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GRAPHO-ANALYTICAL METHOD FOR CALCULATING THE VOLUME FRACTION OF FIBERS IN THE THREADS OF A MULTI-LAYER FABRIC COMPOSITE

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The study focuses on the problem of determining the volume fraction of fibers in the cross-sectional area of strands in a layered fabric composite. Experimental and analytical methods were used to determine the volume content of fibers in different areas of the representative cross-section of laminated carbon fiber filaments. A digital microscope image of the composite cross-sectional structure was obtained using special equipment after conducting an experimental analysis of the polished cross section. Statistical processing of the data revealed an uneven distribution of fiber volume in different regions of the cross section. These results can be used to enhance the accuracy of mathematical modeling of layered fabric composites.

Key words: layered fabric composite, cross section, microscopic image, thread, fiber, fiber volume fraction.

Layered fabric composite materials are widely used in modern aviation and space rocket technologies [1, 2]. Their popularity is due to their excellent performance characteristics: high specific strength, rigidity, durability, and resistance to corrosion and alternating loads. Additionally, these materials offer flexibility in design, allowing for the creation of structures in complex shapes [3]. This opens up new possibilities for the development of more efficient and innovative aviation products.

Let's analyze the internal structure of the composite material. The construction of this material is a macro-object. Our task is to determine its strength. To do this, we need to switch to meso-objects: typical structural elements. At this level, we select the number of fabric layers and study the behavior of the meso-structure of the material under different loading conditions. For example, we can check for delamination in a composite material under load. The next step in studying the composite structure is the micro-level. This includes oval-shaped threads that make up the fabric and fibers that make up these threads. This can be clearly seen in figure 1.

The threads, as a rule, are arranged orthogonally to one another, similar to the ordinary fabric that our clothes are made of. The strength of the thread depends directly on the fiber content in it, which is the reinforcing component. Therefore, it is important for us to determine the volumetric fiber content in a thread in order to assess the strength of a specific fabric and, consequently, the final strength of a product. By knowing the volume of fibers in a thread, we can select the optimal technology for producing composite materials, such as the amount of precursor PAN needed to create a material with the desired strength. The higher the fiber content, the stronger and stiffer the material will be, and the more flexible it will be for molding products with complex shapes.

Ensuring the reliability and safety of composite materials used in aircraft design largely depends on the accuracy and reliability of initial data on their elastic and strength characteristics. Using detailed mathematical models based on experimental data allows us to predict and prevent potential problems, reducing design time

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and costs and creating more reliable and efficient products. For example, using a representative volume model of a composite material allows us to determine a full set of elastic properties in case of limited experimental data [4, 5]. However, as mentioned previously, the elastic and strength properties of a composite are largely dependent on manufacturing technology and component proportions [5]. The volume fiber content is a significant factor that directly influences the mechanical properties of a composite. However, in practice, the average volume content of fibers over the cross-section of the thread is often used, which can lead to an overestimation of the elastic properties of the material. This paper therefore analyzes two methods for studying the distribution of fiber volume in the cross-sectional strands of a laminated fabric composite.

I. Experimental research

In this study, the determination of the fiber volume content in a thread is performed by analyzing a digital microscopic image of the cross-section of a sample of a layered composite fabric. The material which is made by vacuum infusion under investigation is based on alternating layers of carbon (CC201) and glass (T10) structural fabrics, and a two-component epoxy binder (SR8100-SD8824). To conduct an experimental study, composite plates with a thickness of 40×5×40 mm were cut perpendicular to the reinforcing threads. The cut surfaces were machined: first, the samples were sanded with sandpaper of varying grain sizes (from 80 to 400) and then polished using a drilling machine with a felt polishing nozzle. This treatment ensured the maximum smoothness of the cut surface and, consequently, a clear visibility of the composite fibers under a microscope. Composite samples were produced in the laboratory of composite materials and structures at Samara University. The volumetric fiber content of the composite cross-section was determined using a Nicon Eclipse MA 200c microscope with a magnification range from 50 to 1000. Based on the results of the study, images of the cross-sectional material were obtained (fig. 2).

To calculate the volume fraction of fibers in the filaments, we selected fragments containing a cross-section of carbon fibers from the obtained images (fig. 3).

