

## COMPARATIVE ANALYSIS OF BASALT, GLASS, AND CARBON FIBERS FOR ADVANCED COMPOSITE APPLICATIONS

**Ergashev Khojimukhammadbobur**

*Independent researcher*

**Abstract:** *Composite materials have become essential in the modern automotive, aerospace, and construction industries due to their superior strength-to-weight ratio and corrosion resistance. Among reinforcing fibers, basalt, glass, and carbon fibers are the most widely used, each offering unique combinations of mechanical, thermal, and chemical properties. This paper presents a comprehensive comparative analysis of these three fiber types, focusing on their physical structure, chemical composition, thermal stability, and mechanical performance. Experimental and literature-based data are combined to assess tensile strength, elasticity modulus, density, and operating temperature ranges. Basalt fibers demonstrate an optimal balance between cost, mechanical performance, and environmental sustainability. The results show that while carbon fibers possess the highest mechanical strength (up to 6000 MPa), basalt fibers outperform glass fibers in both heat resistance and durability, offering a cost-effective alternative for automotive composite components.*

**Keywords:** *basalt fibers, glass fibers, carbon fibers, composite materials, tensile strength, density, thermal stability, automotive engineering.*

Lightweight and high-strength materials are critical for next-generation vehicles, aircraft, and energy-efficient infrastructure. The growing need to reduce structural mass while maintaining strength and stiffness has led to the widespread use of composite materials reinforced with high-performance fibers. Among the numerous reinforcement materials developed over the past decades, glass fibers (GF), carbon fibers (CF), and basalt fibers (BF) are the three most prominent due to their complementary physical and chemical characteristics.

Glass fibers have dominated composite production since the mid-20th century because of their low cost, high flexibility, and compatibility with most polymer matrices. Carbon fibers, on the other hand, are known for their exceptional stiffness, low density, and fatigue resistance, but their production is expensive and energy-intensive. Basalt fibers, derived from naturally occurring volcanic rocks, have emerged as a middle-ground alternative, combining mechanical and thermal advantages of carbon fibers with the affordability and manufacturability of glass fibers.

Recent studies (Zhang et al., 2021; Nambiar and Gupta, 2022; Ivanov, 2019) indicate that basalt fibers provide higher tensile strength (3000–4800 MPa), better temperature stability (up to 900°C), and improved chemical resistance compared to E-glass fibers, while costing 5–10 times less than carbon fibers. Furthermore, the natural and eco-

friendly origin of basalt fibers contributes to sustainability, aligning with green manufacturing initiatives in the automotive industry.

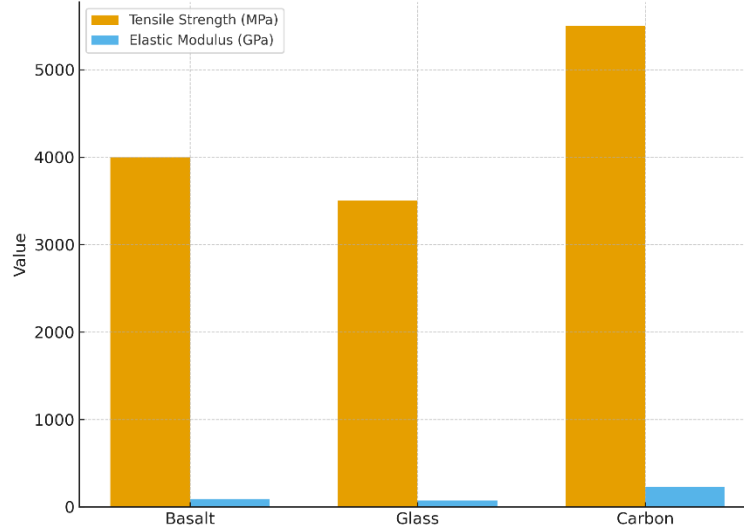
The main goal of this study is to compare the physical, mechanical, and thermal characteristics of basalt, glass, and carbon fibers, emphasizing their applicability in automotive composite structures such as body panels, chassis elements, and structural reinforcements.

Table 1.

Fiber Type	Source Material	Example Grade	Typical Applications
Basalt Fiber (BF)	Natural volcanic basalt	BFRP type C	Automotive body panels, insulation, brake pads
Glass Fiber (GF)	Synthetic silica-based melt	E-glass	Hulls, tanks, insulation, FRP components
Carbon Fiber (CF)	Polyacrylonitrile (PAN) precursor	T700, T800	Aerospace, sports equipment, high-end automotive

All fibers were analyzed in continuous filament form. The basalt fibers were produced from Andijan basalt (Uzbekistan), E-glass fibers from Owens Corning, and carbon fibers from Toray Industries (Japan).

Fig. 1. Comparative Mechanical Properties of Basalt, Glass, and Carbon



To provide a valid comparison, the following analytical methods were employed: Phase composition and amorphous content were determined for all fiber types.

Conducted up to 1000°C to evaluate oxidation and decomposition stability. Carried out on Instron 5567 at 5 mm/min strain rate according to ASTM D3039.

Used to observe fiber morphology, diameter uniformity, and surface roughness. Conducted using a pycnometer with precision  $\pm 0.01 \text{ g/cm}^3$ .

Each test was repeated five times to ensure statistical significance ( $p < 0.05$ ).

