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THE MEANING AND FUTURE OF FIBERGLASS IN MODERN ENGINEERING

Summary. *This paper examines the advantages of using fiberglass-based composite materials in the production of automotive components. The potential of fiberglass-based composites to replace metal structures in vehicles for achieving superior performance characteristics in the automotive industry is explored. Due to their high durability, strength, lightweight, and corrosion resistance, composites with ballistic properties are widely utilized. Attributes such as fire and lightning resistance can be achieved through a straightforward and cost-effective manufacturing process. It is noted that structural elements of vehicles such as chassis, braking system components, steering systems, battery and charging-related components, as well as differential and suspension systems, can be manufactured using fiberglass-based composite materials.*

The use of fiberglass-based composites reduces overall costs compared to traditional materials, thereby expanding opportunities for vehicle manufacturers. The potential of self-healing composites in automotive engineering is highlighted as a promising development.

Key words: *Fiberglass, composite materials, epoxy resin, engineering, self-healing, economic feasibility, polyester.*

Polymers are attractive matrices for composites due to their relatively low density, ease of processing, and excellent mechanical properties. High-temperature resins are widely used in modern engineering. Fiberglass reinforcement receives the main load, especially if the composite consists of fibers dispersed in a weak matrix (for example, carbon-epoxy composite) [1–5]. Fiberglass (GRP or FRP-fiberglass) is made of interwoven glass fibers bonded with resin. It gained popularity due to its excellent characteristics.

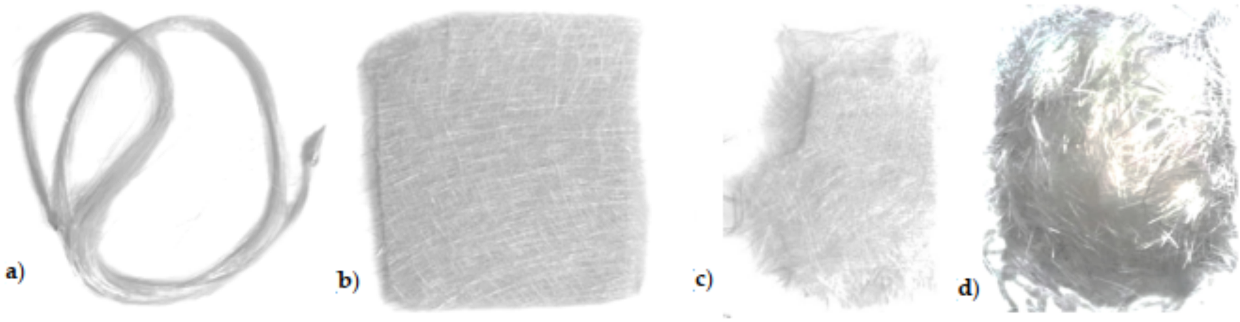

Fig. 1. The main types of fiberglass: with a continuous long thread (a), braided and randomly located (b), fibers with a matte cut (c) and chopped (d)

The history of fiberglass dates back to ancient civilizations such as the Egyptians and Phoenicians, who first experimented with fiberglass for decorative purposes. However, its scope was limited, only coarse fibers were produced, and its true potential remained unrealized.

In the late 19th century, John Player developed an innovative process for the mass production of fiberglass, mainly for insulation. In 1880, Hermann Hammesfahr received a patent for a fabric made of fiberglass mixed with silk, which made it strong and fire resistant. These achievements laid the foundation for future innovations [8].

In the 1930s, researcher Dale Kleist accidentally discovered the technology for obtaining thin glass fibers while trying to weld glass blocks. Realizing the potential of this accidental discovery, engineers improved the technology of glass fiber production and patented it in 1933. This was a turning point when, in 1932, the air filter – the first commercially successful fiberglass product – appeared on the market.

