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THE MECHANISM OF WEAR PROCESS OF THE POLYMERS USED IN SHIPBUILDING STRENGTHENED BY UNIDIRECTIONAL CARBONACEOUS FIBRES

МЕХАНИЗМ ИЗНАШИВАНИЯ ИСПОЛЬЗУЕМЫХ В СУДОСТРОЕНИИ ПОЛИМЕРОВ, УКРЕПЛЕННЫХ ОДНОНАПРАВЛЕННЫМИ УГЛЕРОДИСТЫМИ ВОЛОКНАМИ

The paper presents an analysis of the research results used in shipbuilding in various environments bearings made of reinforced carbon composites. The data of microscopic carbon fiber research and tribological tests bearings conducted under different loading conditions are presented. The impact of the matrix and the fibers on the wear mechanism of composites reinforced with unidirectional carbon fibers oriented is discussed.

Представлен анализ результатов исследований, используемых в судостроении в различных средах подшипников скольжения из армированных углепластиков. Приведены данные микроскопических исследований углепластиков, а также трибологических испытаний подшипников, проведенных при различных условиях нагружения. Обсуждалось влияние матрицы и волокон на механизм изнашивания композитов, армированных однонаправленными ориентированными углеродными волокнами.

Key words: mechanism of wear, carbon plastic, plain bearing, shipbuilding.

Ключевые слова: механизм изнашивания, углепластик, подшипник скольжения, судостроение.

1. Introduction.

Nowadays polymers have been recognized in every area of life [1, c. 240–244; 2, c. 805–816; 3–5]. Also the increasing application in technical solutions such as sliding bearings [6, p. 45–53; 7, c. 245–251; 8, c. 55–56; 9, c. 335–339] was noticed, though friction and wear of polymers is a very complex process, still not to be fully explored. The more, process of friction and wear of carbon (glass, aramide) fiber reinforced polymer is more complicated. In this case we have with at least two materials, which properties and their participation in the friction work, influence on the final wear of the composite.

Many experimental works on behavior of friction couples such as polymer composite-metal operating at different conditions have been published in recent years [10; 11]. Nowadays the mechanism that would describe the process of friction and wear of polymers and their composites was not clearly mentioned, though of course in the literature can be found fairly broad description of subject [8; 9; 12–14].

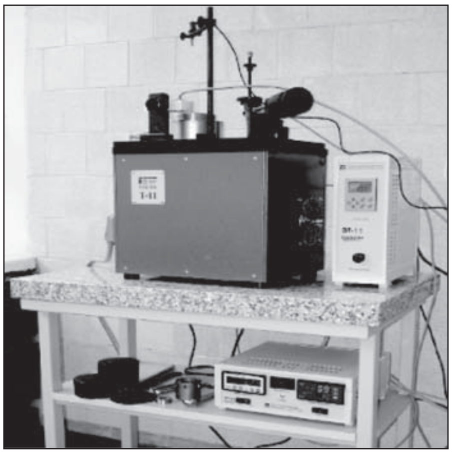

Fig 1. Tribotester T-11

Therefore, it is necessary to carry out further researches for pairs such metal-polymer composite, in order to analyze individual influence of composite components on these processes and total material wear.

In paper the results of experimental studies of frictional pairs, constructed as follows: the sample is made up from polymer composites reinforced with carbon fibers set perpendicular to the friction surface (and friction direction), and a counter bearing steel 100Cr6, were presented.

The researches were conducted in three environments: air, water and oil SAE 15W/40, under variable load and constant sliding velocity. The paper presents the results of experimental researches separately for components of both composites, to determine their effect on the overall intensity of wear of each mentioned CFRP. An analysis of the composites' wear process and behavior of carbon fibers and the matrix in the friction process was also discussed.

2. Methodology.

The experimental researches were carried out for tribological friction couples composed of the following materials:

— PEEK CF30 — (polyetheretherketone) composites reinforced with 30 % carbon fiber, from which samples were made;

— PA66 CF30 – polyamide-based composite 6.6, a reinforced carbon fiber 30 %, from which samples were made;

— 100Cr6 — bearing steel, from which counter sample was prepared.

Both reinforced composites were strengthened with the same carbon fiber, with a diameter equal 7.2 [μm].

