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STRUCTURE AND PROPERTIES OF COMPOSITE REINFORCEMENT WITH UNIDIRECTIONAL FIBERS

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Abstract. This work considers the actual problem of using composite reinforcement in building structures. Traditional steel fittings have some disadvantages, such as susceptibility to corrosion, heavy weight, and the need for frequent maintenance. Composite materials, unlike metals, are lighter, stronger, and less prone to corrosion, which increases the durability of structures and reduces operating costs. In the work, a structural analysis of the composite armature was carried out using modern microscopic methods, making it possible to identify certain structural defects. The ImageJ software package used in the study made it possible to conduct a detailed quantitative analysis of the structure of the composite armature. Thanks to the capabilities of automatic processing of microstructural images, ImageJ provided an accurate determination of the area of fibers, their diameters, and distribution in the material. This greatly simplified analyzing the composite structure and allowed for a more objective assessment of reinforcing quality. . The use of ImageJ made it possible to increase the accuracy of research and provided an opportunity to quickly process large volumes of data. In addition, the microhardness study showed a significant difference in hardness between the matrix and the reinforcing fibers, highlighting the anisotropy of the material properties. The authors recommend improving the mechanical properties of composite reinforcement due to the distribution of fibers in several directions. The use of composite materials is promising, especially in aggressive environments and with increased energy efficiency requirements.

Keywords: composite, reinforcement, mictostructure, fibers, microhardness.

Introduction

Practically all construction structures during operation are exposed to various external factors, such as load, pressure, temperature difference, aggressive environments, etc. Under the influence of these factors, deformation, destruction and destructive processes occur in the material of products, which leads to a reduction in the service life of structures and buildings. Therefore, to ensure the reliability of structures, it is necessary to use building materials that will provide a full range of functional properties, increase the service life, and reduce the cost [1–4].

Review of Modern Information Sources on the Subject of the Paper

The ever-increasing interest in reinforcement made of composite materials is related to its advantages compared to steel. Reinforcements made of composite materials are lighter and stronger than traditional materials, which allows you to create lighter and at the same time stronger structures. Composites are less susceptible to corrosion compared to metals, which increases the service life of structures and reduces the need for regular maintenance. Due to the ease of manufacture, composite materials can be used to create fittings of a complex shape, which is not always possible to achieve with the help of traditional materials. Composite materials have good thermal insulation properties, which can be important in construction to save energy and increase the energy efficiency of buildings. The dielectric properties of composite reinforcement also play an important role in many applications, especially in electrical engineering and electronics [2]. The advantages of using fittings made of composite materials over steel fittings are also the lower energy consumption of production the amount of greenhouse gas emissions and the constant increase in the cost of metal.

However, there are certain disadvantages to using fittings made of composite materials. These include a low modulus of elasticity (4 times less than that of steel) and low heat resistance, which limits the use of composite reinforcement [3].

At present, composite reinforcements are used in the construction of hospitals, airports, radar stations, and various military facilities. In global practice, especially in the USA, Canada, Japan, and Germany, composite reinforcement is widely used in the construction of roads, bridges, and marine structures. It is recommended to use such fittings in structures that are constantly in the zone of high humidity and contact with seawater (dams, piers, breakwaters, coastal fortifications, sewage treatment plants, wells, collectors, canals, fountains, pools, reservoirs). It is advisable to use it in seismically active zones, on objects operated in conditions of increased vibration (nuclear and hydroelectric power plants, bridges, etc.), in water drainage channels, sewerage, and land reclamation [4, 5].

Objectives and Problems of Research

Until recently, the use of composite reinforcements in Ukraine was somewhat limited due to the availability and low cost of steel reinforcements. In addition, the lack of awareness and experience of designers, architects and builders in working with such fittings also somewhat hindered the widespread use of fittings made of composite materials.

Therefore, the purpose of this work is to analyze the structure and some mechanical properties of reinforcement made of composite material. This will make it possible to increase the awareness of scientists and consumers about fittings made of composite material, to develop ways of improving operational properties, and to expand the possibilities of using such fittings in other industries.