The obtained images were used as initial data for analyzing the distribution pattern of the volumetric fiber content in the cross-sectional filament of the composite.

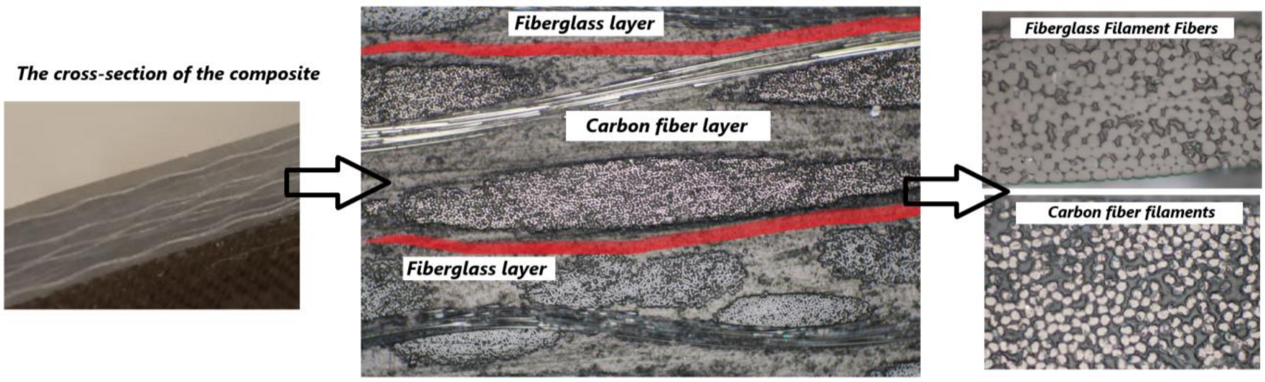

Fig. 1. The structure of the composite material by levels

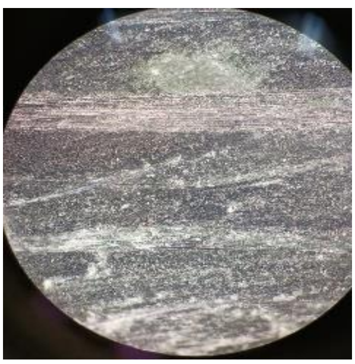

Fig. 2. The structure of the composite material by levels

II. Analysis of the distribution pattern of fibers in the cross section of carbon filament

The quantitative analysis of the volumetric fiber content in the strands of a layered composite material was performed using the educational version of the Compass-3D computer-aided design system. A cross section of carbon filament was divided into several identical fragments (10, 20, and 40). In each fragment, the area of fibers and binder was calculated (see figure 4):

$$V_f = A_f / A,$$

where $A=dl*h$ is the area of the fragment and A_f is the total area of fibers.

Next, a statistical analysis of the data was carried out to assess the distribution pattern of the volume content of carbon fibers in the filaments along the cross-section of the composite. Graphs were obtained for different stages of splitting the cross-section of the thread, showing a picture of changes in the volume content of fibers (figure 5).

Conclusion

The results obtained show that the maximum number of fibers (Vf = 0,44–0,52) occurs at 40–45 % of the length of the thread's cross-section. A smaller splitting step leads to a wider spread of volume content values, as the size of the fragments becomes closer to the size of the individual fiber cross-sections. At the same time, the average volume content value is 0,48.

The results of the experimental and analytical study indicate the importance of considering the nature of the distribution of fiber volume content in the cross-section of a thread for accurate modeling of the elastic-strength properties of layered fabric composites.

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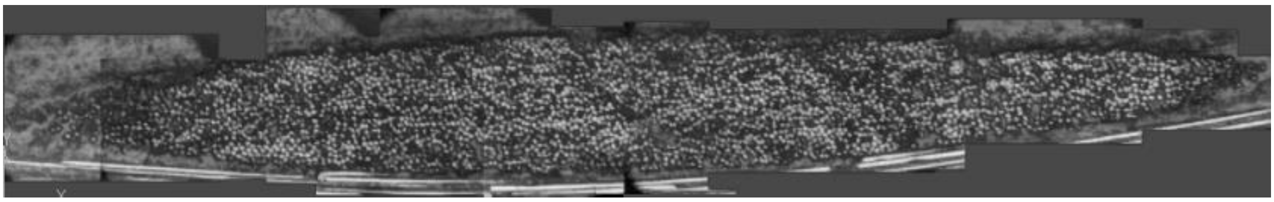

