Problems of Tribology, *V. 26, No 1/99-2021,20-27*

Problems of Tribology

Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2021-99-1-20-27

Regularities of the influence of submicron ceramic powders TiO_2, AlN, Cr_2O_3 on the tribological properties of a friction material

A.V. Leshok[1*], A.V. Dykha[2]

[1]*O.V.Roman Powder Metallurgy Institute, Minsk, Belarus*
[2]*Khmelnitskyi National University, Ukraine*
E-mail: sdilav@tut.by

Abstract

Friction units for automotive and special vehicles are designed to operate under boundary friction conditions. Modern vehicles contain friction assemblies that use friction materials. Currently, friction materials are actively used: based on thermosetting resins; pulp and paper-based materials; sintered powder materials; materials of carbon or carbon composition; materials with a ceramic matrix. The development of a unified understanding of the effect of the size and chemical nature of ceramic additives on the processes occurring in a friction material during friction is very important and can be obtained both on the basis of experimental and theoretical studies. The paper presents the results of a study of the effect of submicron TiO2, Cr2O3, AlN powders with a size of 0.2-0.5 microns on the tribotechnical properties of a frictional material based on copper intended for operation under boundary friction conditions. It was found that when using the addition of Cr2O3 powder, the greatest increase in the value of the friction coefficient is noted - from 0.042 to 0.082, a slightly smaller increase in the friction coefficient is shown by the use of AlN and TiO2 defects - 0.042-0.074 and 0.042-0.060, respectively. The least wear of the friction material was obtained when using 3.0 vol. % aluminum nitride additive - 2.1 microns / km. Increasing the addition of any of the submicron powders by more than 7 vol. % leads to a significant decrease in wear resistance. This is due to the formation on the surface of the friction material of a modified layer containing ceramic particles and the metallic phase of the friction material. For the friction material, an unstable value of the friction coefficient and increased wear were recorded.

Key words: friction material, coefficient of friction, wear, ceramic particles, bronze.

Introduction

Friction units for automotive and special vehicles are designed to operate under boundary friction conditions. Boundary friction is realized when the thickness of the lubricating layer on the contact surfaces of friction is at least 0.1 μm, capable of physical adsorption or chemical reaction. At present, sintered friction materials based on copper are most widely used for operation under boundary friction conditions. This group of materials is characterized by a high value of the coefficient of friction, wear resistance, coefficient of thermal conductivity and service life. However, at present, higher values of tribotechnical and physical-mechanical properties are required. This is achieved through the use of additives of metal and ceramic powders. The most commonly used ceramic powders are 10-200 microns. However, the use of submicron ceramic powders with a size of less than 1.0 μm as an additive in a sintered friction material based on copper is of scientific and practical interest.

Literature review

Modern vehicles contain friction assemblies that use friction materials. Currently, friction materials are actively used: based on thermosetting resins; pulp and paper-based materials; sintered powder materials; materials of carbon or carbon composition; materials with a ceramic matrix [1-7].

Sintered powder friction materials are designed to work in severe operating conditions - temperatures up to 950 C, sliding speed up to 80 m / s, pressure up to 5 MPa. Sintered materials on copper and iron bases are most widely used in hydromechanical transmissions of automotive vehicles, parking brakes, on-board clutches of civil and special-purpose vehicles. Materials of this group are characterized by high wear resistance and heat resistance, mechanical strength. They consist of a metal matrix, and additives for various functional purposes, designed to increase the wear resistance, resistance of the friction material to the formation of a scuff, as well as imparting the required value of the coefficient of friction [8-10].

Providing the required value of the coefficient of friction of the friction material is possible in several ways: by changing the structure and composition of the metal matrix, using additives of metallic and non-metallic powders of various chemical nature. Considering the compositions of sintered friction materials, it can be noted that ceramic powders in the form of oxides, nitrides, borides are used as an additive that increases the value of the friction coefficient [11-17].

The presence of solid particles in the structure of the material allows localizing seizure in small areas of the surface, avoiding seizing and reducing the intensity of wear [18]. The process of friction and wear of a material containing solid inclusions can be considered as a process of continuous formation, change and destruction of frictional bonds at the points of actual contact.

