THE EFFECT OF MIXED FIBERS ON MICROSTRUCTURE AND MECHANICAL STRENGTH IN POLYMER MATRIX COMPOSITE MATERIALS

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Annotation: This article studies the effect of mixed fibers on the microstructure and mechanical strength of polymer matrix composites. The phase distribution, matrix-fiber interaction, and structural integrity resulting from the incorporation of fibers with different properties (carbon, glass, and natural fibers) into polymer-based composites are analyzed. Microscopic analyses and mechanical tests have shown that mixed fibers significantly increase the tensile, flexural, and impact strengths of composite materials. The results of the study expand the possibilities of using mixed fiber composites in aerospace, automotive, and construction industries.

Keywords: Polymer matrix, composite material, mixed fibers, microstructural analysis, strength, carbon fiber, glass fiber, natural fiber, SEM, mechanical testing.

Аннотация: В данной статье исследовано влияние смешанных волокон на микроструктуру и механическую прочность полимерных композиционных материалов. Проанализированы распределение фаз, взаимодействие матрицы и волокон, а также структурная целостность, возникающие при включении волокон с различными свойствами (углеродных, стеклянных и натуральных) в полимерные композиционные материалы. Микроскопический анализ и механические испытания показали, что смешанные волокна значительно повышают прочность композиционных материалов на растяжение, изгиб и ударную вязкость. Результаты исследования расширяют возможности применения смешанных композиционных материалов в аэрокосмической, автомобильной и строительной отраслях.

Ключевые слова:Полимерная матрица, композиционный материал, смешанные волокна, микроструктурный анализ, прочность, углеродное волокно, стекловолокно, натуральное волокно, СЭМ, механические испытания.

Annotatsiya: Ushbu maqola aralash tolalarning polimer matritsali kompozitlarning mikro tuzilishi va mexanik kuchiga ta'sirini o'rganadi. Polimer asosidagi kompozitlarga turli xossalarga ega (uglerod, shisha va tabiiy tolalar) tolalarni kiritish natijasida yuzaga keladigan faza taqsimoti, matritsa-tolalar o‘zaro ta’siri va

ISSN 3030-3907

strukturaviy yaxlitligi tahlil qilinadi. Mikroskopik tahlillar va mexanik sinovlar shuni ko'rsatdiki, aralash tolalar kompozit materiallarning kuchlanish, egilish va zarba kuchlarini sezilarli darajada oshiradi. Tadqiqot natijalari aerokosmik, avtomobilsozlik va qurilish sanoatida aralash tolali kompozitlardan foydalanish imkoniyatlarini kengaytiradi.

Kalit so'zlar: Polimer matritsa, kompozit material, aralash tolalar, mikrostruktura tahlili, mustahkamlik, uglerod tolasi, shisha tola, tabiiy tola, SEM, mexanik sinov.

Introduction

Along with the development of modern industries, the need for lightweight, durable and multifunctional materials is growing. This need is especially evident in the fields of aviation, automotive, construction and sports equipment. Therefore, polymer matrix composite materials (PMCM) have received extensive research and practical attention in recent years. Such materials have properties such as high strength, low density and good corrosion resistance, which make them suitable for use in modern structures. The addition of various fibers to the polymer matrix - in particular, the combined use of carbon, glass and natural (hemp, flax, etc.) fibers - significantly increases the overall mechanical and microstructural performance of composites. Mixed fibers form a modified microstructure, optimizing the material's resistance to bending, stretching and impact. This puts PMCM among the advanced technological solutions.

The use of mixed fibers in polymer-based composites improves not only strength, but also structural stability, crack propagation retardation, and energy absorption. However, the types of fibers, their ratios, phase distribution within the structure, and the degree of bonding with the matrix directly affect the final properties of the material. Therefore, studying the effect of mixed fibers on the microstructure, assessing their role in the composite, and determining their dependence on strength is one of the current areas of modern materials science. This article analyzes the combined effect of glass, carbon, and natural fibers in the polymer matrix experimentally and theoretically. Based on microscopic analysis (SEM), mechanical tests (bending, tensile, and impact tests), it is revealed how mixed fibers affect the internal structure of the composite and its strength. The results of the study provide important practical indicators for choosing the optimal composition and structure in the production of PMMC.