Research was carried out on samples of fittings made of composite material to reveal their structure and properties. The microstructure of the samples was studied using an optical microscope MMT-14C and an electronic scanning microscope EVO-40XVP with an energy-dispersive X-ray spectrometer INCA ENERGY 350. Quantitative assessment of the structure of the investigated composite material, as well as the cross-sectional size of the fibers, was carried out using computer image processing of the microstructure in the ImageJ software package, which allows the automatic processing of photographs. The microhardness of the composite armature was studied on cross sections on a Vickers microhardness tester NOVOTEST TS-MKV1 under a load of 10 grams (0.098 N).

Main Material Presentation

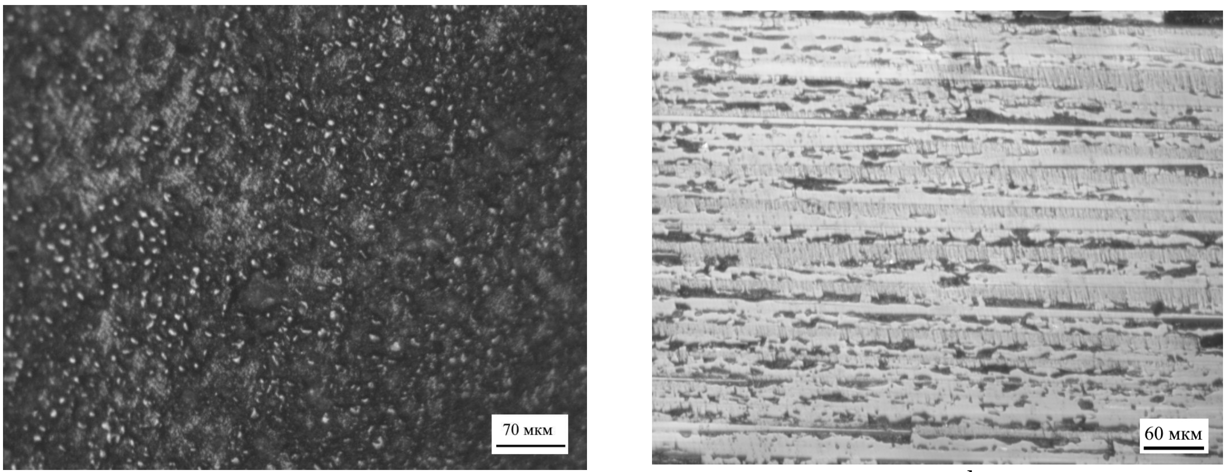
The research was carried out on a long thin composite rod of a circular periodic profile made of a stiffener and a thermoset matrix.

To determine the structure of the studied samples, microstructural studies were carried out using an optical microscope MMT-14C (Fig. 2). As can be seen, the structure of composite reinforcement consists of layers of unreinforced matrix located between layers of fibers. The distribution of fibers is somewhat uneven, there are places depleted of such strengtheners, and in some places, on the contrary, their accumulation is observed. This may be related to non-compliance with the manufacturing regimes of fittings.

When examining the longitudinal section, it is visible that the reinforcing elements of the material under study are fibers (Fig. 2, *b*). They extend in one direction and are located parallel at a distance of 23–28 microns from each other. Even at low magnification, certain structural defects, namely pores and delamination, can be seen.

Fig.1. The appearance of the examined samples of composite fittings

For a more detailed study of the structure, we conducted a study on an EVO-40XVP electron microscope (Fig. 3).



a b

Fig. 2. The microstructure of the investigated armature made of composite material:
a – transverse view; b – longitudinal view, x100

As you can see, the fibers are mostly spherical in cross-section. Their distribution is uneven. When mechanical processing is carried out for the production of micro sand, the surface of the fiber is damaged. Cracking, chipping and delamination are visible (Fig. 4).

According to the results of the elemental analysis performed using the energy-dispersive X-ray spectrometer INCA ENERGY 350, the elemental composition of the studied samples was determined (Fig. 5, Table 1).

