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MODERN APPROACHES TO THE USE OF COMPOSITE MATERIALS IN CONSTRUCTION

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Abstract
A review of the literature on scientific approaches in the development of composite materials and building structures made of composites is carried out. When creating and manufacturing traditional and new composite materials, for example, by additive manufacturing, and when creating structures and structures in engineering calculations, new techniques, finite element computational software systems, and neural network technologies are used, which are used in the creation of modern metal and composite materials, analysis of mechanical characteristics of materials, forecasting loads on the structure, optimization of structures and calculation of their construction characteristics.
The distinctive features of modern composite materials are shown. The main types of composite materials are considered: talc, diatomite, calcium carbonate, gibbsite, barium sulfate, feldspar, nepheline, aragonite, calcium carbonate, wool, silk, cotton, linen, jute, wood pulp, asbestos, fiberglass, metal fibers, quartz fibers, basalt fibers, polyamide fibers, polyester fibers, polyvinyl alcohol fibers, carbon fibers, viscose fibers. The physical and mechanical characteristics of composite materials (based on epoxy, aluminum, carbon, magnesium, and nickel matrices) and traditional (steel, aluminum, brick, concrete) building materials are presented.
The disadvantages of such composite materials as carbon fiber, fiberglass, organoplastics, textolite, carbon concrete, and polystyrene concrete are presented.
Deformation diagrams of some types of fibers for composite materials are considered: high-modulus carbon fibers, high-strength carbon fibers, aramid fibers, glass fibers, and basalt fibers.
The advantages of the system of external reinforcement of building structures with composite materials are described. Examples of reinforcement of building structures are considered: reinforced concrete reinforcement; reinforcement of floor slabs; reinforcement of columns; and reinforcement of brick walls.

Keywords Composite materials, building materials, modulus of elasticity, strength, stiffness, concrete, reinforcement, fibers, matrix, deformation diagrams.

INTRODUCTION

Various knowledge-intensive approaches are used in the construction of modern structures both in the creation and fabrication of traditional and new composite materials [1-3], for example, by additive manufacturing [4,5], and in the creation of structures and structures using new techniques [6-8], finite element calculation programs [9,10] and neural network technologies [11-13] in engineering calculations. Neural networks are used in the creation of modern structural materials [14], analysis of mechanical characteristics of materials [15], prediction of loads on a structure, optimization of structures [16], and calculation of their construction characteristics. These factors are the reason for the tightening of requirements for structural materials, especially composite materials [17-21].

METHODS

The material is designed and strength is calculated simultaneously with the product development. As noted in [22], it is no longer possible to separate material and design. The process of designing and creating a material construction with specified properties includes interconnected design calculation, calculation of material properties depending on the structure, and technological methods of manufacturing.

A necessary property of structural composite material becomes a planned, subject to calculation nature and process of its damage and destruction. This makes it possible to monitor the process of material degradation in the structure with the help of special sensors. Observation of the appearance of structural damage and its development in the process of operation, by the principle of "safe damage", assumes that the damage must be detected, and in case of its development, the structure must be repaired.

In English, composite material is called composite ['kɔmpəzit] with stress on the first syllable, which means something composite, complex. There are not many simple substances in nature (~400), much more complex composites. The main difference between structural composite material and many other structural complex materials is that it is designed by man in such a way that it became possible to control its structure and through it, mainly mechanical and thermophysical properties in the process of manufacturing the material and the product from it.

RESULTS

The creation of new materials is rarely observed because a large number of "simple" (non-composite) materials have already been discovered. Therefore, combining known substances is the main way to create new composite materials.

Figure 1 shows a graph comparing the specific modulus of elasticity of some composites and metallic materials [22]. The record holder in specific stiffness is beryllium, which has a high modulus of elasticity (E = 250 GPa), heat capacity, and corrosion resistance, but it is highly toxic and has low ductility and anisotropy properties.