Currently, this material is used in various fields of human activity, such as buildings and structures of the industrial and civil complex (29%), transport (25%), electricity and electronics (16%), sports and recreation (14%) and industrial equipment (11 %). Among the valuable properties of fiberglass, the following advantages can be distinguished: affordable price, light weight, fire resistance and excellent environmental characteristics (composite materials are recyclable, which is convenient for use in environmentally friendly technologies) [10–15].

Fiberglass is widely used for the production of various reinforced composite materials. Fiberglass insulation is one of the most commonly used insulating materials in construction. It is made from recycled shards of glass and sand, and can be purchased in the form of sheets and blankets. Due to the soft structure of fiberglass insulation, irregularities are easily eliminated.

For example, fiberglass is used for reinforcement, insulation, and optics. In most cases (9 out of 10), fiberglass is used to reinforce concrete or polymers (thermosetting plastic materials such as polyester or epoxy resin) to produce composite materials that can replace steel. For insulation, glass is used in the form of short fibers that form a kind of mattress, often called glass wool. This material is also used for thermal insulation. Fiberglass has high tensile strength: 3400 MPa... 4400 MPa. The fibers in the composite material are protected by a binder and resin. The chemical properties of fiberglass are perfectly manifested when exposed to a humid environment or water. Fiberglass has thermal resistance formed by structural bonds at high temperature, which is called thermal compaction [7].

Let us analyze in more detail the main advantages of fiberglass-based composite materials. Composite materials have a tensile strength that is 15 times higher than similar characteristics of conventional materials. A strength-to-weight ratio of material, known as specific strength, compares its strength to its weight. The high strength-to-weight ratio of composites is perhaps their most significant advantage. Multi-layer composite materials absorb more energy than conventional single-layer steel, allowing automotive engineers to reduce vehicle weight by as much as 60% while improving crash safety. For example, one can make a composite material that does not bend in one direction, while the metal must be thicker to achieve a similar level of strength.

Durability and resistance to damage. Metals are prone to fatigue, while composites retain their shape in hot or cold weather, in wet or dry conditions, without corroding. Composites are more economical in terms of price per cubic inch and cost of raw materials [9].

Impact resistance. Composites can be designed to withstand impacts such as a sudden bullet impact or blast wave. Due to this characteristic, composites are used to make bulletproof vests and panels, as well as to protect buildings, military equipment, helmets and aircraft from explosions.

Corrosion resistance. Products based on composites are highly resistant to aggressive chemical and temperature influences. For more than 25 years, numerous cases of successful operation of air ducts made of fiberglass reinforced polymer in aggressive chemical conditions around the clock have been recorded at chemical industry enterprises. Composite materials containing fiberglass are resistant to corrosion under the influence of oxygen, moisture, aggressive substances, salt water and humid environments. For this reason, composite materials are an important component of the marine industry and companies that transport products and chemicals through pipelines and in containers [6].

Thermal conductivity. Composite materials have low thermal and electrical conductivity, making them excellent insulators for components that require insulation. However, if it is necessary to create heat-conducting parts, heat-conducting materials can be included in the composition of the composite, while maintaining the necessary properties of the composites. For example, polyamide composites have very high thermal conductivity. They are less heavy than metals with a high glass transition temperature. This material can be modified to obtain the best properties depending on the application by substituting carbon fibers that have a low coefficient of thermal expansion (CTE).

Non-magnetic properties. Since composites do not contain metals, they do not have magnetic properties, which allows them to be used in sensitive technological equipment. The large magnets used in magnetic resonance imaging (MRI) machines work more efficiently without magnetic interference. Composite materials inside microchannels are magnetized when two rectangular permanent magnets of the same polarity are placed in the middle of the channel length so that the direction of their magnetization is perpendicular to the channel wall [16].