Titanium dioxide is widely used in industry as an additive of low cost, characterized by stable properties and non-toxicity. In [19] it is noted that titanium dioxide is characterized by a very high specific surface area, up to 600 m2 / g, and a low thermal conductivity.

Chromium (III) oxide Cr2O3 is a typical amphoteric oxide with a corundum-type structure (α-form), thermal and moisture resistance, high microhardness - up to 2940 kgf / mm2, the highest strength of all chromium oxides [20, 21].

The choice of aluminum nitride as an additive in the composition of the composite friction material is based on the fact that it has good thermal conductivity, low temperature coefficient of linear expansion (4.6 10-6 K-1 at 20 - 500 ° C), high hardness (9 on the Mohs scale) and resistance to thermal shock [22].

In [10, 23, 24] it is indicated that the size of ceramic additives used in the compositions of friction materials can vary from 1 to 600 microns. It is noted that the optimal size of SiO2 particles is 20-60 microns, since at a particle size of 1 micron, their abrasive properties are lost, and at more than 60 microns, particles in the process of friction crumble from the surface, causing its wear, and quartz sand particles - 63- 160 microns. However, in [25] it is noted that the particle size of the SiO2 powder should be 20 μm to ensure an effective abrasive action.

The development of a unified understanding of the effect of the size and chemical nature of ceramic additives on the processes occurring in a friction material during friction is very important and can be obtained both on the basis of experimental and theoretical studies.

Purpose

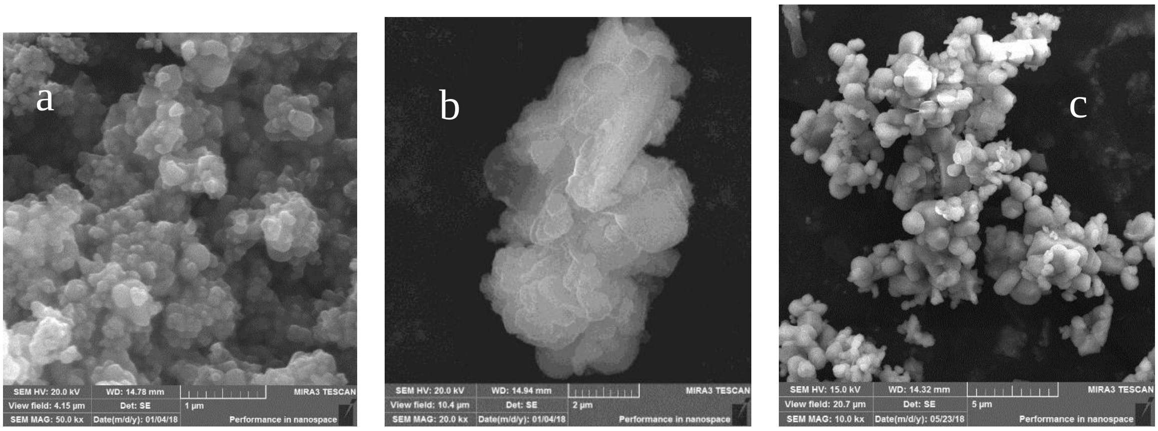
Investigation of the effect of submicron ceramic powders TiO_2, AlN, Cr_2O_3 on the tribological properties of a friction material.

Methods

A mixture of copper powders with 12% tin and 30 vol.% Elemental graphite GE-1 was used as the basis for the friction material. The initial charge was obtained by mixing powders of copper grade PMS-1 with an average particle size of 100 μm, tin grade PO 1 with an average particle size of 20 μm, elemental graphite grade GE-1 (GOST 7478-75), which has a flake shape, with an average size of flakes 100 μm in a "drunken barrel" mixer for 45 minutes. For the formation of friction materials, 7 types of charge were used based on copper with additions of TiO_2, AlN, Cr_2O_3 powders in the amount of 1.0-7.0 wt. % with a step of 1.0 wt.%. Figure 1 shows the appearance of TiO_2, AlN, Cr_2O_3 powders used for research. Powders with high activity are presented in the form of agglomerates, while themselves having a size of less than 1.0 μm.