Table 1

Results of elemental analysis of the studied composite material

Element	Total spectrum, wt. %	Matrix material, wt. %	Reinforcement material, wt. %
$CaCO_3$	48.42	67.86	–
SiO_2	25.47	32.11	37.14
Al_2O_3	3.50	–	8.51
Si	14.31	–	35.72
$CaSiO_3$	7.81	–	18.62

As can be seen, the basis of the investigated armature is a composition consisting of $CaCO_3$ and SiO_2. $CaCO_3$-SiO_2 composite is an ideal material to replace pure SiO_2. The elemental composition of reinforcing fibers includes SiO_2, Al_2O_3, $CaSiO_3$, and pure Si. Fiberglass of this composition can be used in fiberglass reinforcement, which is an alternative to traditional steel reinforcement [6]. Such a fiber has high strength and tensile strength, which helps increase structures' durability, especially in chemical or corrosive environments. Fiberglass is much lighter than steel reinforcement, which facilitates the transportation and installation of structures. This is especially important in high-rise buildings, where the mass of materials is of great importance [7]. SiO_2 and Al_2O_3 fiberglass is corrosion and chemical-resistant, making it an ideal choice for applications with high humidity, chemicals, or seawater.

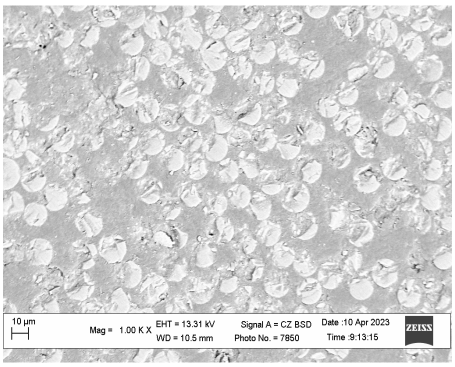
Table 2

Results of quantitative analysis of the structure of the studied composite material

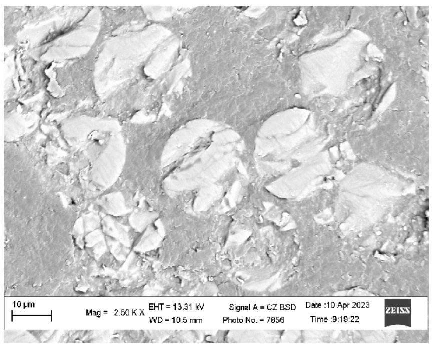
Number of analyzed particles, pcs	Total area, μm^2	Average particle size, µm	Area occupied by particles, %	Feret particle diameter, µm
598	3301.7	5.521	2.91	3.350

To quantify the reinforcing fibers using the ImageJ program, we selected an area on the photomicrograph, formatted it, and divided it into dark (fiber cross-section) and light (matrix) areas, followed by an outline of each dark area (Fig. 6) [8].

The next stage was the analysis of the selected image, namely, we determined the area occupied by the fibers in the examined sample of fiberglass reinforcement, their number, and distribution by Feret diameter (Table 2).



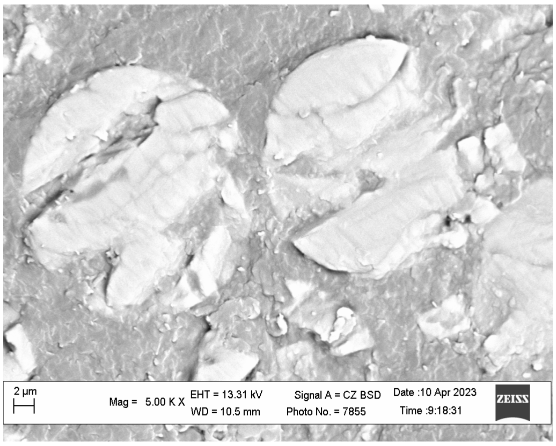
a



b

Fig. 3. SEM image of the unetched microstructure of the investigated armature made of composite