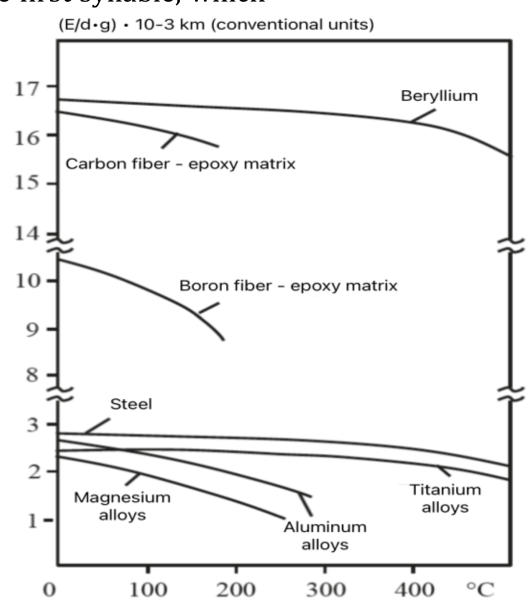

Figure 1. The effect of temperature on the specific modulus of elasticity of various materials (E – modulus of elasticity; d – density; g – acceleration of gravity) [22, 23]

There is a huge number of composite materials and their detailed enumeration cannot be presented within the framework of one scientific article, so the main types of composites are shown schematically in Figure 2.

