intended for operation at liquid lubrication. The multidisc oil-cooled brakes and frictional discs with organic coatings for the clutches of hydromechanical car transmissions seem to be most efficient structures able to raise significantly the operation capacity and reliability of frictional units in vehicles. In this connection, of paramount importance is to work out a high-strong polymer structure of FM that will ensure either a hydrodynamic or boundary friction regime in the solid frictional contact, where the difference between the static and dynamic friction coefficients would be the least independently of the liquid medium viscosity. Just as porous so anisotropic FM can serve as an example of such structures, which abate the probability of tearing off the oil film from the contact surface and transfer to dry friction. The developed highly strong polymer model FM with a microporous and reinforced in orthogonal direction structures for operation in oil are illustrated in the Figure.

The brush structures (the Figure, *b*) with characteristic orientation of superfine basalt fibers chiefly perpendicular to the plane of sliding display the best combination of frictional and vibroacoustic properties among available today FM. Progress in this direction will help to improve substantially the dynamics of transfer processes in vehicles, reduce noise level and elevate reliability of frictional joints.

Our Institute is actively developing the fundamental problems of the vibroacoustics of mechanical dissipating systems, to which various frictional units belong. The noise generated during frictional interaction, especially under unsteady friction regimes, presents an intractable problem of abating noise in transport industry. Latest investigations in the field of noise constitute directly or obliquely almost 50% of the total budget of the leading companies dealing with frictional materials [8]. Within the framework of this problem, the experimental investigations of the main regularities of acoustic generation during friction of FM with a polymer matrix were carried out. Based on the results, structural and mechanical methods of regulating vibration and acoustic processes on the frictional contact were formulated.

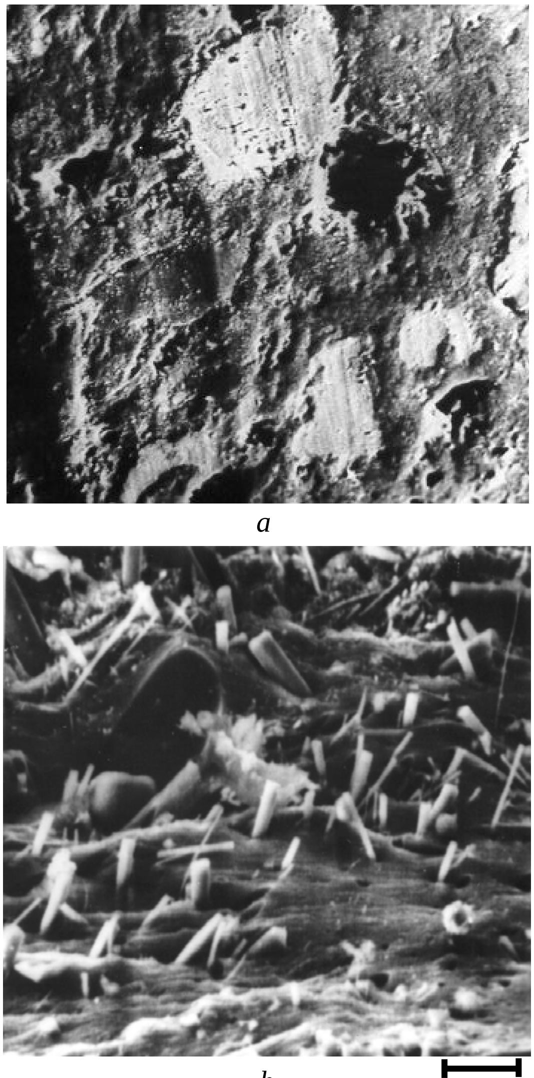

Figure: *SEM image of a microporous (a) and orthogonally reinforced (b) structure of FM*

The number of polymers employed as FM matrices is very limited. Therefore, the problems of synthesizing insoluble and infusible polymer matter of a new chemical structure for the use as the FM matrix stand on the forefront of the frictional materials science.

A promising direction in chemistry and technology of FM is the study of chemical reactions in thermosetting polymer systems, as well as processes of structural recombination and ordering. This is related to the probability of regulating the conformal parameters of macromolecules, cross-linking kinetics, mechanical and tribological properties of polymer matrices, specifically under high velocities and shear stresses. For this aim, it will become possible to use more productive processes of manufacturing.

The problems of chemical modification of phenol formaldehyde binders, most widely applicable today in frictional materials science, are studied with the purpose of raising their resistance to thermooxidative effects and improving plasticity of the cured matrix phase in FM. This can be attained by etherification of the phenolic group, complexing with polyvalent metals or injection of the binding heteroatoms into the structure.

The idea of producing high-strength wear resistant carbonated structures from the matrix polymer has been theoretically substantiated and experimentally verified using ready components under high-temperature effects at friction in air. The carbonated matrix promotes increase in the specific frictional power 2-3 times and reaching the values characteristic of the cermet FM (5-8 Wt/mm^2). Hardness gradient of FM across thickness is preserved, which contributes to improvement of vibroacoustic parameters of FM.

A complex of investigations has been fulfilled in designing and manufacture of new types of reinforcing fillers with a microstructure and properties similar to asbestos that are based on the organic and mineral raw materials. A special attention is paid to production of highly strong and heat-resistant biosoluble fibers, porous fibrous structures and improvement of their adsorptive and adhesive capacity. The technological tasks in this field are focused on providing stability of the size of fibers aimed at refining the parameters of scatter of the main technical characteristics of FM and recording the laws and mechanisms of their wearing as dependent on the structure and chemical composition of the fibers [5, 9].

