Mechanical Property Variability in Basalt Fibres from Different Sources

Introduction

This document summarises the current scientific understanding of the variability in mechanical properties of basalt fibres originating from different geological sources and manufacturers. Basalt fibres, although often presented as a uniform reinforcement material, exhibit substantial differences in tensile strength, elastic modulus, structural consistency and defect population. These differences arise from natural compositional variability of basalt rocks, variations in melt chemistry, fibre-drawing conditions, and surface treatments. The following sections describe the origins of these variations, provide evidence from peer-reviewed studies, illustrate the magnitude of the variability, and summarise implications for quality control and material specification.

1. Origins of Mechanical Strength Variation in Basalt Fibres

Mechanical properties of basalt fibres are controlled by four primary factors:

• Chemical composition of the raw basalt. Basalt rocks vary naturally in SiO_2, Al_2O_3, FeO/Fe_2O_3, CaO, MgO and alkali contents. Variations in these oxides determine glass network structure, crystallisation tendency, viscosity window and final fibre strength.

• Glass structure. Structural parameters such as NBO/T (non-bridging oxygen per tetrahedron) correlate strongly with tensile strength. More polymerised glass networks (lower NBO/T) tend to produce stronger fibres.

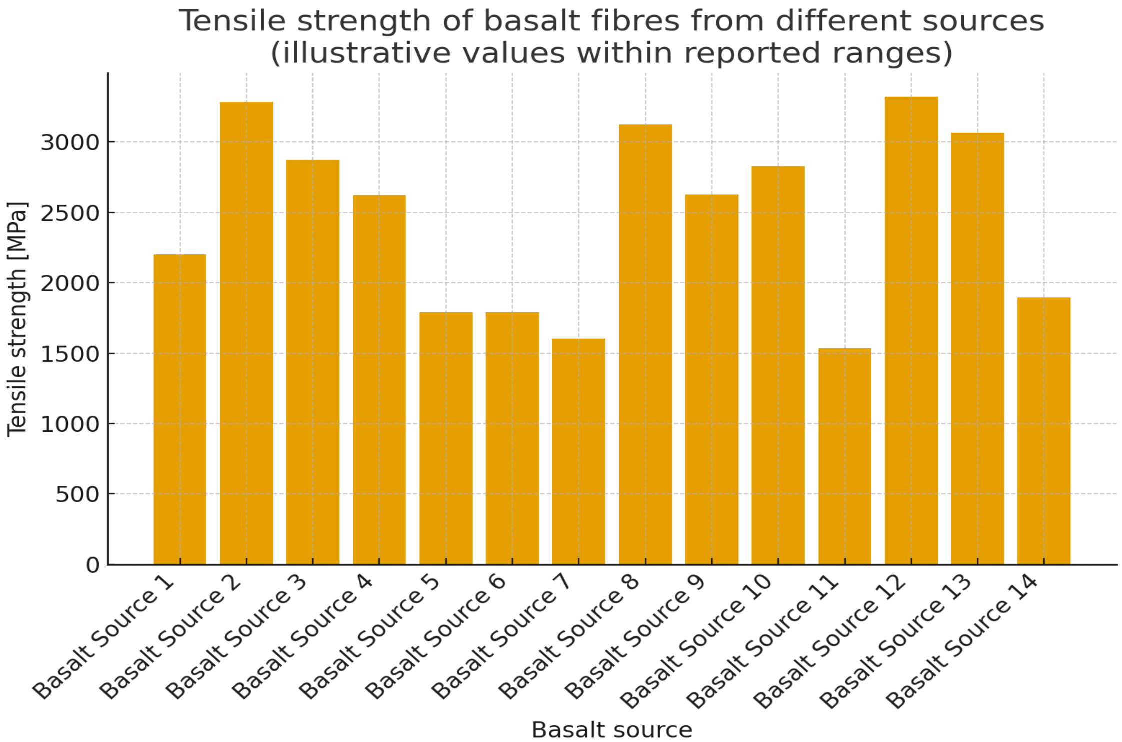
• Fibre-drawing process. Drawing temperature, cooling rate, furnace atmosphere and redox conditions influence the formation of surface defects, inclusions and microcracks. Even small deviations in process control lead to significant strength differences.