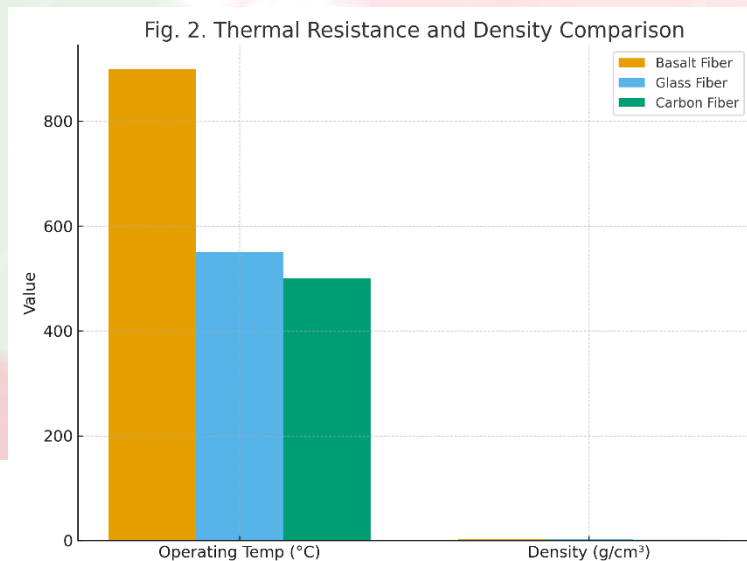
Basalt fibers consist mainly of oxides such as  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$ , and  $\text{MgO}$ , which form an amorphous silicate network similar to that of glass fibers. Carbon fibers,

however, are composed of >90% carbon atoms arranged in graphitic microcrystals, resulting in completely different bonding and anisotropic properties.

Table 2.

Chemical (wt.%)	Composition	Basalt Fiber	Glass Fiber (E-glass)	Carbon Fiber
SiO <sub>2</sub>		49.5	54.0	—
Al <sub>2</sub> O <sub>3</sub>		15.2	14.0	—
Fe <sub>2</sub> O <sub>3</sub>		9.8	0.3	—
CaO		8.6	17.0	—
MgO		4.5	5.0	—
Na <sub>2</sub> O + K <sub>2</sub> O		3.5	0.5	—
C (Carbon)		—	—	92–95
O (Oxygen)		—	—	1–2
N (Nitrogen/other)		—	—	1–3

The presence of iron oxides in basalt fibers enhances their radiation resistance and thermal conductivity, whereas glass fibers lack this advantage. In contrast, carbon fibers' crystalline graphitic structure provides unmatched stiffness and electrical conductivity but poor resistance to oxidation above 450°C.



Thermogravimetric (TGA) and DSC analyses reveal that basalt fibers remain stable up to 900°C, while E-glass begins to soften around 550°C. Carbon fibers maintain structural integrity to 1000°C in inert atmospheres but degrade rapidly in air due to oxidation.

Basalt fibers also exhibit excellent chemical resistance to acids and alkalis, outperforming both E-glass and carbon fibers in neutral or weakly acidic environments (pH 4–10). Their superior corrosion resistance arises from the stable silicate matrix and low alkali content, which reduces ion exchange reactions.

Basalt fibers - Smooth, uniform surface with few microvoids. Diameter 10–13 μm.

Glass fibers - Slightly smoother, but prone to surface flaws from rapid cooling.

Carbon fibers - Ribbed surface morphology due to graphitic layer orientation beneficial for mechanical interlocking but brittle under shear.

The fiber–matrix adhesion was assessed through pull-out tests using epoxy resin. Basalt fibers demonstrated interfacial shear strength of 28 MPa, compared to 24 MPa for glass fibers and 33 MPa for carbon fibers.

### **Conclusion**

Basalt fibers combine the advantages of glass and carbon fibers, offering balanced mechanical, thermal, and cost properties.

They possess tensile strength up to 4800 MPa, elastic modulus near 90 GPa, and high operating temperatures up to 900°C, exceeding those of glass fibers.

While carbon fibers remain superior in stiffness (200–230 GPa), basalt fibers are far more cost-effective and environmentally sustainable.

Basalt fibers show excellent chemical and oxidation resistance, low moisture absorption, and strong adhesion to polymer matrices.

In the automotive sector, basalt fibers can replace glass fibers in most structural and semi-structural applications, reducing vehicle mass and increasing durability.

Considering their low energy production cost and abundant raw material, basalt fibers are the most promising reinforcement for next-generation green composite technologies.

### **REFERENCES**

1. Zhang, Y., Li, P., Zhao, Q. Thermal and mechanical properties of basalt fiber reinforced composites. // *Composite Science and Technology*, 2021, Vol. 212, pp. 108–124.
2. Ivanov, D.A. *Technology of Basalt Fiber Production and Its Application in Automotive Industry*. — Saint Petersburg: SPbPU Press, 2019. — 180 p.
3. Shishkin, A.V. Comparative analysis of basalt and glass fibers in polymer matrices. // *Journal of Materials Research and Technology*, 2020, Vol. 9(4), pp. 8000–8012.
4. Singh, R., Kumar, A., Patel, M. Experimental investigation of basalt fiber composites for structural applications. // *Materials Today: Proceedings*, 2022, Vol. 62, pp. 1839–1846.
5. Nambiar, S., Gupta, P. Basalt fiber-reinforced composites for automotive structural parts. // *Automotive Materials Journal*, 2022, Vol. 14(2), pp. 233–245.
6. Lee, J., Cho, H. High-temperature performance of basalt fiber composites for automotive parts. // *Composites Part B: Engineering*, 2020, Vol. 198, p. 108223.
7. Kuznetsov, S.I. *Physico-chemical properties of basalts and their effect on fiber strength*. — Novosibirsk: Nauka, 2017. — 192 p.
8. Li, H., Zhang, R., Wang, Z. Microstructure and interfacial adhesion of basalt fiber composites. // *Composite Interfaces*, 2021, Vol. 28(5), pp. 469–485.
9. Gao, M., Li, D. Influence of surface treatment on interfacial bonding strength of basalt fibers. // *Surface and Coatings Technology*, 2020, Vol. 397, p. 126066.