Flexibility of design. Composite materials provide structural flexibility in the automotive industry, allowing engineers and designers to create more inventive and efficient designs than traditional metals. Composite materials can be given complex shapes to create aesthetic and economical designs, enhancing the aesthetic appeal and functionality of car exteriors. Composites can be easily adapted to ensure environmental safety. Engineers can tune the mechanical properties of composite materials by changing fiber type, orientation, and stacking order, providing components with precise stiffness, strength, and damping characteristics. Composite materials can be combined into a single part, which simplifies the design and eliminates the need for several components, acting as a sound-proofing, heat-insulating and structural element.

Dimensional stability. Dimensional stability is especially important and critical to the structural integrity and long-term performance of automotive components. For this reason, composite materials are used in the automotive industry to reduce mechanical loads and environmental factors. A low coefficient of thermal expansion is a key design technique for automotive applications, as it minimizes dimensional changes and provides maximum dimensional stability under temperature fluctuations. Some composites, especially those with an organic matrix, can undergo dimensional changes due to moisture absorption, but these changes can be minimized by appropriate design and material selection.

Chemical resistance. Composite materials are becoming increasingly popular in the automotive industry due to their chemical resistance, which is determined by the type of material and environmental conditions.

Electrical non-conductivity. The low electrical conductivity of composite materials is crucial to prevent problems such as interference and short circuits. Their electrical conductivity depends on the used fibers, matrix materials and additives [18].

Flexibility of design. Composite materials open up new possibilities for design due to their versatility. With proper tool design and operating conditions, traditional machining methods including drilling, turning, sawing, milling, and grinding can be used to process composite materials. Other non-traditional methods are also used, such as water jet, laser, electric discharge and ultrasonic processing.

Manufacturing methods. Depending on the type of composite and specific application in the automotive industry, various methods of manufacturing composite materials are used. Let us describe several typical manufacturing methods [17]:

– Hand laying. One of the earliest and most basic methods is hand or manual laying, which involves applying layers of reinforcing materials to the form by hand. The polymer matrix is also poured manually in layers. This method is often used for prototyping or small-volume production. Various methods can be recommended for the manufacture of composite plate leaf springs.

A type of reinforcement known as "pre-cut, pre-impregnated" is applied by hand in individual layers in a manufacturing process called "hand laying". This method involves the processing of a large number of fibers pre-impregnated with resin, collected in harnesses and either woven together or arranged in one unidirectional layer. Each layer is molded by hand into the required shape before it is firmly glued to the surface of the previous layer or mold, leaving no gaps between the layers. The hand layup method is often used to create fiberglass and composite automotive materials. Composite materials that store strain energy well include e-glass/epoxy in the direction of the fibers. As a result, the stacking is chosen in such a way that it is unidirectional along the longitudinal direction of the spring [19].

– Resin Transfer Molding (RTM). According to this technology, dry reinforcing materials are placed in the cavity of the mold during the molding process, followed by the injection of polymer resin under pressure. Resin transfer molding technology allows better control of resin content and part thickness and is suitable for medium volume production. Thanks to automation capabilities, interesting product characteristics and reproducibility of parts, RTM is attractive to the automotive industry. Recent studies of the injection molding process using multigate resin transfer molding have shown that air voids are often formed in the weld lines or in the resin contact zone due to the head-on collision of opposing resin streams. RTM technology is well suited for manufacturing parts that require a high strength-to-weight ratio, excellent dimensional accuracy, and complex geometry [20].
– Pressing. Compression molding is used for mass production of products from composite materials. During this process, prepreg and fabric are placed in the mold cavity. The mold is then sealed to harden the resin and form the fiberglass composite product. Compression molding is used to produce body panels, hoods, roofs and spoilers. Rubber tires, glass-matted thermoplastic materials such as bumpers, and sheet molding compounds for automotive exterior panels are the most common materials used in compression molding with composite materials based on fiberglass. Pre-impregnated intermediates such as thermosetting sheet molding compounds (SMC), glass matte thermoplastics (GMT) or long fiber

thermoplastics (LFT) are processed by compression molding to create semi-structural and structural fiberglass composite components.