The researches were done using tribo-tester T-11 (fig. 1), where pin-on-disk scheme during sliding friction was implemented.

Experimental studies were carried out under the following conditions:

— the range of the contact pressure is 2.8÷13.5 [MPa];

— test runs were carried out in three environments: air, water, oil SAE 15W/40;

— constant sliding velocity 1 [m/s];

— time of test — 2 [h].

The parameters measured directly during experimental tests were: temperature measured close frictional contact area, linear wear of samples (the linear dimension of the pin), friction force. Polymer samples were subjected to reaching pre-test before general test under a load of 0.2 [MPa] at the time 600 [s].

In order to receive a qualitative analysis of the surface, microscopy researches were performed using a scanning electron microscope Hitachi S-3000 N. The surface layer composites researches was done, using an atomic force microscope, the application of microscope is increasingly being used to evaluate the structure of materials and their wear mechanism [15; 16, s. 92–101]. The quality of the used materials has been verified on the basis of the documents received and owner checkups.

3. Results and analysis.

a) Tribological researches

As a result of experimental researches, following parameters were receive: friction force, wear and temperature measured near contact area in function of the contact pressure.

Additionally, sample' mass wear was measured to verify the linear wear.

The average values of wear intensity as a function of unit pressure, were presented as graphs above (fig. 2, *a*, *b*). The values of friction coefficient and temperature due to the limited space of paper was not presented here, but it's available in [17].

On the base of tribological researches, it could be claim that the process of friction of considered couples is not stable during entire load range. Indicates on it, the values of all parameters obtained during the study. And particular example of this variation is mass intensity of samples in all environments.

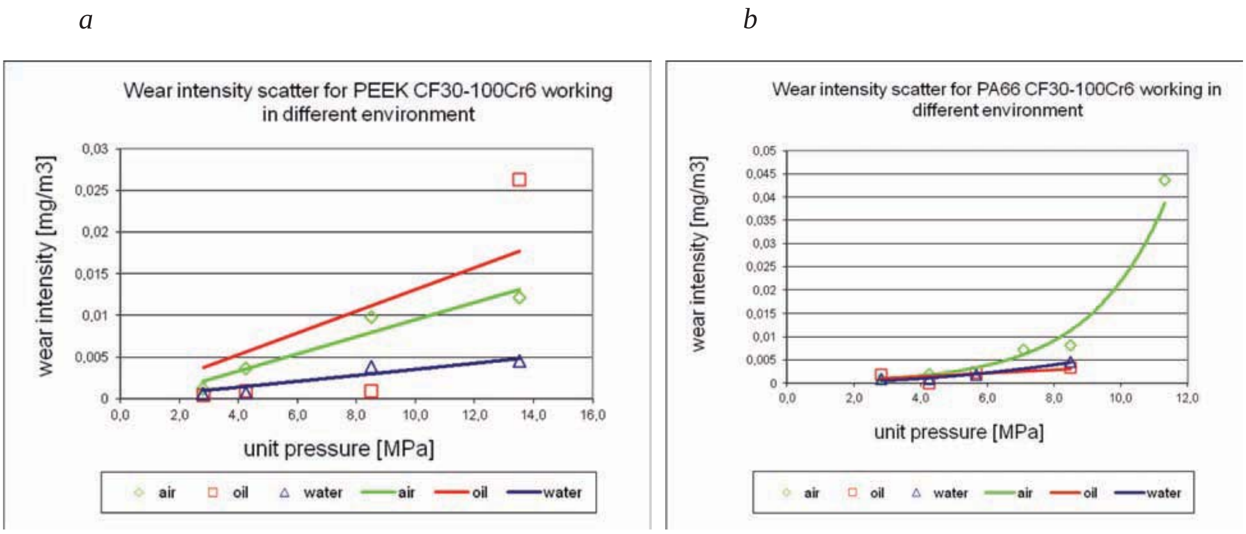

Fig. 2. Wear intensity scatter of PEEK CA30-100Cr (*a*) and PA66 CF30-100Cr6 (*b*) in three environments: as a function of unit contact pressure

— The values of friction coefficient of couples both composites working in the water and oil are very similar throughout the load range. Scattering of friction coefficient' values of couples worked in the air is significantly different. Those values are much higher, which is caused by lack of lubricant between working surfaces. Lack of lubricant allows to create better conditions that are needed for creation of an adhesion between the sample and the layer of polymer applied on the surface of the metal sample (visible track on counter sample) [16].

