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The study of the surface fracture during wear of C/C fiber composites by SPM and SEM

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Abstract

Composite materials based on a carbon fiber and a carbon matrix (C/C composites) are widely used in brake systems and other friction units with high loads and temperatures on the friction surface. The variety of structure and properties of the components of carbon composites causes different wear mechanisms during friction of these materials. The paper is considered samples of carbon friction composites of various structures and compositions used in aircraft brakes. These materials demonstrate numerous mechanisms of surface destruction during wear, often even for the same sample, due to the significant heterogeneity of the composite structure. The determination of these mechanisms and their parameters is an important part of the study of carbon composites. For these purposes, combination of scanning probe microscopy (SPM) and scanning electron microscopy (SEM) can be used.

Keywords: Type your keywords here, separated by semicolons ;

The study of carbon composite friction surface by SEM methods allows determining the area of friction, identifying regions with different structures of the material and estimating its areas. Thus, we get a map of the friction surface, on which regions with different mechanisms of surface destruction during friction are indicated. The selected regions can be investigated by SPM methods to obtain a detailed structure of the friction surface and determine its profile at the micro level. This specifies the wear mechanism in each region, and allows estimating parameters of the wear process.

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This paper considers three types of material with different structure and wear resistance. The first type is a two-dimensionally randomly reinforced composite based on carbonized fibers and carbon matrix with a density of at least 1.82 g / cm3 synthesized from coke-coal tar pitch. The second type is a woven 3D-stitched carbon-carbon material with a coarse-laminar pyrocarbon matrix with a density of at least 1.79 g / cm3. The third type differs from the first one exclusively by the use of graphite fibers as a reinforcing element. The studied materials were preliminarily tested on an inertial friction test machine in the form of full-size brake discs, with loads equal to the operating conditions of the TU-204 aircraft wheels. The value of linear wear for the first material was about 2-3 microns per one braking at operational and forced braking modes, respectively. The value of linear wear of the second material was 0.8-1 microns per one braking. The value of linear wear of the third material was 0.8-1 microns.

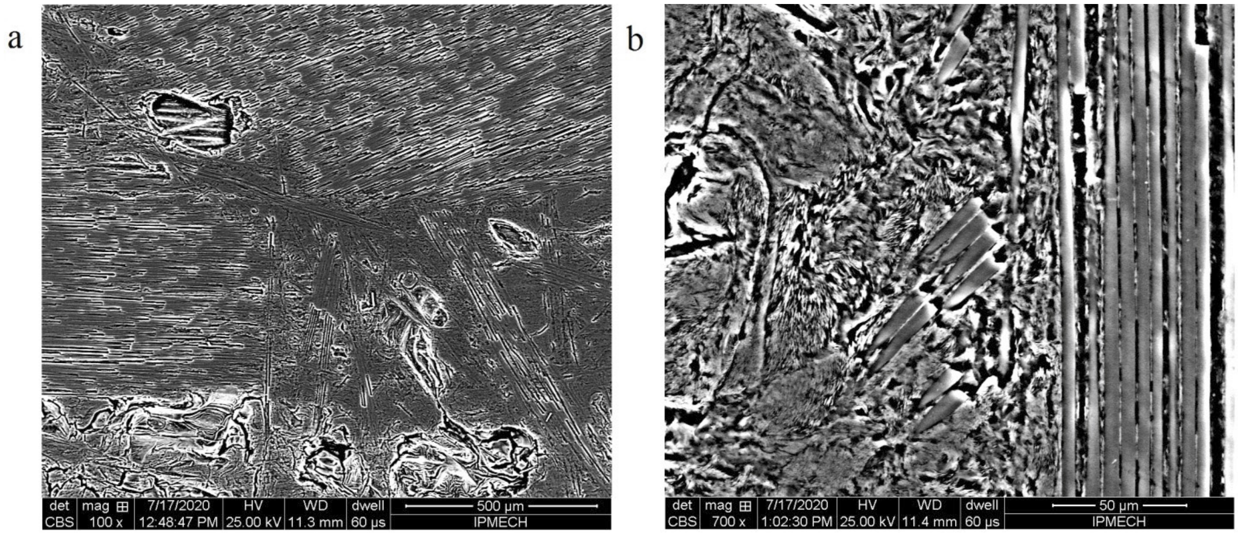

Fig. 1. Friction surface of C/C composite based on carbonized fibers and pitch matrix, SEM images.