Titanium dioxide is agglomerates with a size of 100-150 microns, consisting of submicron powders, predominantly spherical, up to 0.2 microns in size (Fig. 1a). Aluminum nitride also represents agglomerates with an average size of 20 μm, with a particle size of 0.5 μm (Fig. 1b). Chromium oxide powder consists of agglomerates 20-30 microns in size, including spherical particles 0.2-0.4 microns in size (Fig. 1c).

Samples of friction discs for testing were prepared as follows: the resulting mixture from the initial powders was applied by free pouring onto the surface of a steel base using special technological equipment, then preliminary sintering was carried out in dissociated ammonia at a temperature of 840 ° C for 50 min. The sintered blank of the friction disk was subjected to plastic deformation (embossing) with a punch having a profile in the form of a "mesh" on the surface, for molding a system of oil channels and grooves on the surface of the sintered material, as well as obtaining a porosity of 12-18%. Then the final sintering was carried out under a pressure of 0.1 MPa in a dissociated ammonia medium, which contains,%: H2 - 75, N2 - 25 at a temperature of 840 ° C for 3 hours.



а) б) в)

Fig. 1. Ceramic additives used for research in the composition of a composite friction material based on copper^ a) TiO2; b) AlN; c) Cr2O3

The principle of the tribological testing method was to simulate the braking process on the IM-58 inertial stand in the "A" oil medium during registration of the change in the moment of friction forces depending on the speed and time of braking [10]. The coefficient of friction and wear of the material was fixed after 500 test cycles. Measurement of material wear was carried out using MK 25-1 micrometer GOST 6507-90.

The tests were carried out under the following conditions:

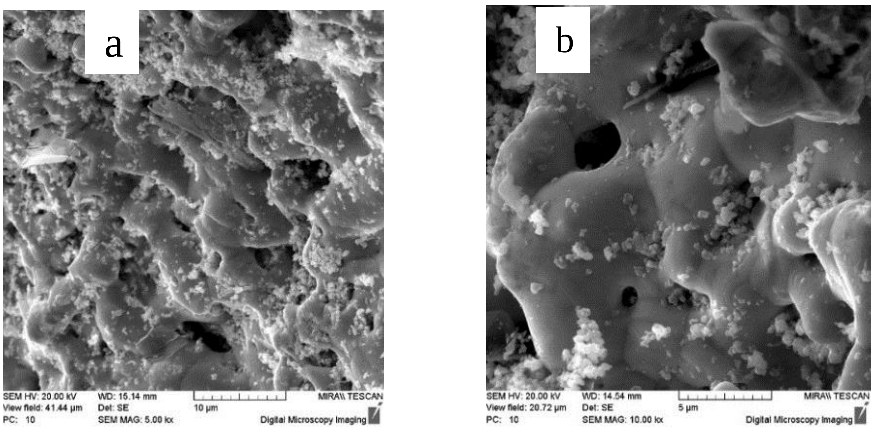
- initial braking speed – 19 m/s;
- specific load – 0.85 MPa;
- moment of inertia of flywheel masses – 0.56 N•m•s^2;
- friction work – 27.5 kJ;
- the coefficient of mutual overlap – 0.29.

A disc made of 65G steel with a hardness of 260-320 HB and a roughness of the working surface of Ra 0.7-0.8 was used as a counterbody.

The structure was studied using an optical microscope MEF-3 (Austria). The morphology of the friction disk friction surface and its microstructure were investigated on a high-resolution scanning electron microscope MIRA (Czech Republic) with an INCA 350 X-ray microscope attachment from Oxford Instruments (Great Britain). Non-etched areas were examined in a cross section perpendicular to the deposited layer. The strength of the powder material was determined by compressive testing of specimens 20 mm high, 15 mm wide and 15 mm long on a Tinius Olsen H150K-U testing machine at a loading rate of 2 mm / min.

Results

A very important condition for the use of ultrafine powders is their uniform mixing. Having a high activity, such powders are capable of forming agglomerates, which affects the properties of the finished product [26]. After mixing the initial charge of the friction material, a fairly uniform distribution of the addition of submicron particles of TiO_2, AlN, Cr_2O_3 powder on the side surface of the copper powder is observed (Fig. 2).