Automated fiber placement (AFP) and automatic tape laying (ATL) use robotic devices to automatically apply continuous fibers or tapes to the mold surface. Thanks to high accuracy and repeatability, these methods allow to obtain composite materials of complex shape using pro-technology. The ATL is capable of applying wide unidirectional prepreg tapes to a machined surface with automatic backing removal. In contrast, AFP uses tapes of thin strips of prepreg material called harnesses. AFP is a method of creating complex, lightweight and high-quality structures for modern cars.

The use of fiberglass-based composite materials in the chassis helps to reduce the overall weight of the car, improve handling and fuel economy. Composite materials have built-in damping properties that reduce noise and vibration transmitted through the chassis. Fiberglass-based composite materials can have excellent fatigue strength, ensuring that the chassis will maintain its performance characteristics.

Sheet springs are an important component of the car suspension system. They consist of many layers of sheet springs of different sizes, with the most important layer on top and the rest of the layers attached to each other. Plate springs are directly connected to the frame either at both ends or only at one end. Corvette springs are made of fiberglass-reinforced epoxy polymer composite and have more than five times the life of steel springs. Compared to steel springs, composite springs provide a smoother ride and quicker response to road impact pressure. In addition, fiberglass composite plate springs provide excellent corrosion resistance and reduce the likelihood of accidental failure, which helps reduce vehicle suspension noise.

Car bumpers are designed to absorb and distribute energy in low-speed collisions, which reduces damage to the car and its passengers. Recently, there has been a tendency to use composite materials based on fiberglass in the construction of bumpers due to their attractive properties. Polymer composites reinforced with carbon fiber and glass fiber are often used for car bumpers. Composite materials with high impact properties include carbon fiber reinforced polymers (CFRP) and glass fiber reinforced polymers (GFRP). It reduces vehicle damage and increases occupant safety by absorbing and dissipating energy in low-speed collisions.

Fiberglass composite car doors combine two or more different materials with different properties, such as fiber and resin. Composite materials have a high degree of stiffness and strength, which improves the structural integrity of car doors and their impact resistance. They can resist corrosion, wear and fatigue more effectively than metals. The high strength and impact resistance of composite materials is well known. In the event of a crash, composite doors can protect people inside the vehicle, allowing automakers to create doors with complex curves and decorative elements. This makes it possible to create doors that harmoniously complement the overall design of the car, giving it a more elegant look. Fiberglass-based composite doors provide better sound insulation, helping to reduce the level of noise that penetrates through the doors, making the car interior quieter.

Fiberglass-based composite materials are used to manufacture car sunroofs, which have unique characteristics. They provide natural lighting, ventilation and aesthetic appeal of the car, as well as improve dynamic characteristics. Weight reduction is one of the main reasons for using composite materials in sunroofs, as it can increase the overall efficiency of the vehicle. Compared to ordinary glass, fiberglass-based composites have increased impact resistance.

Another application of automotive fiberglass composites is in the engine cradle, a structural member that holds the engine and other related components. One of the most important parts of the engine subsystem is the engine mount, which performs four main functions: supporting the engine, transmission and suspension, distributing large loads on the chassis, reducing vibration and impact, as well as increasing rigidity and preventing collisions. Due to their natural thermal insulation properties, fiberglass-based composite materials can improve thermal regulation by reducing heat transfer from the engine to other parts of the vehicle. Fiberglass-based composite materials are capable of absorbing collision energy due to their shock-absorbing properties. Composite engine mounts can reduce impact and protect other critical vehicle components in the event of a crash, and facilitate integration with other components such as suspension systems and mounting points, resulting in a more unified and efficient vehicle design.

Fiberglass-based composite fenders are commonly used in high-performance and sports cars to reduce weight and improve the overall performance of the vehicle.

In the automotive industry, numerous types of fiberglass composites are used for the manufacture of various parts. Due to different operational characteristics, they are used in different ways.

