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**TRIBOENGINEERING AND STRUCTURAL
PECULIARITIES OF FRICTIONAL MATERIALS
WITH A POLYMER MATRIX AIMED
AT OPERATION WITH LUBRICATION**

**WŁAŚCIWOŚCI TRIBOLOGICZNE I STRUKTURALNE
MATERIAŁÓW CIERNYCH Z MATRYCĄ POLIMEROWĄ
PRZEZNACZONYCH DO PRACY W ŚRODOWISKU
SMARNYM OLEJOWYM**

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Summary

Holding problems in the field of operation of frictional materials in oil are discussed, the results of fundamental investigations and practical applications of frictional materials intended for lubricated friction are cited and wear mechanisms of said materials are analyzed.

INTRODUCTION

Augment in capacity and reliability of frictional systems intended for modern mobile machines, those of brakes and transmissions, in the first place, have resulted in the development of new designs of friction units where dissipative processes take place in a liquid medium, mainly oil. The core requirements to frictional materials for operation in oil consist in the reduction of the heat load on friction joints and, as a consequence that of the wear rate, elimination of warping of the rubbing members and impact loads in transmission and brake assemblies. Inevitable in this case lowering of the friction force can be compensated by increasing number of rubbing pairs (**Fig. 1**). This is where the idea of multidisc oil-cooled friction devices (MFD) lies.

Forced heat removal from the friction zone helps to improve power, durability and reliability of friction joints in machines. The demands to actuation smoothness of transmissions and brakes can be realized by minimizing difference between the static (μ_{stat}) and dynamic (μ_{dyn}) friction coefficients of the materials. This can also be made by creating such a structure of the friction material that is able to lower the probability of transfer from the liquid friction regime to the dry one. In spite of continuous perfection of the composition and properties of frictional materials, the problem of raising friction power of the friction devices and damping impact loads in the friction joints at transfer processes has not so far found its solution. Therefore, the cornerstone of many researchers presents the development of new frictional materials (FM) intended for operation in oil and investigations of tribological phenomena on the oil-cooled friction contact [**L. 1**].

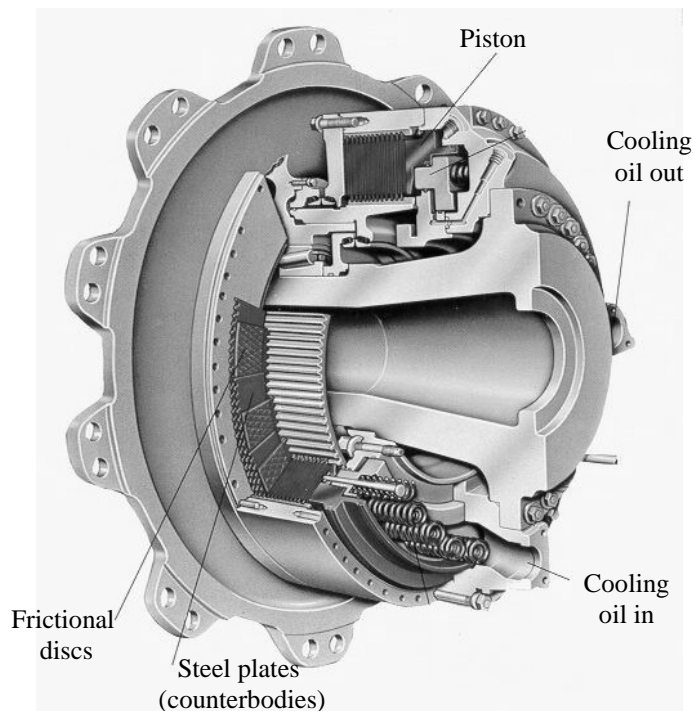


Fig. 1. General view of multidisc oil-cooled brake “Caterpillar”

Rys. 1. Ogólny widok wielotarczowego chłodzonego olejem hamulca «Caterpillar»

The objective of the present paper is to study some regularities of frictional interaction between composite materials and metal counterbody during lubricated friction proceeding from the data obtained for hydro-mechanical transmissions (HMT) and multidisc oil-cooled brakes (MOB) of vehicles.