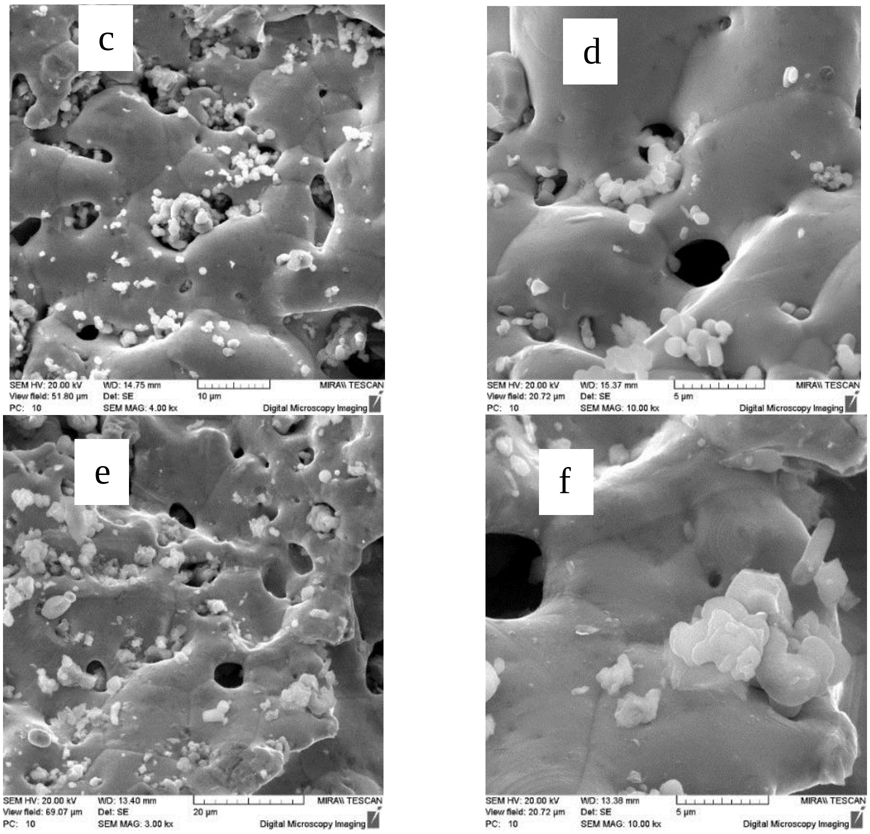


Fig. 2. Distribution of the addition of submicron powder particles in the friction material^ a, b) TiO2; c, d) Cr2O3; e, f) AlN

In fig. 3a shows the dependences of the change in the friction coefficient of the friction material on the content of the used additives of submicron powders. The addition of Cr_2O_3 powder provides the greatest increase in the value of the friction coefficient - from 0.042 to 0.082, slightly less - the addition of AlN and TiO_2 powders - 0.042-0.074 and 0.042-0.060, respectively.

The least wear of the friction material was observed when using 3.0 vol. % aluminum nitride additive - 2.1 microns / km. The wear of the material with the addition of 1.0 vol.% Chromium oxide is 2.6 μm / km. Titanium oxide in the amount of 0.5-7.0 vol. % has a lesser effect on reducing material wear. When the additive is increased by more than 7 vol. %, material wear is noted above the established value of 9.0 μm / km (Figure 3b).

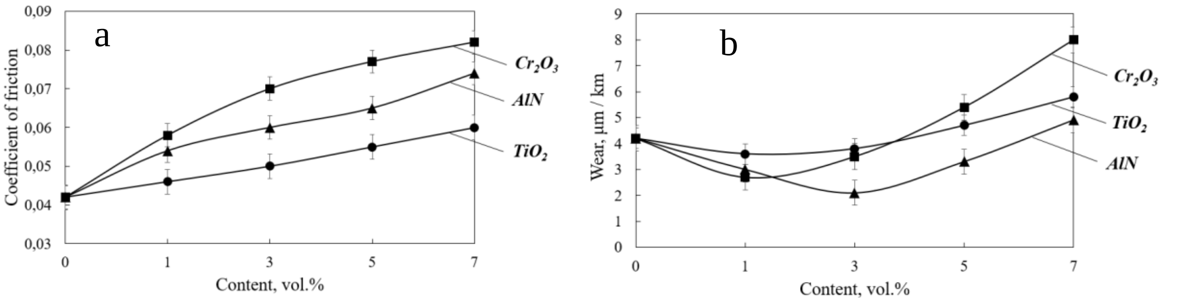


Fig. 3. Change in the coefficient of friction and wear of a friction material based on 12% tin bronze with 30 vol.% GE-1 versus the amount of addition of submicron ceramic powders TiO_2, AlN, Cr_2O_3