Fiberglass is also used in the production of toothed and V-belts due to its high tensile strength, which is provided by reinforcing the glass fiber with rubber. Abrasion resistance is another important property that determines its use in the production of brake pads and clutches. The clutch discs are reinforced with woven fiberglass to ensure the integrity of the composite material. In the manufacturing process, anti-abrasive additives are often used. These components are added to the cladding, which is the first of three layers of the composite. As a rule, the lining consists of 85% resin, to which anti-abrasive chemicals are added, and is covered with several layers of mat made of reflective threads. The high content of resin in the upper layer provides a smooth surface, which makes it suitable for the manufacture of hoods and contributes to the reduction of aerodynamic losses. Adding one layer of C-veil allows for an even smoother surface. It is easy to add dyes to the top layer of resin and provide protection against ultraviolet radiation, which allows you to keep the coating for a long time. Therefore, the automotive industry increasingly prefers the use of fiberglass.

A promising direction for the use of fiberglass in the automotive industry is the development of composite materials capable of recovering after damage without external assistance. Self-healing technology can improve a vehicle's overall durability, safety, and performance. Thanks to increased elasticity, the consequences of collisions will be reduced, which will increase the safety of passengers. Car owners will be able to save on maintenance, thanks to the self-healing technology, which reduces the need for regular repairs or touch-ups. Self-healing coatings also protect the car from environmental pollution, acid rain and ultraviolet rays.

Given the growing demand for glass fiber composite materials in the automotive sector, it is expected that their use will continue to grow successfully in the future.

Conclusions. The development of composite materials based on fiberglass for the automotive industry has significantly changed the automotive industry, providing many advantages that increase environmental friendliness, efficiency and operational characteristics. It was found that due to the outstanding strength-to-weight ratio, composite materials are ideal for use in various structural elements of cars. The feasibility of manufacturing such elements of the car as the chassis, brake pads, hood, bumper, wing, engine support, interior and exterior elements, tires and roof hatch from composite materials based on fiberglass was considered, in order to achieve light weight, high strength, good fatigue resistance, viscosity, resistance to damage, stiffness, thermal insulation and wear resistance. It has been established that self-healing composite materials can be adapted to future vehicle performance.

References

1. Ahmad H., Markina A. A., Porotnikov M. V., Ahmad F. A review of carbon fibre materials in automotive industry. *IOP Conf. Ser.* 2020. 971 (3). 032011. doi: https://doi.org/10.1088/1757-899x/971/3/032011.

2. Agarwal J., Sahoo S., Mohanty S., Nayak S. K. Progress of novel techniques for lightweight automobile applications through innovative eco-friendly composite materials: A review. *J. Thermoplast. Compos. Mater*. 2020. 33 (7). P. 978-1013. doi: https://doi.org/10.1177/08927057188155.

3. Brasington A., Sacco C., Halbritter J., Wehbe R., Harik R. Automated fibre placement: a review of history, current technologies, and future paths forward. *Compos. Part C: Open Access.* 2021. 6. 100182. doi: https://doi.org/10.1016/j.jcomc.2021.100182.

4. El-Wazerya M. S., El-Elamy M. I., Zoalfakar S. H. Mechanical Properties of Glass Fiber Reinforced Polyester Composites. *International Journal of Applied Science and Engineering.* 2017. 14 (3). P. 121-131. doi: https://doi.org/10.6703/IJASE.2017.14(3).121.

5. Gajjar T., Shah D., Joshi S., Patel K. M. Analysis of Process Parameters for Composites Manufacturing using Vacuum Infusion Process. *Mater. Today.: Proc.* 2020. 21. P. 1244-1249. doi: https://doi.org/10.1016/j.matpr.2020.01.112.

6. Kumar S. N., Kumar V. G., Kumar V. C., Prabhu M. Experimental Investigation on Mechanical Behavior of EGlass and S-Glass Fiber Reinforced with Polyester Resin. *SSRG International Journal of Mechanical Engineering*. 2018. 5(5). P. 19-26. doi: https://doi.org/10.14445/23488360/IJME-V5I5P104.