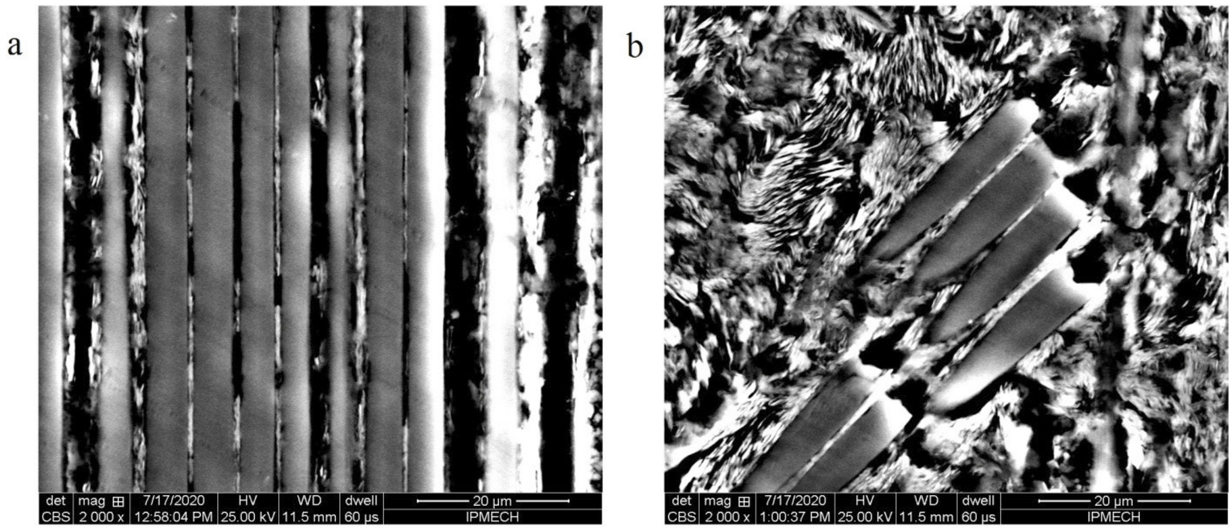

Fig. 2. Friction surface of C/C composite based on carbonized fibers and pitch matrix, SEM images.

The theory of composite materials wear, in general, suggests two main mechanisms of wear: uniform abrasive wear and wear with destruction of the wear surface and crushing of material components. The first mechanism was investigated in [Khruschov M.M., 1974; Goryacheva I.G., Torskaya E.V., 1992]. It assumes an equal wear rate of the composite material components. This mechanism is clearly visible, for example, in material of the first type material (based on carbonized fibers synthesized from polyacrylonitrile and combined in bundles and coke matrix synthesized from coal tar pitch). Fig. 1 and 2 show SEM images of the friction surface of such a material.

One can observe fiber bundles parallel to the friction surface (fig. 2a), matrix regions and small groups of fibers surrounded by matrix (fig 2b).