Fig. 3. Cross-section of carbon fibers in a thread

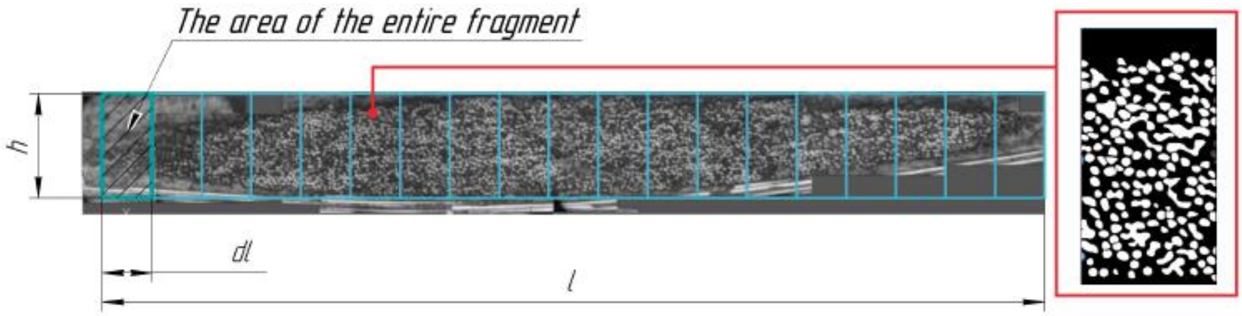

Fig. 4. Splitting a digital image into fragments

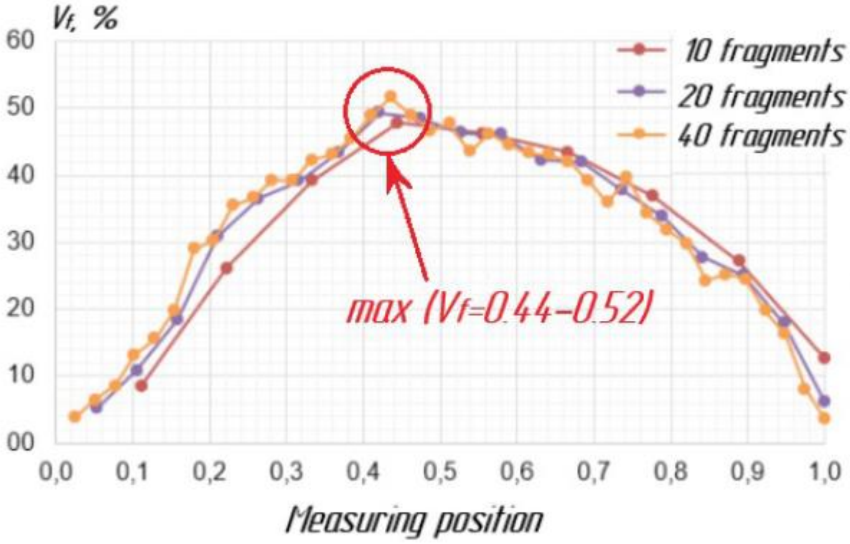

Fig. 5. A visual representation of the distribution of fibers within the cross-section of a carbon fiber

ГРАФОАНАЛИТИЧЕСКИЙ МЕТОД РАСЧЁТА ОБЪЁМНОГО СОДЕРЖАНИЯ В НИТЯХ СЛОИСТОГО ТКАНЕВОГО КОМПОЗИТА

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Рассматривается задача определения картины распределения объёмного содержания волокон в поперечном сечении нитей слоистого тканевого композита. В работе использовались экспериментальные и аналитические методы определения объёмного содержания волокон в различных областях характерного поперечного сечения нити слоистого углепластика. Экспериментальное исследование шлифованного поперечного сечения структуры композита с использованием специального оборудования позволило получить цифровой микроскопический снимок поперечного сечения композита и измерить объём волокон в каждой области. На основе полученных данных проведена статистическая обработка, которая показывает неравномерность распределения объёмного содержания волокон в различных областях поперечного сечения.

Key words: слоистый тканевый композит; поперечное сечение; микроскопический снимок; нить; волокно; объёмное содержание.

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