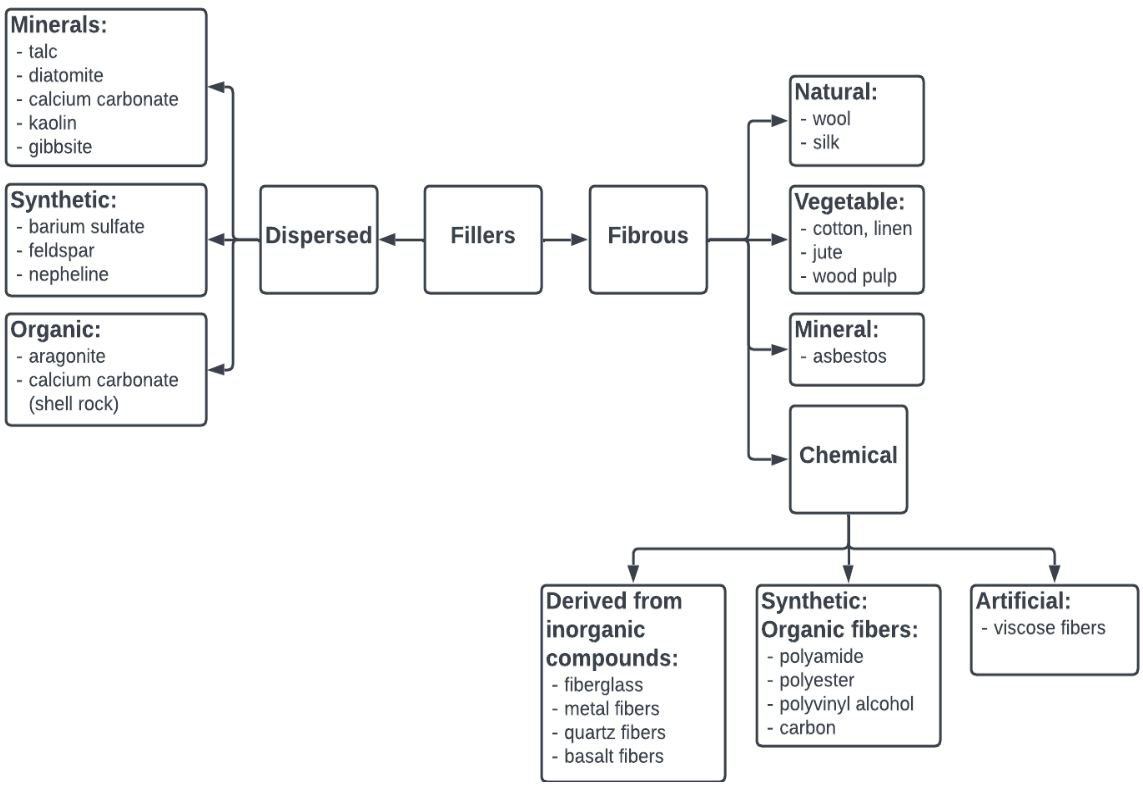

Figure 2. The main types of composite materials

The most widely used composite materials are polymer composite materials (PCM) [24, 25]. Strong anisotropy of mechanical characteristics forces the designer together with the technologist, using the accumulated experience of designing products from quasi-isotropic materials, to lead carbon fiber-reinforced plastic by choice of reinforcement schemes to a quasi-isotropic structure. Or, which is more difficult and less worked out by design practice, using only the strengths of the material, to apply the rule of coincidence of reinforcement scheme with the flow of forces and to design the optimal product structure for the perception of external forces. Both options can be realized using carbon harnesses. The second option allows to significantly reduce the weight of the product. Examples of such designs are the Eiffel Tower in Paris and the Shukhov Tower in Moscow, mesh structures, designed using additive technologies, in which, with an isotropic material, this is solved by the optimal choice of the cross-sectional area of the load-bearing direction.

Table 1 presents the physical and mechanical characteristics of composite and traditional building materials.

Table 1. Physical and mechanical characteristics of composite and building materials [22]

Matrix/Material	Reinforcing Filler/Brand of Material	Density, g/cm³	Strength, MPa	Modulus of Elasticity, GPa
Epoxy Matrix	Carbon Fiber	1.4 – 1.5	800 – 1500	120 – 220
	Fiberglass	1.9 – 2.2	1200 – 2500	50 – 68
	Organic (Aramid) Fiber	1.3 – 1.4	1700 – 2500	75 – 90
	Boron Fiber	2.0 – 2.1	1000 – 1700	220
Al Matrix	Carbon Fiber	2.3	800 – 1000	200 – 220
	Boron Fiber	2.6	1000 – 1500	220 – 250
C Matrix	Carbon Fiber	1.5 – 1.8	350 – 1000*	120 – 220
Mg Matrix	Carbon Fiber	1.8	600 – 800	180 – 220
	Boron Fiber	2.0	700 – 1000	200 – 220
Ni Matrix	Molybdenum Wire	9.3	700	235
	Tungsten Wire	12.5	800	265
Steel	High Carbon (Steel 45)	7.8 – 7.9	200 – 230	205
Aluminum	D16	2.7 – 2.8	400 – 470	70
Brick	Silicate (M300)	1.8 – 2.0	4*	25 – 27
Concrete	Heavy	2.4 – 2.5	0.9 – 18	28

*Flexural strength.

Table 2 shows the disadvantages of composite materials compared to traditional building materials (Table 2).

Table 2. Disadvantages of composite materials

Material	Properties and Characteristics
Carbon Fiber	Complex and lengthy manufacturing process. Sensitive to impact damage which reduces its strength characteristics. To avoid contact with metal, carbon fiber inserts are made from fiberglass. High cost.

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Fiberglass	High cost. Low modulus of elasticity. Strength decreases in aggressive environments.
Organoplastic	Short lifespan (about five years). Low compressive strength (significantly lower than tensile strength). Begins to age in humid conditions.
Textolite	Strength and water resistance drastically decrease if manufacturing technology is violated. Dust from mechanical processing is explosive.
Carbon Concrete	Susceptible to chemical effects, hence it is coated with special protection. Textile material used to reinforce carbon concrete needs to be treated with a special coating to ensure adhesion. High cost. Low density.
Polystyrene Concrete	Low adhesion levels.

The properties of composite reinforcement are selected by choosing the type of reinforcing material, resin, percentage of reinforcing material, and its orientation. The choice of fiber type and percentage is based on the requirements for stiffness, strength, and durability, while the choice of matrix is determined by the production technology of the composite itself and the external operating conditions. Deformation diagrams of some fiber types for composites are shown in Figure 3.