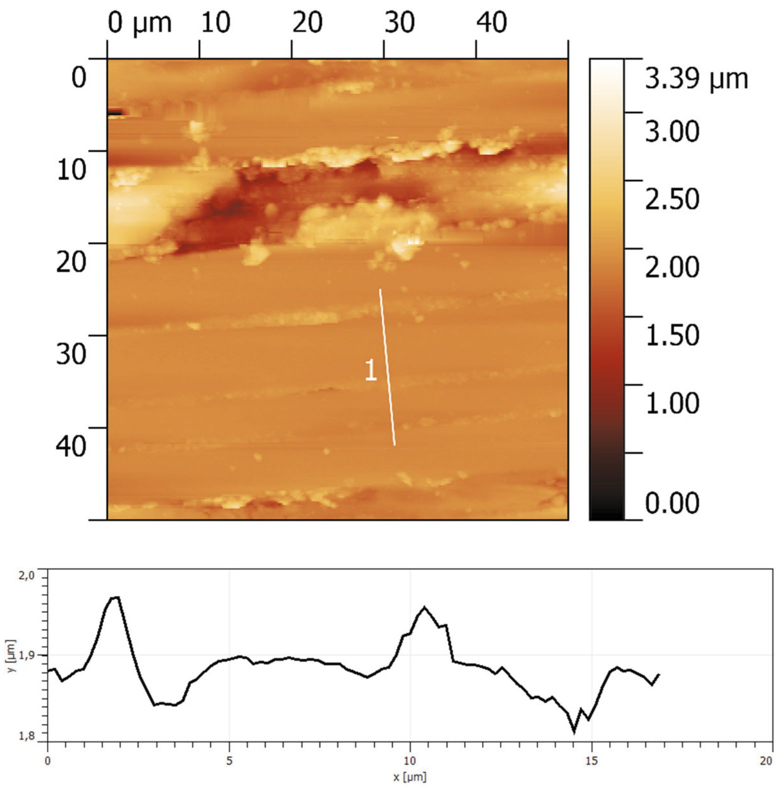

Fig. 3. Friction surface of a carbon composite based on carbonized fiber and a pitch matrix in the area of a fiber bundle, SPM-image and profile.

Fig. 3 shows the SPM image of the area of fiber bundle that lies parallel to the friction surface. The profilogram shows an almost flat surface with slight protrusions of the interfiber structure. This is typical for the case of a close wear rate of the composite components. Matrix inside fiber bundle is denser and harder than outside of bundles and demonstrates high wear resistance, equal to that one of the fibers. The maximum difference in profile heights fluctuates around 0.2 microns.

If the wear resistance of the components differs significantly, a developed relief may occur on the surface. Fig. 4 shows the surface of this composite near a single group of fibers in the matrix massive in the inter-bundle volume. Profilogram shows that more wear resistant fibers tower over less wear resistant matrix. As a result, the maximum difference in profile heights can be up to 2 microns. Based on the profile maps in fig. 3 and 4, it can be assumed that the wear resistance of the interbundle matrix of the composite is very low and it is it that is responsible for the main wear of this material.

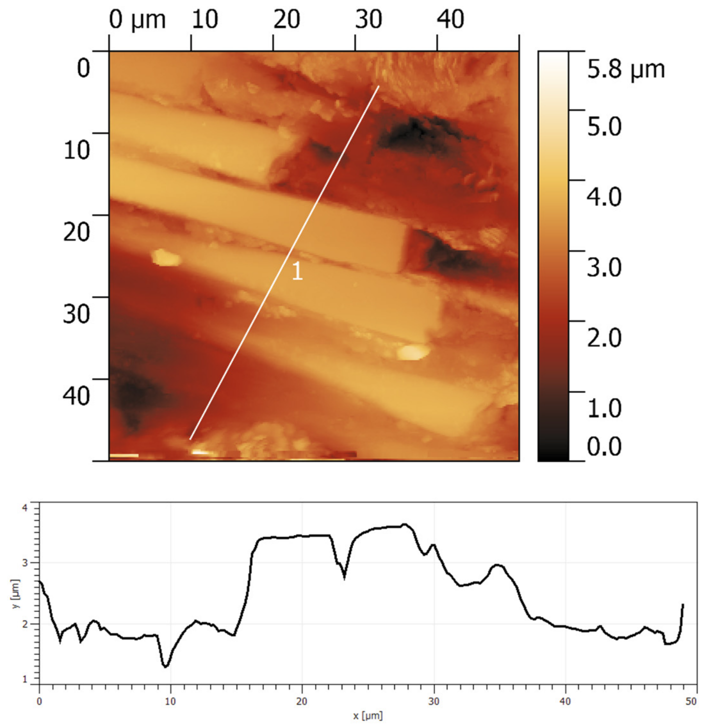

Fig. 4. Friction surface of a carbon composite based on carbonized fiber and a pitch matrix in the area of the matrix reinforced by individual fibers, SPM-image and profile.