DISCUSSION AND INVESTIGATION RESULTS

Judging by the data presented in the **Table 1**, five classes of materials have been employed in MFD on the main by the present time, namely: metal-ceramic, molded composites with organic matrix, carbon, sheet (frictional paper) and metallic frictional coatings [L. 2]. There is a great variety of formulations for FM inside each class of materials developed with respect to certain requirements and operation conditions. Thermal regime during friction pair operation is the main criterion for selecting

one or another class of FM for dry service conditions [L. 3]. This, however, is not a governing parameter for the FM intended for operation in oil since the service temperature of such materials is limited by that of thermal stability of the oil. Wear of the bodies found in frictional interaction is not a crucial parameter either because friction in oil does not lead to intensive wearing of the rubbing surfaces. The efficiency of oil-cooled friction joints is largely determined by the material structure, friction surface geometry [L. 4], as well as lubricant grade, its rheological characteristics and oil circulation velocity through the volume bounding the multidisc friction pairs. Named properties of lubricating materials impose a considerable effect on the sintered, sintered in dispersion, molybdenum, carbon materials and frictional paper. Less sensitive to oil properties and heat removal intensity from the friction zone are cermet materials based on iron and molded FM with a polymer matrix [L. 2].

Table 1. Triboengineering characteristics of frictional materials intended for operation in oil

Tabela 1. Właściwości tribologiczne materiałów ciernych przeznaczonych do pracy w środowisku smarnym (olejowym)

Type of frictional material	Triboengineering characteristics		
	Friction coefficient		Specific friction energy MJ/m ²
	μ_{dyn}	μ_{stat}	
FM with organic matrix reinforced with carbon and graphite fibers	0.10–0.16	0.08–0.14	0.90–1.76
Asbestos-free FM reinforced by cellulose and Kevlar fibers	0.10–0.15	0.12–0.16	0.45–0.60
Asbestos-free FM with organic matrix and graphite filler	0.08–0.11	0.09–0.12	0.3–2.5
Molybdenum frictional linings	0.08–0.12	0.08–0.14	1.0–2.6
Multilayered carbon FM	0.10–0.12	0.10–0.12	0.46–2.0
Basalt-filled FM with polymer matrix	0.11–0.14	0.12–0.16	0.9–1.9
Sheet (paper) FM:			
– carbon-filled	0.11–0.14	0.15–0.19	2.1–2.5
– elastic	0.11–0.14	0.16–0.20	1.6–2.5
– filled with Kevlar fibers	0.11–0.15	0.15–0.18	1.0–2.1
Bronze-based cermet	0.075–0.123	0.08–0.14	0.94–1.14
Sintered in dispersion FM (with a brass-bronze base)	0.09–0.12	0.10–0.14	0.94–2.0
Iron-based cermet	0.05–0.14	0.09–0.18	2.15–2.40

Vast experience in application and maintenance of cermet friction parts has been gained in transport and engineering industries. Benefits of these materials consist in high specific friction power, thermal conductivity and wear resistance at elevated unit work of friction. Specific friction power of cermet FM based on iron and designed for operation in oil is about 0.9–4.0 MWt/m², limiting sliding velocity is up to 80 m/s. Novel copper–graphite materials provide for a high efficiency of frictional interaction at specific friction power till 6 MWt/m². Their unit work of friction reaches 8.5 MJ/m² at braking [L. 5]. For comparison, the recommended specific friction power of the frictional paper materials makes up 0.85 till 1.5 MWt/m², that of graphite-based materials is 0.5–1.5 MWt/m² at the maximal effective sliding velocity 30–42 m/s. It should be noted that cermet FM show a significant drawback at operation in oil, that is, they do not provide a stable friction torque and smoothness of engagement of the friction units, impairing thereby the dynamics of transfer processes in machinery. An adverse factor is elevated vibroacoustic activity of these materials. Noticeable noise in transmission and brake units is hard to combat, so it often worsens the subjective perception of machine's quality [L. 6, 7].

The materials with improved damping properties, e.g. FM with a polymer matrix, contribute to elimination of above-named drawbacks. In this connection, the main task is to create a high-strength heat-resistant polymer structure in FM able to ensure liquid or boundary friction regime with the least difference between the static and dynamic friction coefficients of the solids independently of the lubricant viscosity. The authors of [L. 8] describe newly developed porous anisotropic FM that reduce the probability of rupture of the oil film on the contact surface and transfer to dry friction.

FM exerts an effect on the friction coefficient value via the plastic deformation process of microasperities and dynamic squeezing of the lubricating layers from the friction zone under a normal or tangential load applied, which means that the higher the tangential shift in a tribosystem before sliding onset, the closer the values of the dynamic and static friction coefficients. The mechanism of impact load emergence during friction of the rigid and high-modular materials consists in the reduction of tangential shift of the friction discs reached prior to or at the final stage of sliding under simultaneously applied normal and tangential load to the friction pair, which results in a leap of the sliding friction force [L. 9].

A proof to the deformation processes occurring at the friction surface microrelief can be the reduced roughness of the friction surface observed on the metal counterbody discs of vehicle MFD. Roughness R_a of metallic discs has reduced 8 to 10 times (**Fig. 2**) after two thousand cycles of braking on a test bench for the brakes at running in mineral oil (SAE 15 W40) with a unit work of friction 0.9 MJ/m^2 .