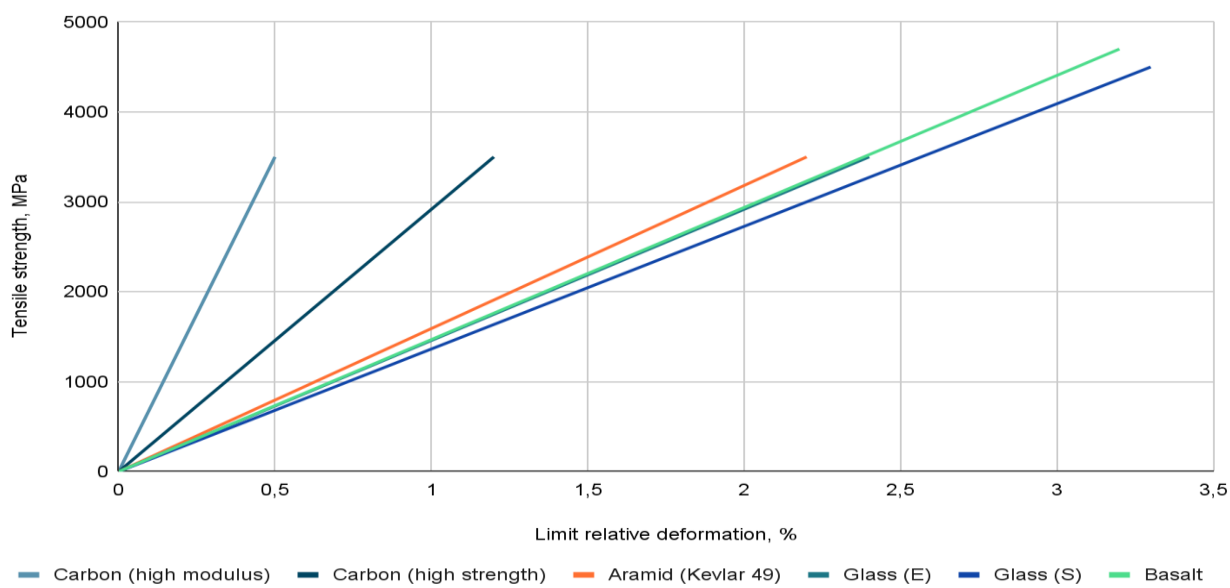

Figure 3. Deformation diagrams for the main types of reinforcing fibers

Among the most widely used composite materials in construction are: fiber concretes; polymer concretes; textiles; organoplastic composites; glass plastics and carbon plastics [27];

Among the most widely used building elements and structural solutions are: piles; rebars; panels; bridges; water supply systems; poles; tanks; ceilings, etc.

Figure 4 shows examples of reinforcement of building structures.

а

б

в

г

Figure 4. Reinforcement of building structures:

a – reinforced concrete reinforcement; b – reinforcement of the floor slab; c – reinforcement of columns; d – reinforcement of brick walls

DISCUSSION

This study highlights the transformative potential and crucial role of composite materials in modern construction. Through the integration of advanced scientific approaches and advanced technologies, composite materials are becoming increasingly indispensable in the design and engineering of modern structures. These materials offer improved performance characteristics, such as superior strength-to-weight ratio and adapted mechanical properties, which are essential to meet the stringent requirements of modern construction projects.

The significance of this research lies in the comprehensive study of the design, fabrication, and application of composite materials. Using methodologies such as additive manufacturing, finite element analysis, and neural network technologies, the study shows how these materials can be optimized for specific structural and performance requirements. Such optimization is critical to ensure the durability, safety, and efficiency of constructed structures.

A notable contribution of this work is the detailed study of the physical and mechanical properties of various composite materials in comparison to traditional building materials. This comparison provides valuable information on the advantages and limitations of composites, helping engineers and architects select and apply the materials. The analysis shows that while composites offer many advantages, they also pose challenges such as complex manufacturing processes and sensitivity to environmental conditions.

Despite the promising results, this study recognizes several limitations. One major limitation is the lack of a standardized regulatory framework governing the use of composite materials in construction. This regulatory gap may hinder wider adoption and require further development of industry standards and guidelines. In addition, the high costs associated with composite materials and manufacturing processes pose economic challenges that need to be addressed to facilitate wider adoption.

Moreover, the study emphasizes the importance of continuous research and innovation in the field of composite materials. Continuous progress in materials science and engineering is necessary to overcome current limitations and discover new applications. This includes developing more cost-effective manufacturing techniques, improving material properties, and establishing comprehensive testing and validation protocols.

CONCLUSION

In conclusion, composite materials represent a major advancement in the construction industry, offering unprecedented opportunities for innovation and performance enhancement. This study provides a fundamental understanding of their potential and challenges and serves as a guide for future developments. By addressing the identified limitations and continuing to push the boundaries of materials science, the construction industry will be able to take full advantage of the benefits of composite materials, leading to safer, more efficient, and sustainable building environments.

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