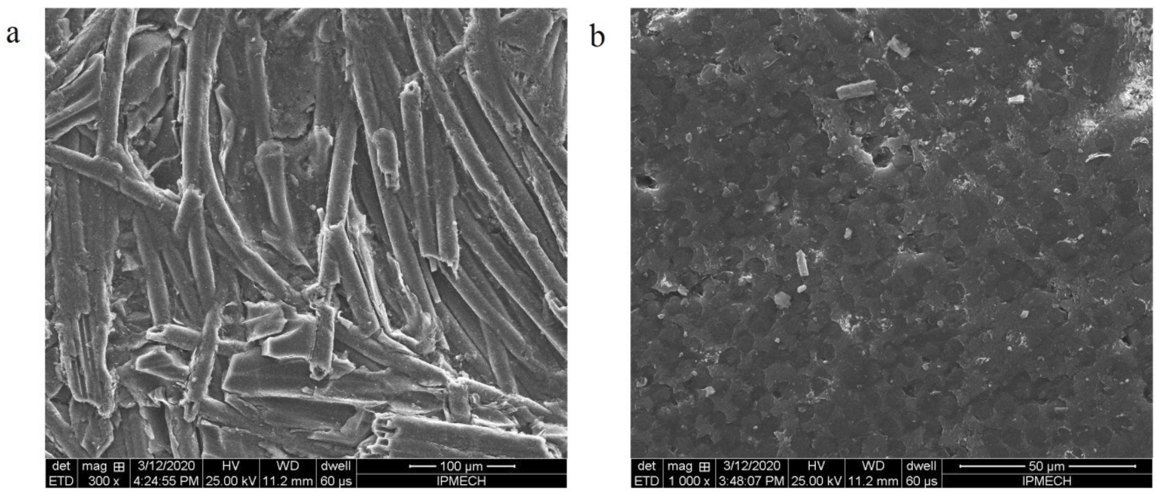

Fig. 5. Friction surface of composite based on carbonized fibers and a gas-phase matrix, SEM images.

Wear with surface destruction is a much more complex mechanism that is responsible for most of the wear volume of carbon composites under heavy loading conditions. A feature of this mechanism is the dependence of the wear processes and the elastically deformed state of the surface layers on the configuration of reinforcing inclusions, the direction of occurrence of fibers in fibrous composites, and many other factors. In carbon composites, almost all known scenarios for the destruction of the surface of composite materials are possible. Fig. 5 and 6 show the surface of the second material (composite based on carbonized fibers and coarse-laminar pyrocarbon matrix). Here you can see areas of randomly reinforced matrix (fig. 5a), fibers lying parallel to the friction surfaces in bundles (fig. 6a) and fibers perpendicular to the friction surfaces (z-fibers, fig. 5b, 6b).

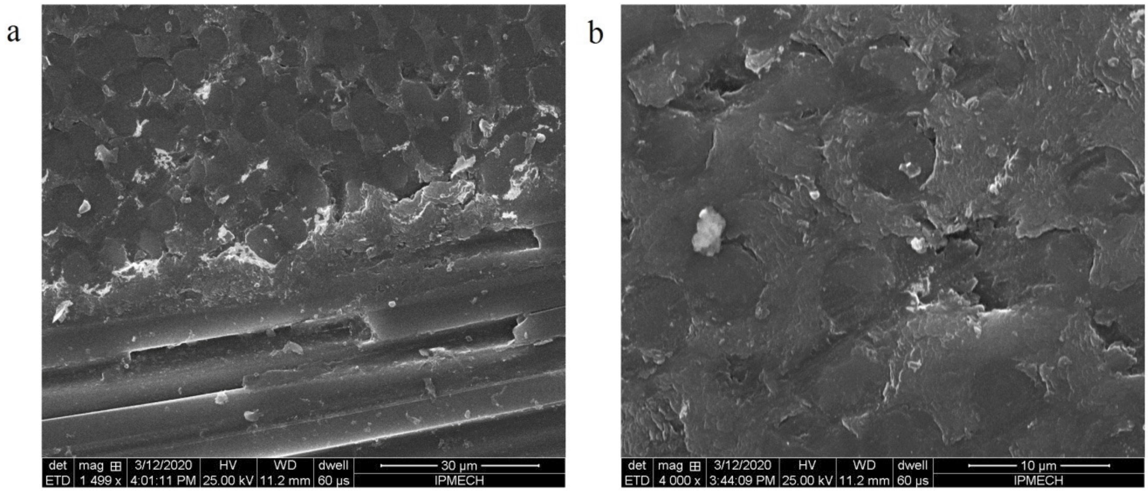

Fig. 6. Friction surface of composite based on carbonized fibers and a gas-phase matrix, SEM images.