material at different magnifications: a – x1000; b – x2500; c – x5000



c

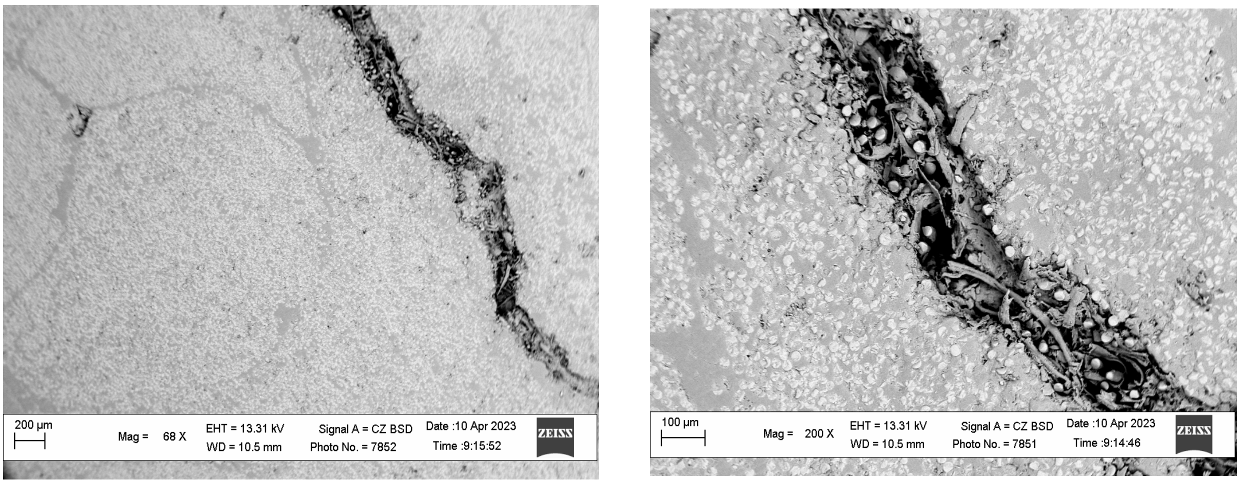
Fig. 3. (Continuation) SEM image of the unetched microstructure of the investigated armature made of composite material at different magnifications: a – x1000; b – x2500; c – x5000

Table 3

The microhardness of the composite reinforcement material under load is 0.098 N

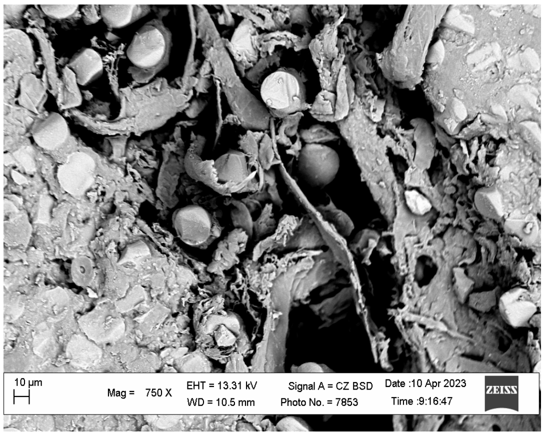
Place of testing	The diagonal of the print d_1, µm	The diagonal of the print d_2, µm	HV
Matrix	31.0	30.6	19.5
Reinforcing fibers	6.7	6.6	415.0

According to the results of the analysis, it was established that the distribution of fibers is uniform according to the Feret diameter. The cross-sectional diameter of the investigated fibers ranges from 1 to 8 µm, the predominant part belongs to fibers with a diameter of 3 µm (Fig. 4).



a b

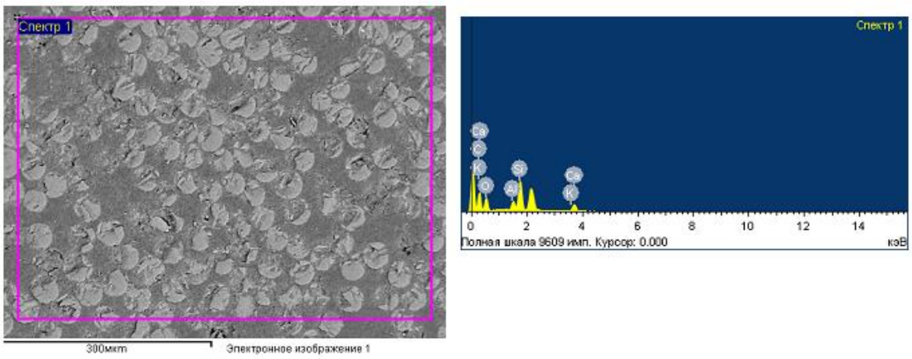
Fig. 4. SEM image of the tested armature made of composite material with signs of cracking: a – x68; b – x200; c – x750