In the process of friction, a modified surface layer is formed, which can be present both on one of the friction surfaces, and on both. The formation of such layers during friction was noted in his works by the famous scientist L.I. Bershadsky, pointing out that such layers have a structure different from the structure of the initial materials, and determine the value of the coefficient of friction and wear [27]. These processes are discussed in great detail in the works of B.I. Kostetsky and representatives of his school [28].

Investigations in characteristic X-ray radiation over the surface area of the friction material showed the presence of such a layer. The layer is a mechanical mixture of the metallic phase of the friction material (tin bronze) with submicron ceramic particles (Fig. 4).

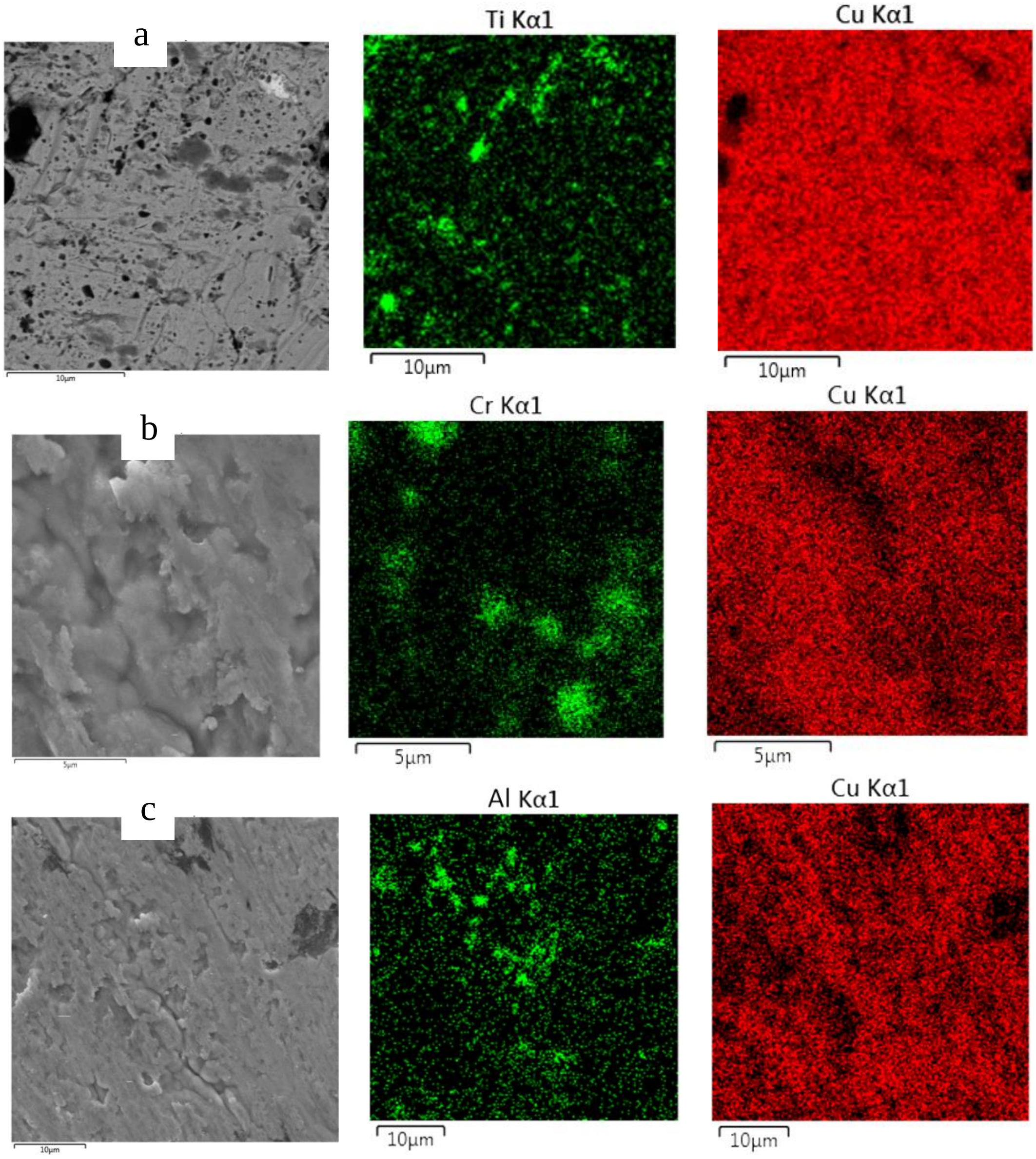


Fig. 4. Micro X-ray spectral analysis of the friction surface of a friction material containing submicron ceramic powders (300 test cycles): a) TiO_2; b) Cr_2O_3; c) AlN

It is noted in [29] that when ceramic particles of Al_2O_3 with a size of 100 μm are used in the composition of a sintered friction material, the friction surface is modified. It manifests itself in plastic deformation of the softer friction material, with an increase in wear. In addition, it is marked by the closure of the surface pores of the friction material. The effect of closing the pores is highly undesirable, since they, being additional sources of lubrication, preserve the conditions of boundary friction. To a greater extent, the effect of lubrication from the pores is manifested in the case of prolonged sliding, for friction materials called the slipping process.