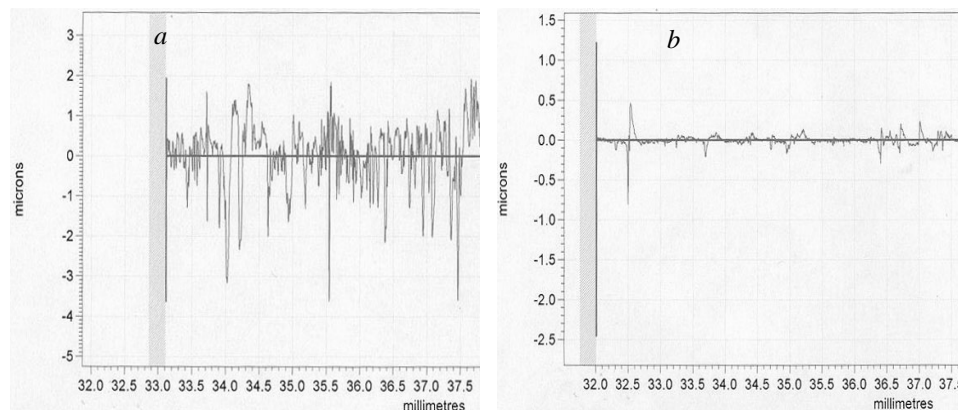


Fig. 2. Roughness of metallic counterbody disc: *a* – initial: $R_a = 0.5600 \mu\text{m}$, $R_z = 4.1722 \mu\text{m}$; *b* – after 2000 braking cycles on the bench, $R_a = 0.0624 \mu\text{m}$, $R_z = 0.4085 \mu\text{m}$

Rys. 2. Chropowatość metalowej tarczy przeciwtrącej: *a* – początkowa: $R_a = 0,5600 \mu\text{m}$, $R_z = 4,1722 \mu\text{m}$; *b* – po 2000 cykli hamowania: $R_a = 0,0624 \mu\text{m}$, $R_z = 0,4085 \mu\text{m}$

It follows from the photos presented in **Fig. 3** that the structure of the contact surface of frictional materials during rubbing without lubrication and at friction in oil (M10G2, State standard 8581–78) differ drastically, consequently wear mechanisms of FM differ as well. Abrasive wearing of FM characteristic for dry friction (**Fig. 3a**) converts into other wear modes. For instance, either erosive (**Fig. 3b**) or combined erosion–cavitation wearing may occur under liquid friction in MFD. This is because just as abrasive wear debris so vapor bubbles and dissolved gases are present in the lubricant, which are formed as a result of quick motion of the solid discs in the liquid medium. A stable polymolecular layer of the lubricant is absorbed on the friction surface of oil-cooled parts. The oil film is retained on the friction surface owing to the microporous structure and strong initial roughness of the friction surface (**Fig. 2a**). Reduced

cooling action of the oil as a result of rupture of the oil film may result in the appearance of dry friction areas and, as a consequence, intensified heat generation. The numerical simulation results of temperature fields on the friction surface of a MOB brake disc of “Belarus” tractor for the cases of oil film rupture are presented in **Fig. 4**. It was presumed in calculations that the energy dissipated by the braking system friction pair in a tractor of 156 kWt power was 350 kJ at braking time 3.5 s. The maximum value of 700 K the friction temperature reaches after the first second of braking, at which the temperature maximum zone localizes in the peripheral region of the brake disc widthwise. Surface temperatures in this case surpass those of oil thermal stability and are close to the temperature of structural transformations of the metal discs (counterbodies). The friction temperature becomes a critical factor that governs the efficiency and durability of the friction joint. The authors have observed fading of MOB due to formation of the plastic insoluble in oil resinous products (a mixture of aromatic hydrocarbons and olefins) in the adsorbed boundary layers during thermal destruction of the mineral oil. These processes are known to originate from oil heating above 623 K [L. 10]. The data obtained proves that being by their nature aromatic hydrocarbons, these products can be formed as a result of destruction of the matrix polymer, i.e. phenol formaldehyde resin, and their content may reach 30% of the resin mass in the initial FM [L. 11]. Nonetheless, studies of structural transformations in the counterbody material made of steel 65G (State Standard 14959–79) have shown that the initial structure of the steel (troostite–sorbite) has changed at a high–temperature friction with formation of a grainy structure similar to that of the secondary sorbite formed at the hardened steel heating above 800 K. For the metallic discs, the counterbody and friction disc microhardness was found to be independent through the disc thickness to a depth surpassing the heat–generating layer. Besides, statistically significant microhardness reduction was observed for the friction pair materials, while the discs with the molded–on FM underwent the strongest weakening. Proceeding from the above, we can make a conclusion on the effect of heat–generation conditions and heat transfer in the friction pair on variations in the microstructure and properties of the rubbing materials. Wear resistance of steel after a high–temperature tempering drops by 16–20% and the counterbody material becomes more prone to temperature–induced deformations.