— Temperature values for friction pairs working in air environment definitely exceed the values of temperature pairs working in water and oil, especially in the final load range. Naturally, it is caused by much less leading off heat from contact area.

— Range of wear intensity of polymer composite samples is fundamentally different in the final load range above the unit pressure 8 [MPa]. In this case, author's observed rapid increase of PA66-CF30 samples wear, which were working in the air. It can be concluded that under those conditions, matrix PA66 is definitely weaker as a material than the matrix PEEK and is rapidly destroyed (deformed) because of high temperature.

b) Microscoping researches

In order to verify the character of polymer composites' wear, both: microscopic researches of polymer samples and determination of their chemical composition, were executed. The initial microscopic researches indicate that the sample made on base of polymer have the following structure: the carbon fibers are aligned perpendicular to the friction surface, along the axis of samples (cylinders) and are surrounded by a polymer matrix (fig. 3).

Examples of the microscopic researches' results were presented in [17].

Analyzing the obtained microscoping photos and chemical compositions of the samples working in three environments, the following conclusions could be presented. The dominant mechanical wear (abrasive wear) can be observed during friction in dry environment (in the air). The oxygen content in the surface layer of both composites is significantly lower comparing to the samples worked in water and oil.

A large number of different chemical elements occurred in the surface layer of composite samples working in oil and water, is a result of these samples

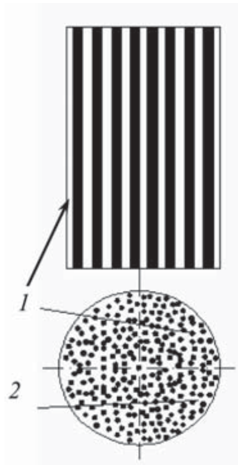

Fig. 3. Schematic structure of composite reinforced with carbon fibers, the fibers are set perpendicular to friction area and sliding direction: *1* — polymer matrix, *2* — carbon fibers

work in this special environments. The nature of friction process of samples, working especially in oil is particularly different. The secondary layers are clearly visible in structure of sample layers (elements oxides). Due to dominant mechanism of abrasive wear and small or lack of secondary layers observed in the surface layer of both composites (lack of additional components in the surface layer of the composite), in further part of paper, the authors focuses on samples' analysis, worked in air.

c) Tribological researches of composite' components

Therefore, the experimental researches were carried out of both composites' components and parameters of these work and corresponding parameters of composite, were compared below.

The results were presented in fig. 4.