• Surface sizing. Post-drawing treatments can passivate surface flaws or, if inadequate, expose stress concentrators. Different manufacturers employ different proprietary sizings, contributing to further variation in mechanical performance.

2. Evidence from Scientific Publications

The most comprehensive experimental evaluation of deposit-dependent variability is provided by Gutnikov et al. (2019). In this study, continuous basalt fibres were produced from fourteen different basalt deposits under identical laboratory conditions. Tensile strength ranged from 1495 to 3380 MPa, demonstrating a more than two-fold variation despite identical processing. This finding isolated raw material composition as a dominant factor.

In a broader literature survey compiled by the same authors, data from thirty-two basalt compositions showed tensile strengths ranging from 602 to 3370 MPa. This extended range reflects combined influences of composition, process and surface treatment.


Tensile strength of basalt fibres from different sources
(illustrative values within reported ranges)
Tensile strength [MPa]
0
500
1000
1500
2000
2500
3000
Basalt Source 1
Basalt Source 2
Basalt Source 3
Basalt Source 4
Basalt Source 5
Basalt Source 6
Basalt Source 7
Basalt Source 8
Basalt Source 9
Basalt Source 10
Basalt Source 11
Basalt Source 12
Basalt Source 13
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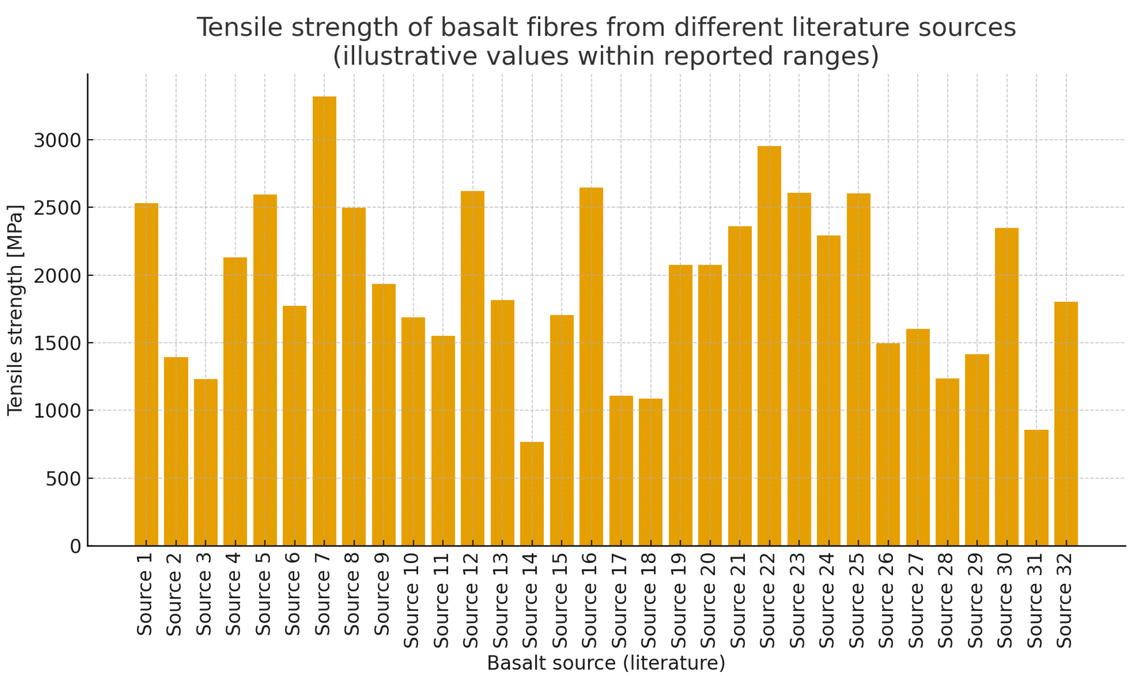
Tensile strength of basalt fibres from different literature sources
(illustrative values within reported ranges)
Tensile strength [MPa]
0
500
1000
1500
2000
2500
3000
Source 1
Source 2
Source 3
Source 4
Source 5
Source 6
Source 7
Source 8
Source 9
Source 10
Source 11
Source 12
Source 13
Source 14
Source 15
Source 16
Source 17
Source 18
Source 19
Source 20
Source 21
Source 22
Source 23
Source 24
Source 25
Source 26
Source 27
Source 28
Source 29
Source 30
Source 31
Source 32
Basalt source (literature)