It has been found that the use of additives of ultrafine powders TiO_2, Cr_2O_3, AlN in the range of 0.5-7.0 vol.% Preserves the structure of the surface layer of the friction material (Fig. 5). The presence of pores on the friction surface can be noted. In the case of an increase in the particle size of the TiO_2 defect to 100 μm, already at 3.0 vol.% On the friction surface of the friction material, plastic deformation is recorded, the formation of directed friction tracks from the abrasive action of ceramic particles, as well as the closure of surface pores (Fig. 5d). For the friction material, an unstable value of the friction coefficient and increased wear were recorded.

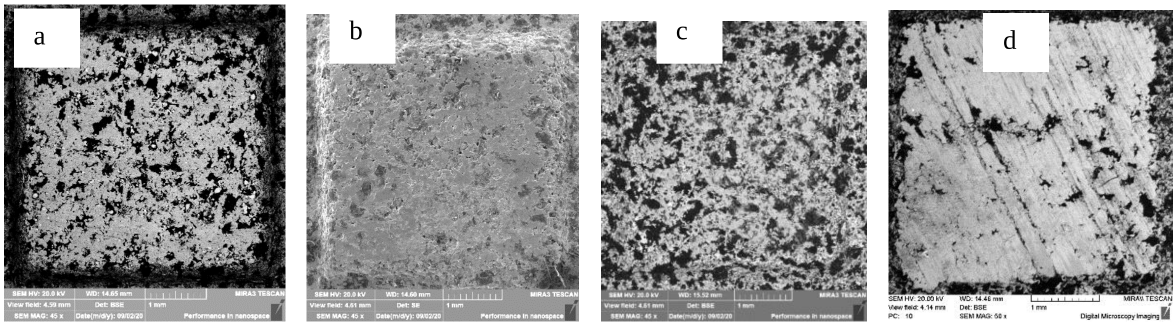


Fig. 5. Morphology of the friction surface of a friction material based on copper containing additives of ceramic powders (a - 7.0 vol.% TiO_2 (0.2 μm); b - 7.0 vol.% AlN (0.5 μm); c - 7.0 vol.% Cr_2O_3 (0.3 μm); d - 3.0 vol.% TiO_2 (100.0 μm)) after 500 test cycles

Conclusions

The addition of submicron powders of TiO2, Cr2O3, AlN (0.2-0.5 μm) into the sintered friction material based on copper leads to an increase in the value of the friction coefficient. So, when using the addition of Cr2O3 powder, the greatest increase in the value of the friction coefficient is noted - from 0.042 to 0.082. A slightly smaller increase in the friction coefficient is shown by the use of AlN and TiO2 defects - 0.042-0.074 and 0.042-0.060, respectively. It was found that the least wear of a friction material based on copper operating under boundary friction conditions was observed when using 3.0 vol. % aluminum nitride additive - 2.1 microns / km. The wear of the material with the addition of 1.0 vol.% Chromium oxide is 2.6 μm / km. Titanium oxide in the amount of 0.5-7.0 vol. % affects wear resistance to a lesser extent. Increasing the addition of any of the submicron powders by more than 7 vol. % leads to a significant decrease in wear resistance.