a *b*

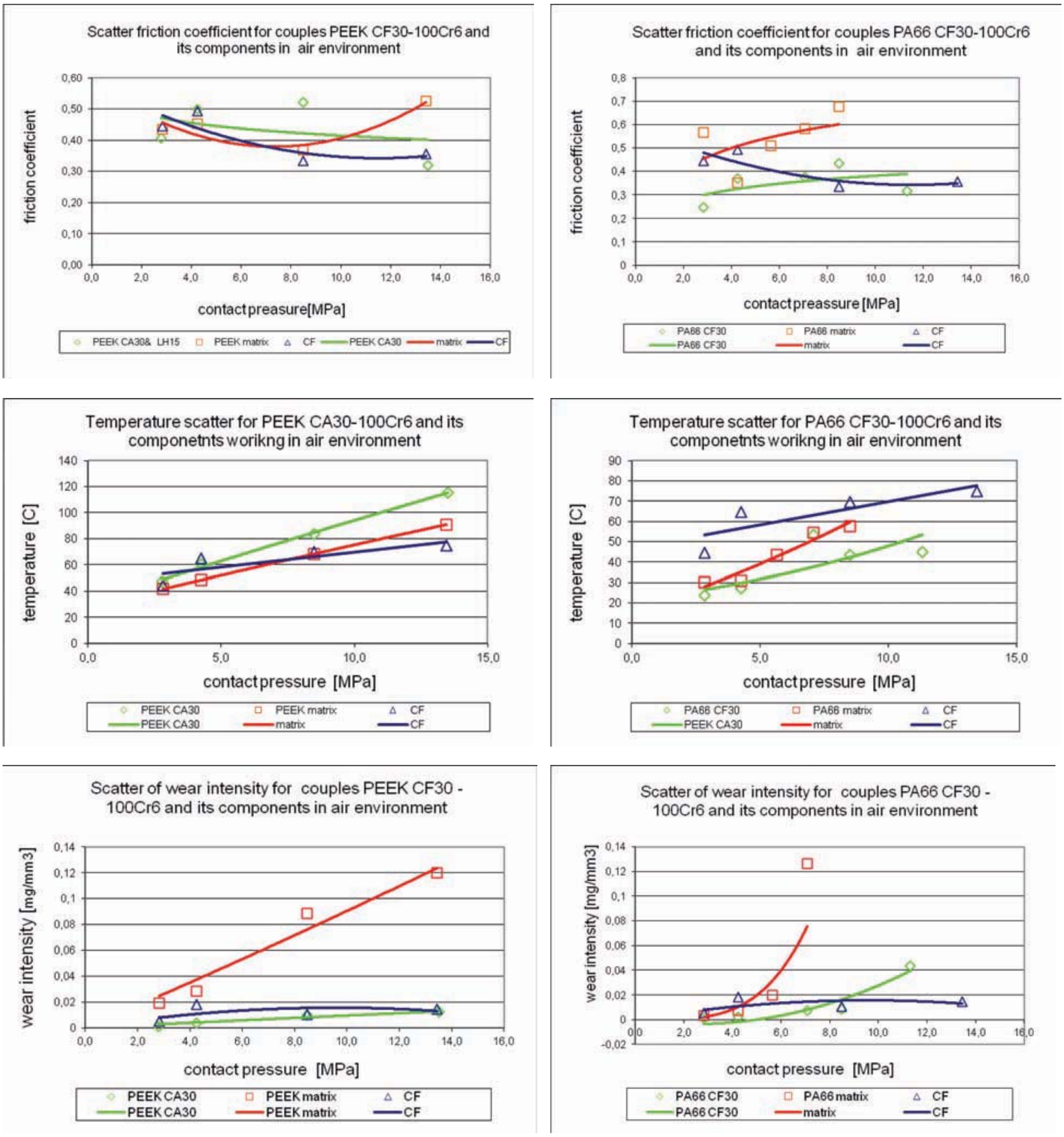

Fig. 4. Scatter of friction coefficient, temperature, and mass wear intensity as a function of unit pressure of PEEK CF30 (*a*) and PA66 CF30 (*b*) and their components, working in the air

Based on above researches the following conclusions were expressed:

— friction coefficient values of composite samples and samples made from components are similar in almost the entire range of loads. This statement concerns both tested composites;

— a similar relationship was observed in case of temperature measured near frictional contact throughout entire range of load;

— special attention should by paid for wear intensity of both composites and their components. The lowest wear intensity' values were obtained for the samples made from composite material for both PEEK CF30 and PA66 CF30. Scatter of wear intensity of samples made from the carbon fibers and composites are similar. Wear intensity of samples made from pure matrix is several times higher (which is confirmed in both composites). In order to verify the above comparative analysis, mass wear intensity was also checked, to confirm the above statement and the composite nature of the wear of its individual components.

Summing the tribological results indicate that the wear intensity of the composite depends significantly of the participation of both components during friction, their properties and their percentage in the surface layer of the working sample.

In the following part of paper, authors determine the effect of individual components of composite (percentage contribution influence of two components and matrix material influence) on the wear intensity of the composite.

d) Topography of the surface layer composites study

Below relationship of composite wear intensity from the percentage contribution of carbon fibers in the surface layer was presented. The percentage of the fibers was determined by counting of their surface area relative to the total surface of the sample.

The scan of PEEK CFx surfaces layer after friction in air environment, was done. Counting were made of the areas of carbon fibers and the matrix (fig. 5), taking into account whole sample surface, and then a following comparison was made: wear intensity of composite samples with obtained percentage contribution of carbon fibers in the whole surface.