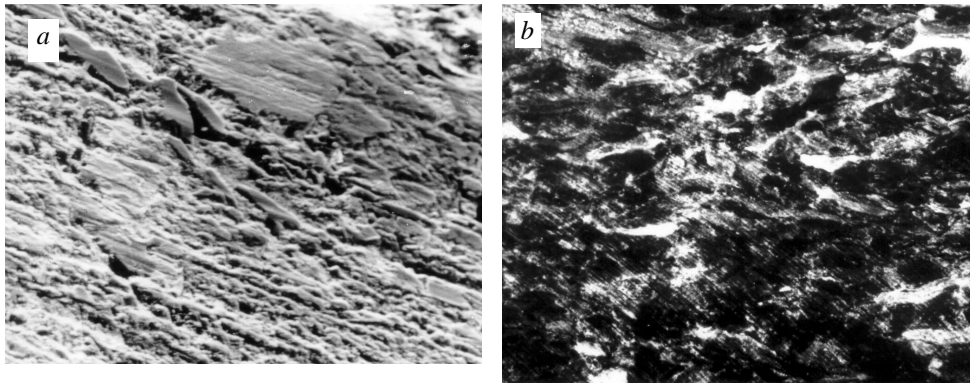


Fig. 3. SEM images of FM friction surface after abrasive (a) and erosive (b) wearing (x500)

Rys. 3. REM – zmiany powierzchni trących materiałów po abrazyjnym (a) i erozyjnym (b) zużyciu (x500)

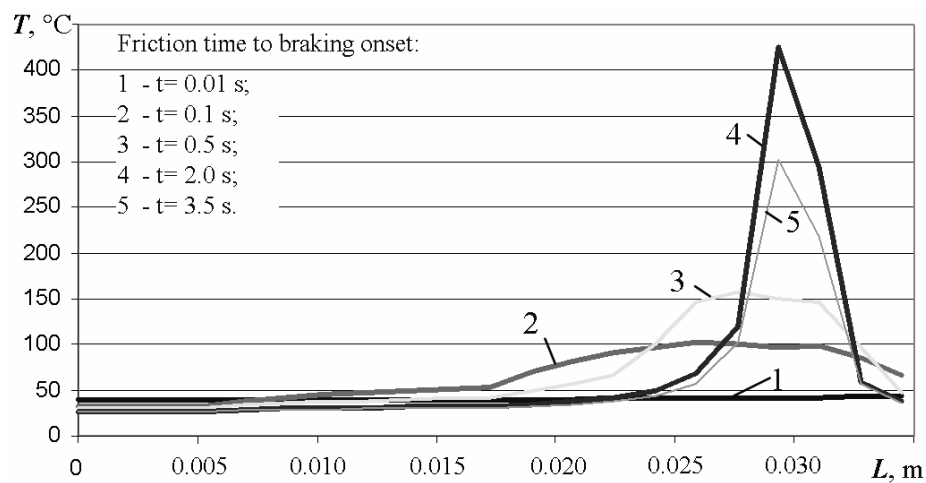


Fig. 4. Radial temperature distribution widthwise of the friction lining (L) for different braking time (t) at dry friction. Total braking time – 3.5 s

Rys. 4. Rozkład promieniowy temperatur na szerokości ścieranej nakładki (L) dla różnych czasów hamowania (t) podczas tarcia bez smarowania, łączny czas hamowania 3,5 s

CONCLUSIONS

In spite of the reduction of the mean specific friction force value in the multidisc frictional devices, friction-induced heat generation in the friction pairs depends much on the presence of a sustained oil film and the

intensity of heat exchange on the friction contact. Thermal deformations in the metal discs and chemical conversions in the matrix polymer and lubricating material result from elevated heat generation after oil film rupture leading to the reduction of friction torque and, as a consequence, to loss of the efficiency of MFD. When the lubricant is present in the contact zone, structure of FM and the friction surface geometry become critical factors for ensuring the efficiency of MFD. Wear mechanisms of the solids found in frictional interaction with and without lubrication were found to differ essentially.

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Streszczenie

Przeprowadzono analizę procesów tarcia materiałów ciernych pracujących w środowisku smarnym, przedstawiono rezultaty badań podstawowych oraz praktycznych opracowań materiałów ciernych przeznaczonych do pracy w środowisku smarnym, przeprowadzono analizę mechanizmu zużycia materiałów ciernych z matrycą polimerową.