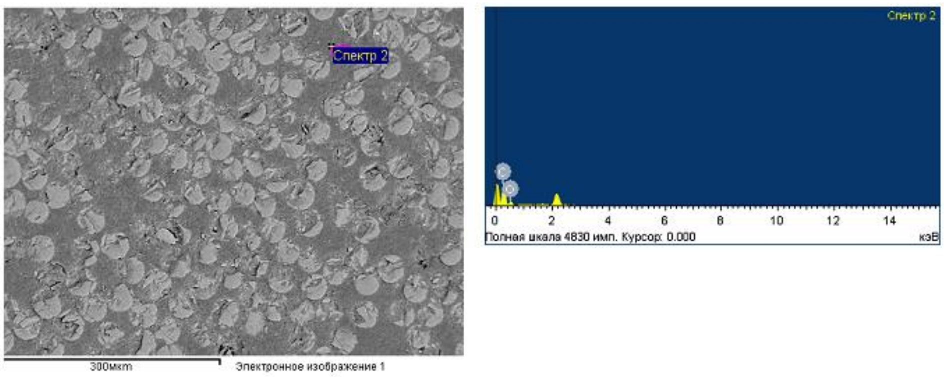
c

Fig. 4. (Continuation) SEM image of the tested armature made of composite material with signs of cracking:
a – x68; b – x200; c – x750

The microhardness of the samples was studied on transverse microsands under a load of 0.098 N (Table 3). The matrix hardness of the composite material averages 19.5 HV, which is more than 20 times less than the microhardness of the reinforcing fibers (415 HV). Given the fact that the fibers are stretched in one direction along the structure of the composite reinforcement, such a large difference in hardness will increase the property anisotropy factor.