Fig. 7 demonstrates the process of fiber spalling during wear in the case of their parallel arrangement relative to the friction surface [Gun Y. Lee, Dharan C.K.H., Ritchie R.O., 2002, Zum-Gahr K.H., 1985]. Fig. 8 shows the surface of the same material in the region of fibers perpendicular to the friction surface (z-fibers).

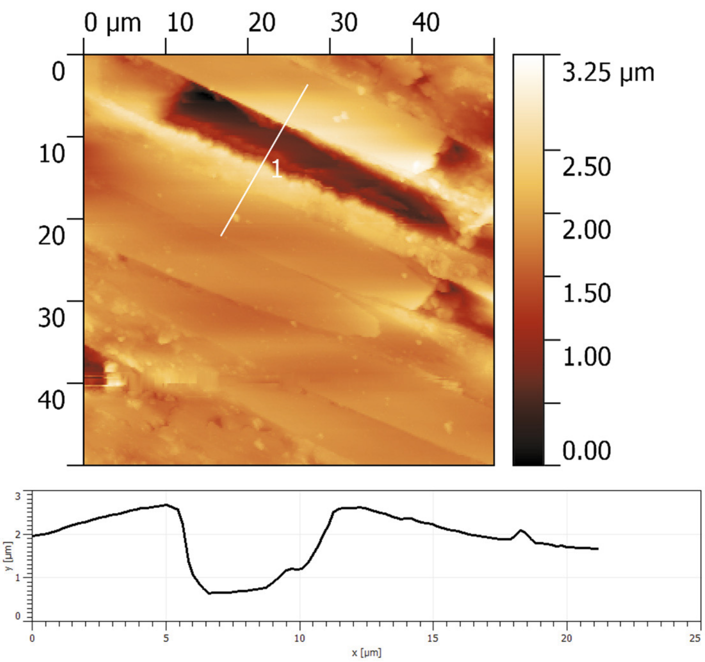

Fig. 7. Friction surface of a carbon composite based on carbonized fibers and a gas-phase matrix in the area of fibers parallel to the friction surface, SPM-image and profile.

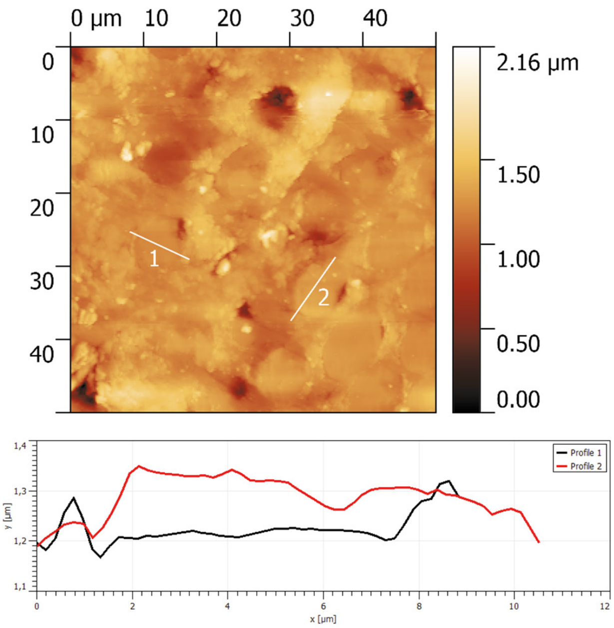

Fig. 8. Friction surface of a carbon composite based on carbonized fibers and a gas-phase matrix in the area of fibers perpendicular to the friction surface, SPM-image and profile.

Here the process of breaking off of the fiber tips that tower up above the surface of the matrix is demonstrated [Yen B., Dharan C.K.H., 1996; Shpenev A.G., 2018]. After breaking off the fiber tip, it begins to tower above the matrix surface again, that makes this process cyclic. On the profilogram, both fibers rising above the matrix and fibers recessed beneath the friction surface are visible, as a result of fiber tips breaking off.