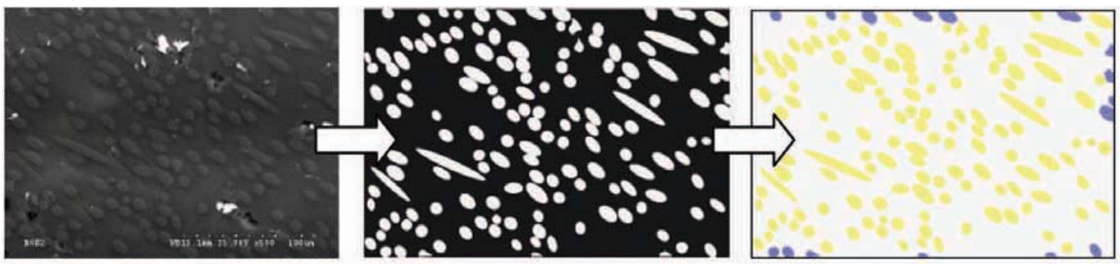

Fig. 5. Counting of carbon fibers in the surface layer of the composite (counting method)

Mass wear intensity of the composite samples of PEEK CF30 in relationship with percentage contribution of carbon fibers in the surface layer of the sample is shown in fig. 6.

Above relationship indicates that one of the key parameters affecting on friction process and total wear of composite is the percentage contribution of carbon fibers, which are involved in the work of both co-operating parts. The increase of carbon fibers contribution in the friction surface of the sample, follows by decrease of wear intensity of the composite sample.

— The second considered factor influence on wear intensity of composite was type of matrix and the effect of load on the surface topography of the composites samples. In order to analyze the topography scans of surface layers of both the polyether and polyamide were done.

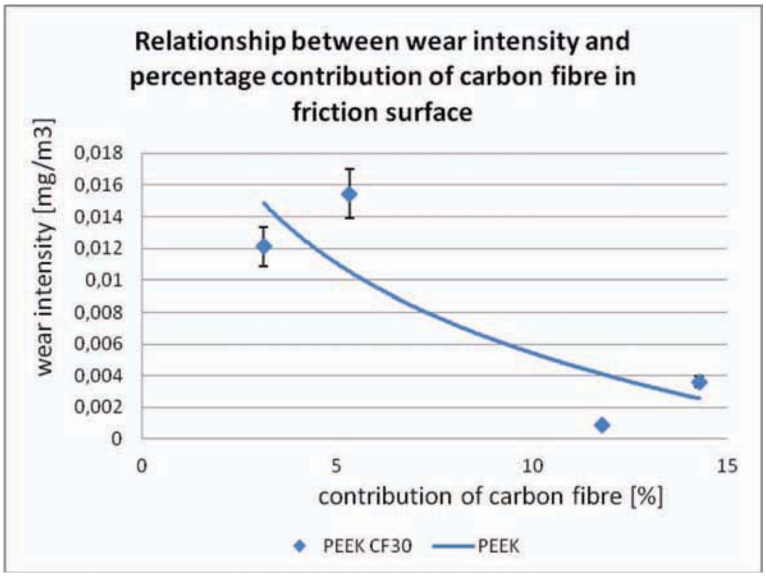

Fig. 6. Composite wear relationship with percentage contribution of carbon fibers in the surface layer of the composite

— Topography of the surface layer of both composites allowed for measurement of height of fibers compared to the surrounding matrix and the inclination of the face of the fibers during the friction to metal element (fig. 8). Through obtained researches, the relationship between fibers' height and angle depending on the combination of matrix (fig. 7) was established.