7. Kurien R. A., Selvaraj D. P., Sekar M., Koshy C. P. Green composite materials for green technology in the automotive industry. *IOP Conf. Ser*. 2020. 872 (1). 012064. doi: https://doi.org/10.1088/1757-899x/872/1/012064.

8. Marichelvam M., Kandakodeeswaran K., Maheswaran K., Geetha M. Investigation on mechanical properties of automobile strut made by GFRP

composites. *Mater. Today.: Proc*. 2020. 45. P. 1338-1347. doi: https://doi.org/10.1016/j.matpr.2020.06.026.

9. Mohammadi H., Ahmad Z., Mazlan S. A., Faizal Johari M. A., Siebert G., Petrů M. Lightweight glass fibre-reinforced polymer composite for automotive bumper applications: a review. *Polymers*. 2022. 15 (1). 193. doi: https://doi.org/10.3390/polym15010193.

10. Ngo T. Introduction to Composite Materials. *IntechOpen eBooks*. 2020. doi: https://doi.org/10.5772/intechopen.91285.

11. Praveenkumar B., Gnanaraj S. D. Case Studies on the Applications of Phenolic Resin-Based Composite Materials for Developing Eco-Friendly Brake Pads. *J. Inst. Eng. (India) Ser. D*. 2020. 101 (2). P. 327-334. doi: https://doi.org/10.1007/s40033-020-00231-4.

12. Rajak D. K., Wagh P. H., Linul E. Manufacturing Technologies of Carbon / Glass Fiber-Reinforced Polymer Composites and Their Properties: a review. *Polymers*. 2021. 13. 3721. doi: https://doi.org/10.3390/polym13213721.

13. Rajak D. K., Pagar D. D., Behera A., Menezes P. L. Role of composite materials in the automotive sector: Potential applications. *Energy, Environment, and Sustainability, Springer Nature*. 2021. P. 193-217. doi: https://doi.org/10.1007/978-981-16-8337-4_10.

14. Rubino F., Nistico A., Tucci F., Carlone P. Marine application of fibre reinforced composites: a review. *J. Mar. Sci. Eng*. 2020. 8 (1). 26. doi: https://doi.org/10.3390/jmse8010026.

15. Sajan S. S.P. S., Selvaraj D. P. A review on polymer matrix composite materials and their applications. *Mater. Today.: Proc*. 2021. 47. P. 5493-5498. doi: https://doi.org/10.1016/j.matpr.2021.08.034.

16. Sarfraz M. S., Hong H., Kim S. S. Recent developments in the manufacturing technologies of composite components and their cost-effectiveness in the automotive industry: A review study. *Compos. Struct*. 2021. 266. 113864. doi: https://doi.org/10.1016/j.compstruct.2021.113864.

17. Salifu S., Desai D., Ogunbiyi O. F., Mwale K. Recent development in the additive manufacturing of polymer-based composites for automotive structures – a review. *Int. J. Adv. Manuf. Technol.* 2022. 119 (11-12). P. 6877-6891. doi: https://doi.org/10.1007/s00170-021-08569-z.

18. Seydibeyoglu M. O., Dogru A., Kandemir M. B., Aksoy O. Lightweight composite materials in transport structures. *CRC Press eBooks.* 2020. P. 103-130. doi: https://doi.org/10.1201/9780429244087-5.

19. Vlase S., Gheorghe V., Marin M., Ochsner A. Study of structures made of composite materials used in automotive industry. Proc. Inst. Mech. Eng., Part L. *J. Mater.: Des. Appl.* 2021. Vol. 235, Is. 11. doi: https://doi.org/10.1177/14644207211019767.

20. Yuliang X., Zhang Y. He, F., Liu Y., Leng J. A Review of Shape Memory Polymers and Composites: Mechanisms, Materials, and Applications. *Adv. Mater*. 2020. 33 (6). 2000713. doi: https://doi.org/10.1002/adma.202000713.