References

1 Sharipov V.M. (2002) Proyektirovaniye mekhanicheskikh, gidromekhanicheskikh i gidroob"yomnykh peredach traktorov. - M.: MGTU MAMI. - 2002. – S.300.

2 Tarasik V. P. (1973) Friktsionnyye mufty avtomobil'nykh gidromekhanicheskikh peredach. – Minsk: Nauka i tekhnika. – S.320.

3 Gordeyev R.V., Pyzhev A.I. (2014) Rossiyskoye avtomobilestroyeniye: rezul'taty, tendentsii i perspektivy [Ekonomicheskiy analiz: teoriya i praktika]. (48). – S.26-35.

4 Al'gin V. B., Poddubko S.N (2019) Resursnaya mekhanika transmissiy mobil'nykh mashin. - Minsk: Belaruskaya navuka. – S.549.

5 Miroshnichenko A.N. (2014) Osnovy teorii avtomobilya i traktora [Tomsk: Izd-vo Tom. gos. arkhit.-stroit. un-ta]. – S.489.

6 Rumyantsev L.A. (2008) Ustroystva upravleniya planetarnoy korobkoy peremeny peredach [Stroitel'nyye i dorozhnyye mashiny]. - (11). – S.31-35.

7 Krasnevskiy, L.G., Poddubko S.N., Nikolayev YU.I. (2014) Razvitiye konstruktsiy gidromekhanicheskikh peredach bol'shoy moshchnosti [Aktual'nyye voprosy mashinovedeniya: sb. nauch. tr. OIM NAN Belarusi], - (3). - S.83–87.

8 Ilyushchanka A.Ph., Leshok A.V., Dyachkova L.N., Alekseenko N.A. (2019) Formation of the friction surface of a friction material based on copper depending on the amount of tin under lubrication condition [10-th International conference Balttrib, 14-16 November 2019, Vytautas Magnus University Lithuanian Scientific Society Department “Tribologija” Akademija, Kaunas, Lithuania]. - Pp.100-106.

9 Ilyuschenko A.Ph., Leaghok A.V., Rogovoy A.N., Rudakovsky V.O. (2017) Application of sintered powder material FM-15 in the clutch coupling "Belarus-3522" tractors [Agricultural engineering]. – (49). - P.56-62.

10 Fedorchenko I. M., Pugina L.I. (1980) Kompozitsionnyye spechennyye antifriktsionnyye materialy [Nauk. Dumka]. - S.404.

11 Copper alloy powder, sintered copper alloy body, and brake lining for use in high-speed railways: pat.: US20160047016A1 / Futoshi Katsuki, Fumio Ishimoto, Osamu Kanda. – 18.02.2016.

12 Friction material containing brass powders: pat.: US5324592A / Fred Blankenhagen, Hermann Putz. – 28.06.1994.

13 Sintered friction material for high-speed railway: pat.: US20140109723A1 / Fumio Ishimoto, Futoshi Katsuki, Kazutaka Asabe. – 24.04.2014.

14 Sintered friction material: pat.: US20200038959A1 / Manabu Kubota, Naomitsu Mizui, Fumio Ishimoto. – 06.02.2020.

15 Sintered friction material for a friction lining: pat.: US20170363167A1 / Zoltan Csanadi, Bruno Tourneret, Peter Echtler. – 02.04.2019.

16 Sintered friction material for railway vehicles and method for producing the same: pat.: US20190292634A1 / Manabu Kubota, Kazutaka Asabe, Yuki Ichikawa, Takeshi Nakano. – 26.09.2019.