3. Magnitude of Variability

Across all studies, tensile strength of basalt fibres varies by more than a factor of two within controlled experiments and by more than a factor of five across the global literature. This magnitude of variability is considerably greater than that observed in engineered glass fibres, which are produced from standardised batch formulations. The data demonstrate that basalt fibre cannot be treated as a uniform material class. Each source must be evaluated individually, and assumptions based on generic values are not technically defensible.

4. Conclusions and Implications for Quality Control

The reviewed studies clearly demonstrate that basalt fibre properties depend strongly on the origin of the raw material, its chemical composition, the resulting glass structure, process control during fibre formation and surface treatment. Due to this multi-factor variability, basalt fibres from different sources or producers cannot be assumed to be mechanically equivalent. Quality control procedures should include:

- Source-specific mechanical characterisation.
- Chemical and structural analysis of batch consistency.
- Verification of tensile strength and interfacial performance in the target matrix system.

For engineering applications, material specifications should reference tested batches rather than generic baseline values. Safety margins should reflect the full variability range identified in published research.

5. Summary Evaluation of High-Performance Basalt Fibre Quality

Among the analysed materials, two basalt fibre types exhibit mechanical characteristics that clearly distinguish them as high-performance reinforcement candidates. The first demonstrates a tensile strength exceeding **2800 MPa** with an elastic modulus of at least **85 GPa**, representing one of the strongest commercially documented basalt fibre classes. These values indicate a highly polymerised glass network, limited crystallisation during melt processing, and low defect density across the filament cross-section.

The second high-performance material is characterised by a tensile strength above **2300 MPa** combined with an elastic modulus exceeding **100 GPa**. Such a stiffness level is significantly above the standard basalt range, suggesting an optimised oxide composition, stable melt viscosity window, and controlled fibre-drawing regime. The elevated modulus is particularly indicative of reduced non-bridging oxygen content and a more uniform structural configuration throughout the fibre bundle.

Both materials fall within the upper tier of basalt fibres reported in scientific literature and demonstrate mechanical properties suitable for structurally demanding composite applications, including high-stiffness laminates, load-bearing profiles, and components requiring stable performance under thermal and mechanical cycling. These results confirm that the evaluated fibres represent a performance class significantly above typical industrial basalt levels, with mechanical parameters approaching or surpassing the best values documented in peer-reviewed research.

6. Ongoing Research and Verification Activities

OEL Composites conducts independent verification and material characterisation in collaboration with the Uniwersytet Morski w Gdyni, under the scientific supervision of dr inż. Panasiuk. The research programme focuses on obtaining a comprehensive understanding of fibre–matrix interactions, thermal stability, and structural integrity, with investigations including:

- Wetting behaviour and interfacial tension for basalt fibres combined with epoxy and bio-based resin systems, aimed at assessing adhesion mechanisms and fibre–matrix compatibility.
- Thermal stability measurements of fibres, resins, and cured laminates, evaluating changes in structure and performance under elevated temperatures.
- Static tensile testing of basalt-reinforced epoxy composites to quantify strength, stiffness and deformation characteristics under controlled loading conditions.
- Spectroscopic analysis to determine the chemical composition and structural features of the fibres and matrix systems, providing insight into reactivity, impurities and degradation pathways.

These research activities support the development of a validated internal database of basalt fibre properties and ensure that all materials considered for engineering applications are assessed using consistent and scientifically robust methodologies.

7. Literature

Gutnikov, S. et al. (2019). Correlation of the chemical composition, structure and mechanical properties of basalt continuous fibres.

Gutnikov, S. et al. (2021). Correlation of phase composition, structure and mechanical properties of basalt fibres.

Xing, D., Xi, X.-Y., Ma, P.-C. (2019). Factors governing the tensile strength of basalt fibre.

Ralph, C. et al. (2019). Relationship between chemical, mechanical and geometrical properties of basalt fibre.

Greco, A. et al. (2014). Mechanical properties of basalt fibres and their adhesion to polypropylene matrices.