Layered silicates are traditionally used as the fillers for FM. They may be talc, vermiculite and fine particles of metals, which are treated today as a promising means of obtaining nanocomposites [10]. The problem consists in developing and perfection of chemical and mechanochemical methods of manufacturing nanomaterials, methods of filler dispersion till a nanosize (delamination) and the maintenance of monodispersity of the particles via chemical modification of clay minerals. To this also belong the reduction of their susceptibility to aggregation and oxidation. It's impossible to obtain satisfactorily formed nanosystems without solving the problem of how to introduce nanoparticles into the structurally unstable thermosetting composite matrix in the presence of other solid-phase fillers. The fundamental investigations in this direction may anticipate a striking practical result consisting in abrupt increase in thermal resistance, stability of frictional characteristics and thermal conductivity of FM by means of approaching matrix properties to analogous properties of the filler [11].

In the field of practical use, the engineering procedures for modeling the processing and manufacturing processes of FM have been elaborated. They ensure an optimum level of tribological and mechanical characteristics of FM at the stage of structure formation. The modification methods of the phenolic matrix by the substances of non-elastomeric type have been studied to improve plasticity of FM. We have examined the wear mechanism of such structures at external friction when the weak boundary layers are formed as a result of absorption of dispersed fillers of the plasticizer liquid phase on the fiber surfaces. Highly efficient and chemically active towards the matrix polymer primers have been designed. Their use in surface treatment of mineral fibers included into FM as a fibrous component leads to improved wear resistance, mechanical strength and frictional heat stability of the composites [12].

Novel procedures, technologies and formulations of wear resistant FM of various functional purposes are suggested for operation in both dry and lubricated friction joints. The main technical characteristics of developed materials are presented in Table.

Aside from above mentioned, the compositions and methods of manufacturing FM with elevated friction coefficient stability, resistance to hostile media and high wear resistance have been developed for the friction joints of the equipment used in steel-making and metal cord industry. A series of FM grades that surpass by their efficiency and durability the asbestos-containing materials have been developed for the brakes and transmissions of wheel tractors of 4-184 kWt power. Positive results of both bench and longevity tests have been obtained for the elastic frictional materials and frictional discs of the hydromechanical transmission clutches. The FM with highly stable friction torque in the oil medium have been worked out for the new design of multidisc oil-cooled brakes of wheel tractors and heavy-duty dump-trucks "BelAZ". The results of investigations on reduction of vibroacoustic activity of materials have yielded an engineering effect in abating noise of disc brakes of wheel tractors by 4-6 dB.

Table. Technical Characteristics of Developed Materials

Parameter	Brake materials		Clutch materials	
	Dry friction	Friction in oil	Dry friction	Friction in oil
Density, g/cm^3	2.20-2.46	1.86-2.13	1.86-2.09	1.71-1.82
Friction coefficient	0.45-0.63	0.11-0.16	0.53-0.66	0.10-0.14
Wear rate: –dry friction, I_h, 10^{-8} (P=1.0 MPa; V=2.0 m/s); –friction in oil, (P=0.6-2.5 MPa; V=0.3-25.0 m/s)	3.1-5.0	0.01 mm/ 20 h (at stationary friction regime)	0.68-3.74	0.002 μm/contact
Lasting thermal stability, K	670	540	620	570

REFERENCES

[1] Chichinadze A.V., Matveevsky R.M., Braun E.D. Materials in tribology of non-stationary processes. Moscow, 1986. 248 p.

[2] Friction, wear and lubrication (tribology and triboengineering). Ed. by A.V. Chichinadze, Moscow, 2003. 576 p.

[3] Kokonin S.S., et al. Heavy-loaded multidisc brakes and the factors defining efficiency and stability of their operation. Heavy engineering, 2001, № 4, p. 19-26.

[4] Pleskachevsky Yu.M., Sivyi B.P., Pesetsky S.S. Modern materials science and promises of development in Belarus. Science and innovations, 2004, № 12, p. 46-59.

[5] S.r. "Compositions, Functions and Testing of Friction Brake Materials and Their Additives" Oak Ridge National Laboratory. 2001. ORNL/TM-2001/64.

[6] Ilnitsky A. Asbestos. Labor protection and social insurance, 1997, № 7, p. 20-22.

[7] Consolidated list of products forbidden for consumption or/and production, withdrawn, strictly bounded or not certified by the governments, 1996, № 1, p. 32-36.

[8] Abendroth H. The integrated test concept Dyno-Vehicle: performance and noise. Proc. of the 18th Brake Colloquium. San Diego. CA. 200, p. 143-148.

[9] Verheijen M. About the use of man-made mineral fibers in non-asbestos friction materials. Proc. of the 5th Int. Symposium of friction products and materials. Yaroslavl. Russia. 2003, p. 162-174.

[10] Tutorsky I.A., Pokidko B.V. Elastomeric nanocomposites with layered silicates. 1. Structure of layered silicates, structure and production of nanocomposites. Caoutchouc and rubber, 2004, №5, p. 23-30.

[11] Tretiyakov N.D., Lukashin A.V., Eliseev A.A. Synthesis of functional nanocomposites based on solid-phase nanoreactors. Successes in chemistry, 2004, №9 (73), p. 974-998.

[12] Sergienko V.P., Kupchinov B.I. Effect of structural plasticizers on wear resistance of high-filled polymer composites. Proc. Belarussian AS, 1997, №4 (41), p. 108-110.