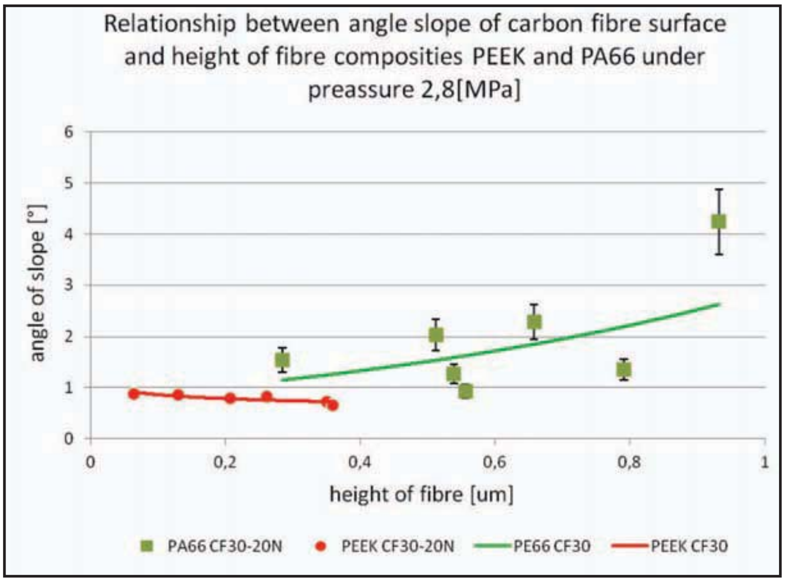

Fig. 7. Relationship between angle and height of fibers and the matrix used, under unit pressure equal 2.8 [MPa]

The relationship obtained from fig. 7 was determined by measuring the height and angle of the carbon fibers (fig. 8) in the surface layer of both composite samples which have worked in an air environment at the same unit pressure equal 2.8 [MPa]. The relationship indicates the significant role of used matrix used, its "behaviour" in the friction process with metal element, and thus influence on wear mechanism of composite. The spread of fiber samples PEEK CF30' height is much narrow (0.064÷0.359 microns) than in case of composite PA66 CF30 (0.2846÷0.932 microns).

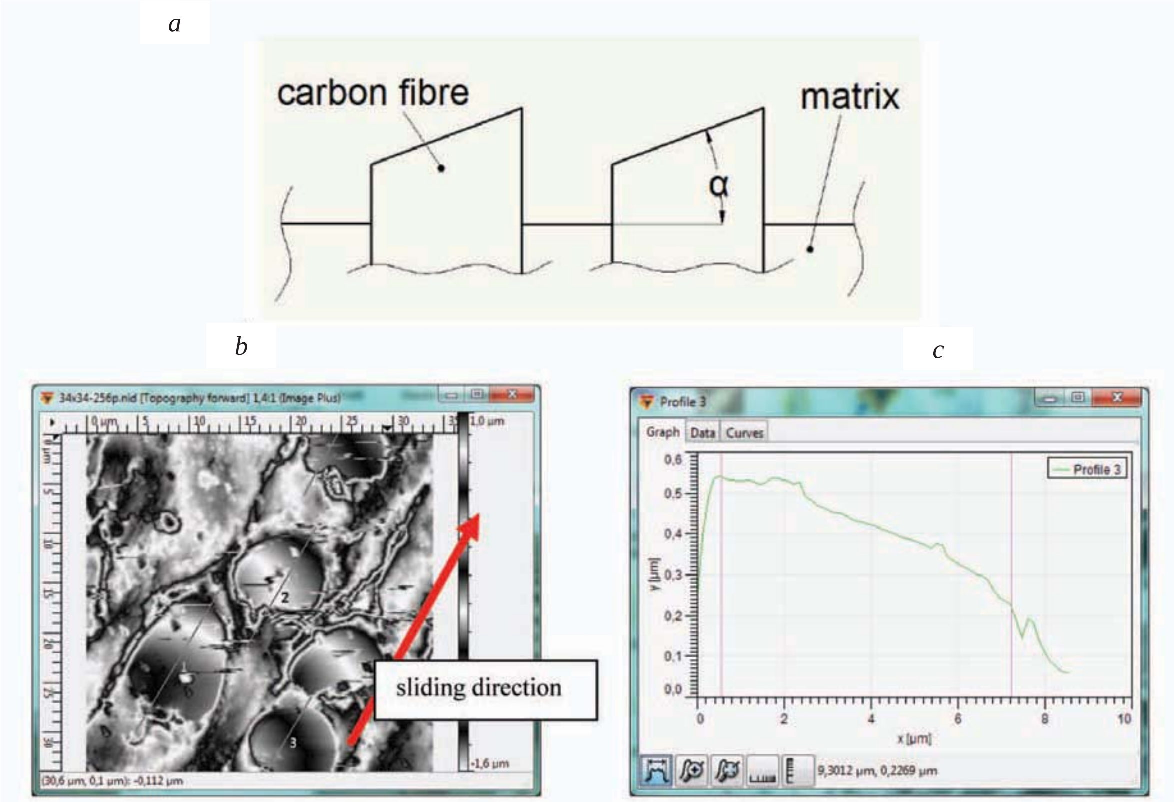

Fig. 8. *a* — Measurement of slope angle α of carbon fiber to matrix surface;
b — the topography of the surface layer made with the atomic force microscope;
c — profile of a carbon fiber after friction