17 Sintered material for a magnetic track brake.: pat. US6648108B2 / Eckart Saumweber, Wolfgang Schröer, Wolfgang Valentin. –

18.11.2003. 18 Mashkov, YU. K. (2013) Tribofizika metallov i polimerov [Omsk : Izd-vo OmGTU]. - 2013. – 240 s.

19 Tarasov A.B. (2016) Sintez, struktura i funktsional'nyye svoystva nanostrukturirovannogo dioksida titana, poluchennogo geterogennym gidrolizom tetrakhlorida titana v aerozol'nykh sistemakh [dis. … kand. khim. nauk: 02.00.04]. – Chernogolovka. – 123 l.

20 Kozhina, L.F. (2017) Khrom i yego soyedineniya [Saratov]. - 48 s.

21 Arkhipov D.I. (2017) Regulirovaniye dispersnosti nanoporoshkov dioksida khroma putom modifitsirovaniya komponentami Mo-Sb, W-Sb, Mo-Sb-Fe, Sn-Te, Sn-Te-Fe [dis. … kand. tekhn. nauk : 05.16.08]. – 132 l.

22 Kudyakova V.S. (2019) Razrabotka tekhnologii stabilizatsii kubicheskikh modifikatsiy nitrida alyuminiya [dis. … kagd. tekhn. nauk : 05.17.11]. – Yekaterinburg. - 154 l.

23 Fedorchenko I.M. (1976) Issledovaniye materialov dlya tormoznykh i peredatochnykh ustroystv [Kiyev.: Naukova dumka]. – 240 s.

24 Fedorchenko I. M., Kryachek V. M., Panaioti I. I. (1975) Sovremennyye friktsionnyye materialy [Naukova dumka, Kiyev]. – s.336.

25 Bowden F.P. Tabor D. (1950) The friction and lubrication of solids [Clarendon press, Oxford]. – 424 p.

26 Girshov V.L., Kotov S.A., Tsemenko V.N. (2010) Sovremennyye tekhnologii v poroshkovoy metallurgii [SPb.: Izd-vo Politekhn. Un-ta]. - 385 s.

27 Bershadskiy L.I. (1990) Strukturnaya termodinamika tribosistem [Kiyev: Znaniye]. – 245s.

28 Kostetskiy B.I., Natanson M.E., Bershadskiy L.I. (1972) Mekhano-khimicheskiye protsessy pri granichnom trenii. [M.: Nauka]. - 1972. – 170s.

Лешок А.В., Дыха А.В. Закономерности влияния субмикронных керамических порошков TiO_2, AlN, Cr_2O_3 на трибологические свойства фрикционного материала

Узлы трения для автомобильной и специальной техники предназначены для работы в условиях граничного трения. Современные автомобили содержат фрикционные узлы, в которых используются фрикционные материалы. В настоящее время активно используются фрикционные материалы: на основе термореактивных смол; целлюлозно-бумажные материалы; спеченные порошковые материалы; материалы углеродного или углеродного состава; материалы с керамической матрицей. Развитие единого понимания влияния размера и химической природы керамических добавок на процессы, происходящие в фрикционном материале при трении, очень важно и может быть получено как на основе экспериментальных, так и теоретических исследований. В работе представлены результаты исследования влияния субмикронных порошков TiO2, Cr2O3, AlN размером 0,2-0,5 мкм на триботехнические свойства фрикционного материала на основе меди, предназначенного для работы в условиях граничного трения. Установлено, что при использовании добавки порошка Cr2O3 отмечается наибольшее увеличение значения коэффициента трения - с 0,042 до 0,082, несколько меньшее увеличение коэффициента трения показывает использование дефектов AlN и TiO2 - 0,042 -0,074 и 0,042-0,060 соответственно. Наименьший износ фрикционного материала был получен при использовании 3,0 об. % добавки нитрида алюминия - 2,1 мкм / км. Увеличение добавления любого из субмикронных порошков более чем на 7 об. % приводит к значительному снижению износостойкости. Это связано с образованием на поверхности фрикционного материала модифицированного слоя, содержащего керамические частицы и металлическую фазу фрикционного материала. Для фрикционного материала зафиксировано нестабильное значение коэффициента трения и повышенный износ.

Ключевые слова: фрикционный материал, коэффициент трения, износ, керамические частицы, бронза.