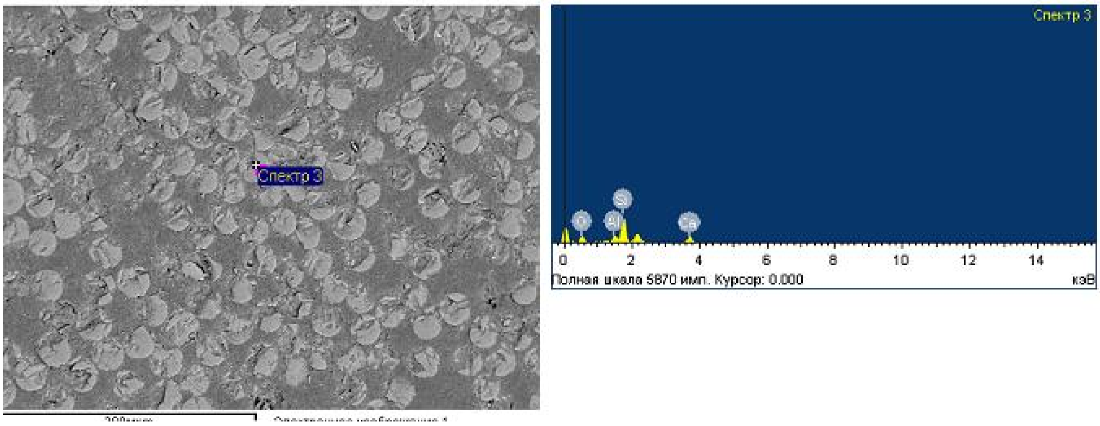


a



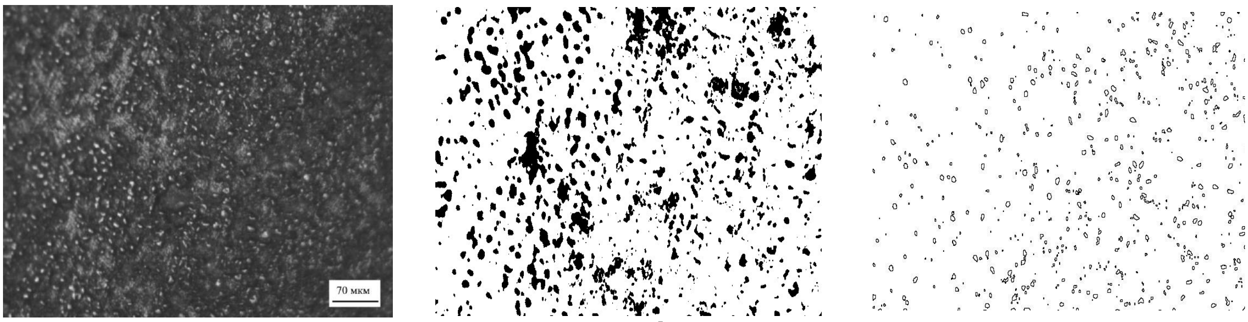
b

Fig. 5. Elemental analysis of the studied composite (a), quantitative analysis of matrix (b) and strengthener (c) with corresponding EDS spectra and concentration graphs



c

Fig. 5. (Continuation) Elemental analysis of the studied composite (a), quantitative analysis of matrix (b) and strengthener (c) with corresponding EDS spectra and concentration graphs



a b c

Fig. 6. Stages of image preparation: a – initial image; b – selection of fibers in dark color; c – outline of fibers

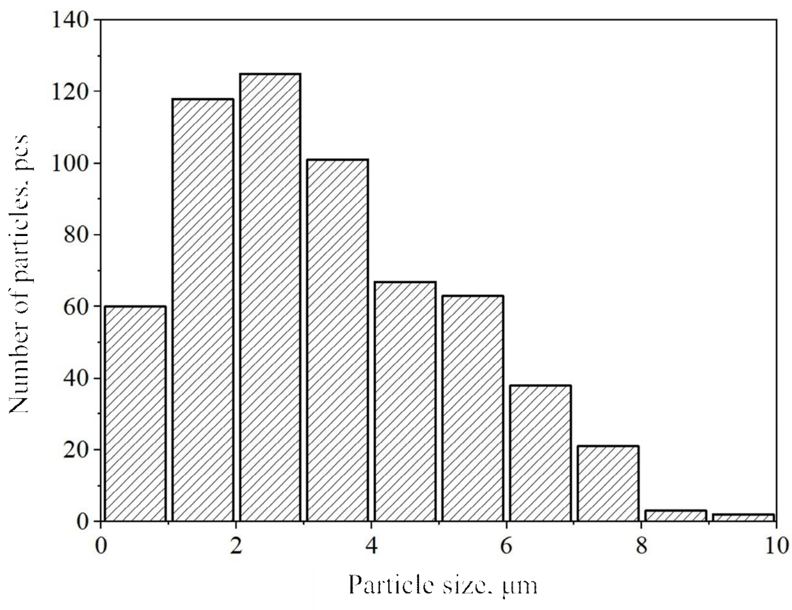


Fig. 7. Histograms of the distribution of the Ferét diameters of the studied fibers of composite reinforcements

Conclusions

Conducted studies of the structure and properties of composite reinforcement confirm its effectiveness and also indicate opportunities for improvement and further implementation in the construction industry. The microstructure of the composite consists of fibers unevenly distributed in the matrix. Fibers are mostly spherical, and their distribution in the material turned out to be heterogeneous, which may be a consequence of non-compliance with the technological modes of production. Defects such as pores, delaminations and microcracks were detected, which can negatively affect the mechanical properties of the reinforcement. Elemental analysis showed that the basis of the composite is $CaCl_3$ and SiO_2, which provide strength and corrosion resistance. However, the fibers can be damaged during mechanical processing, which requires further improvement of production processes. Microhardness analysis showed a significant difference between the reinforcing fibers and the matrix, which creates anisotropy of properties and can be an important factor in the operation of the reinforcement. In general, the structure of the composite reinforcement needs further improvement to achieve a more uniform distribution of fibers and reduce defects, which will improve its operational characteristics..

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