On the base of graphs, it should be noticed, that along with increase of carbon fibers' height, the slope angle also increase. Much wider spread of inclination angle was observed also for composite samples based on polyamide. The differences in both: height and angle of the carbon fibers, occurring between samples PEEK CF30 and CF30 PA66, which worked under the same load, may occur due to matrix material. Based on the documentation of both polymers, it can be concluded that the PEEK (i. e. Young's modulus 4400 MPa, 230 MPa Hardness HB) has a much higher strength properties than PA66 (1100 MPa Young's modulus, hardness HB 140 MPa), which explains the higher destruction resistance of composite for considered unit pressure.

4. Summary.

The results of executed researches allow authors for following conclusions:

— Comparative analysis of the structures of the surface layers formed after friction in the air, allow to conclude that there is a significant difference in the character of work and the mechanisms of friction couples compared to samples working in the oil. Visible carbon fibers and insignificant mark (or lack) of secondary structures, indicate on dominant form of abrasive wear of the samples worked in air. The low content of oxygen and other elements which may form compounds in the surface layer, also give an evidence according to above statement;

— according to samples PEEK CA30 and PA66 CF30 working in the oil, the situation is essentially different. Considerably, developed secondary structure were noticed, which indicates on typical abrasive-chemical wear nature;

— tribological tests and presented analysis of individual components' work indicate for significant influence of mechanical properties of both components, as well as their percentage of the friction surface of the composite on composite' friction and wear mechanism;

— topography researches of surface layer after the friction in air environment, indicates the variability of the surface layer structure shape and thus wear mechanism variation, i. e. carbon fiber different work during friction depending on the distribution of unit pressures occurring on matrix and fibers and properties of both components.

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ДИНАМИКА ПОПЕРЕЧНЫХ КОЛЕБАНИЙ ВЕРТИКАЛЬНОЙ ЗАЩЕМЛЕННОЙ БАЛКИ

DYNAMICS OF TRANSVERSE OSCILLATIONS OF A RIGID VERTICAL BEAM

Статья посвящена вопросу устойчивости конструкций из тонких вертикальных стен. Рассматривается математическая модель поперечных колебаний вертикальной упругой балки с защемленным нижним концом под действием внешней силы. Описаны алгоритмы решения дифференциального уравнения поперечных колебаний упругой балки с применением «балочных» функций А. Н. Крылова и метода Б. Г. Галеркина в варианте В. З. Власова — Л. В. Канторовича Приведены результаты вычислительного эксперимента, выполненного в программе Mathcad.

The article is devoted to the stability of rising walls structures. A mathematical model of the vertical transverse vibrations of an elastic beam clamped at the lower end by an external force is considered. The algorithms for solving differential equations of transverse vibrations of an elastic beam with the use of "beam" functions of A. N. Krylov, and B. G. Galerkin in the version of V. Z. Vlasov — L. V. Kantorovich are described. The results of numerical experiments performed in the program Mathcad are given.

Ключевые слова: гидротехническое строительство, устойчивость сооружений, поперечные колебания упругой балки.

Key words: hydraulic engineering, sustainability of structures, transversal vibrations of an elastic beam.

Введение

В портовом строительстве для создания причальных и волнозащитных сооружений применяются конструкции с элементами тонких вертикальных стенок. На открытой акватории часто применяются больверки (тонкие подпорные стенки), выполненные из шпунтовых свай или свай специальных профилей. Использование таких сооружений связано с проблемой возникновения аварийных ситуаций при производстве работ в условиях открытой морской акватории, а именно:

— трещины, заломы элементов стен, расхождение замков;

— отклонение стенки от проектного положения;

— обрушение свайных рядов.

Из множества процессов, происходящих с тонкой вертикальной стенкой, заглубленной в грунт на морской акватории, представляют интерес [1]:

— колебания стержня под воздействием волновой нагрузки;