In this case, despite the fact that the wear mechanisms of the second material demonstrate the presence of significant destruction of the friction surface, its wear resistance is on average higher than that of the first material. This is a consequence of the lack of the soft inter-bundle matrix significant volumes in the second material, which is responsible for the main part of the first material wear.

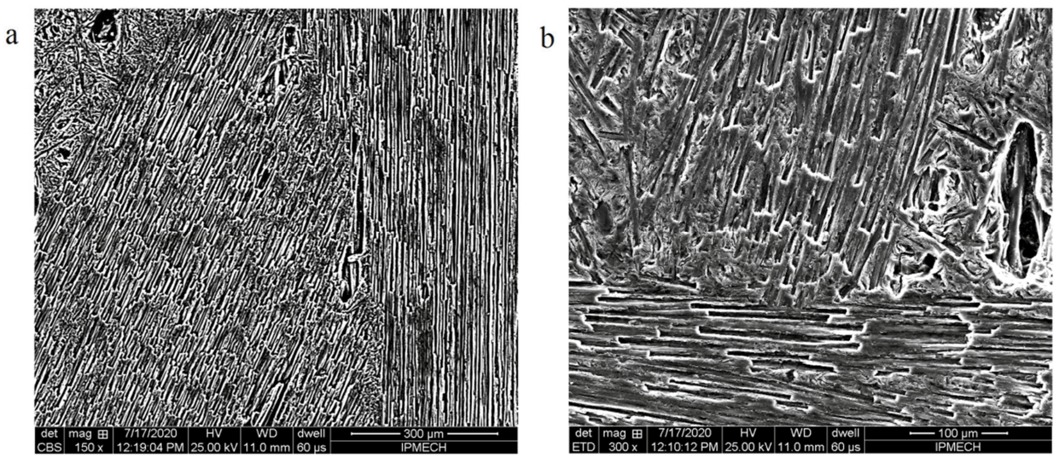

Fig. 9. Friction surface of C/C composite based on graphitized fibers and pitch matrix, SEM images.

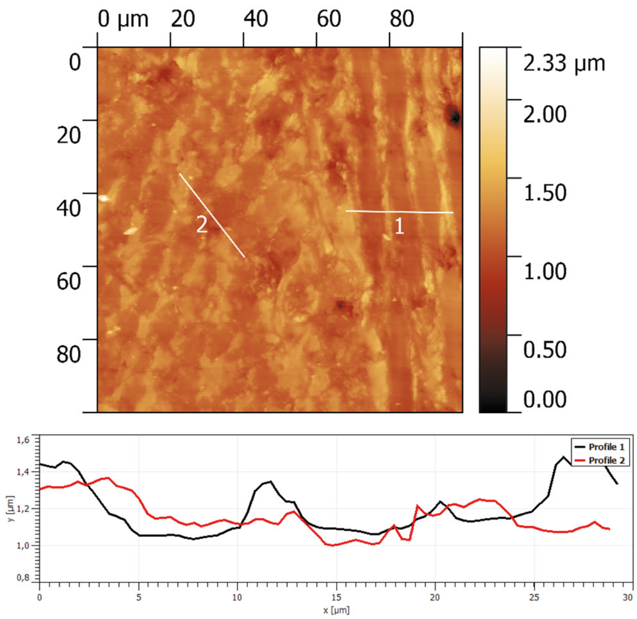

Fig. 10. Friction surface of a carbon composite based on graphitized fiber and a pitch matrix in the area of the matrix reinforced by short fibers and fiber bundle, SPM-image and profile

Fig. 9 shows the surface of the third composite (material based on graphite fiber and pitch matrix). The images show bundles of fibers and an inter-bundle matrix, randomly reinforced with short fragments of graphite fiber. Profile maps of the third material are shown in fig. 10. Based on the profile maps, it can be concluded that as a result of friction, this material has a small height difference both in the fiber bundle and in the interbundle matrix reinforced with short fibers. This leads to the absence of high wear in the inter-bundle space and thus high wear resistance of the material as a whole (in contrast to the first composite).

The methodology for studying the friction surface of carbon composites obtained in the paper allows one to identify various wear mechanisms of these materials and give qualitative and quantitative characteristics to these processes. This is extremely important in the design and manufacture of new friction composites, as it allows more reasonable work on increasing their wear resistance.

Acknowledgements

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