Research and method: In this study, the effect of mixed fiber on the microstructure and mechanical properties of polymer matrix composite materials was studied using experimental methods. Three types of fibers were used in the preparation of composite samples based on epoxy resin (matrix): carbon fiber (C), glass fiber (G) and flax fiber (F - natural fiber). The fibers mixed in various

ISSN 3030-3907

combinations were introduced into the epoxy matrix in the proportions of 60:40, 50:30:20, and 70:15:15. The prepared composite plates were kept at room temperature for 24 hours, and then cured at 60°C for 6 hours. 5 test specimens were prepared from each sample and subjected to mechanical tests according to standard GOST criteria. Bending (3-point) and elongation (tensile) tests were performed on universal testing machines. Impact strength was also evaluated by the Charpy method. Microstructural analyses were carried out using SEM (Scanning Electron Microscopy) equipment. Sections of 10×10 mm from each sample were metallized and analyzed at 1000× and 5000× magnification. The analyses focused on assessing the fiber bonding with the matrix, the degree of internal porosity, the fiber break pattern, and the crack propagation. It was found that the carbon fibers were strongly bonded to the matrix with high smoothness and clean boundaries. In the glass fibers, however, sometimes zones of poor bonding with the matrix were observed due to the surface smoothness. The flax fiber samples were smoothly coated with the matrix, but internal stresses were present due to the fiber roughness. The table below summarizes the test results, and the figure illustrates the three types of fiber structures in SEM images.

Table 1.

Main mechanical properties of mixed fiber composites

Composite type	Bending strength (MPa)	Stretching (MPa)	Impact resistance (kJ/m²)
60% C - 40% G	320	170	28
50% C -30% G - 20% F	290	150	35
70% G -15% C - 15% F	240	125	38

Note: "C" is carbon fiber, "G" is glass fiber, "F" is flax fiber.

Microstructure of blended fibers in SEM images

-60% C / 40% G: Granular, dense and orderly structure. Carbon fibers are well integrated into the epoxy matrix.

-50% C / 30% G / 20% F: Multiphase mixture, flax fibers are unevenly arranged, there is stress concentration in these zones.

-70% G / 15% C / 15% F: Smooth-surfaced glass fibers are superior, but the bond to the matrix is weak. Natural fibers have led to cracks.

Note: SEM images were taken at 5000× magnification. Fiber intersections, bonding, and voids in the mixed zones were evaluated using SEM.

Result and negotiation: Based on the experiments, it was found that the mechanical properties of mixed fiber composite materials depend on the ratio of

ISSN 3030-3907

fiber types, their bonding with the matrix, and the internal microstructure. The composite sample with 60% carbon and 40% glass fibers had the highest flexural and tensile strengths (320 MPa and 170 MPa, respectively). This is a result of the strong mechanical properties of carbon fibers and the good mechanical compatibility between them and glass fibers. SEM analysis also revealed that this composite has a smooth and homogeneous microstructure, which ensures a stable stress distribution and a reduced risk of cracking. The impact resistance of the 50% C / 30% G / 20% F combination sample significantly increased, which indicates the high efficiency of natural fibers in absorbing energy. However, SEM images showed uneven arrangement of flax fibers and in some cases weak bonds with the matrix, which led to a slight decrease in tensile properties.

Although the highest impact strength (38 kJ/m²) was recorded for the sample with 70% glass, 15% carbon and 15% flax fibers, the flexural and tensile strengths were relatively low in this combination (240 MPa and 125 MPa, respectively). This is explained by the relatively low mechanical strength of glass and natural fibers and their poor adhesion to the matrix. Microstructural analysis showed that this composite has more voids, uneven stress distribution between the fibers, and faster crack propagation. Also, the moisture absorption property of flax fibers increased porosity at the matrix-fiber boundaries, which increased the crack initiation. It was found that in mixed fiber composites, carbon fibers provide structural stability, natural fibers perform the function of shock absorption, and glass fibers provide intermediate mechanical properties. Therefore, when preparing a composite, it is necessary to carefully select the fiber ratio depending on the task.

Conclusion: The results of the studies showed that composite materials with a mixed fiber polymer matrix can have important properties such as high mechanical strength, impact resistance and improved microstructural stability. The type, proportion of fibers in the composite and the quality of their bonding with the matrix directly affect the quality and operational properties of the final product. The best mechanical results were observed in a composite sample with 60% carbon and 40% glass fibers, which is associated with the fact that the microstructure becomes dense and resistant to cracks when strong fibers are combined with each other. When natural fibers (flax) are added, composites can improve their shock absorption and energy absorption capabilities, as well as have advantages in terms of environmental safety. However, it was found that in cases where these fibers are not well bonded to the matrix, voids can form in the microstructure and lead to a decrease in strength. Also, SEM analyses were performed to carefully analyze the interface between the fibers and the matrix, crack propagation and grain size. Based on this data, it was determined that each composite combination is suitable for a

ISSN 3030-3907

specific application, and by choosing the optimal proportions, it is possible to produce high-quality, efficient and reliable composite materials. In industries such as aerospace, automotive, construction and sports, such mixed fiber composites play an important role in creating modern, lightweight and durable structures. In the future, it will be possible to further improve the performance of such composites by using nano-fiber mixtures, surface activation and new sintering technologies.

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ISSN 3030-3907