Basalt Fibre (BF) - GZI (Grado Zero Innovation - http://www.gzespace.com/)

Properties, characteristics and issues to be solved

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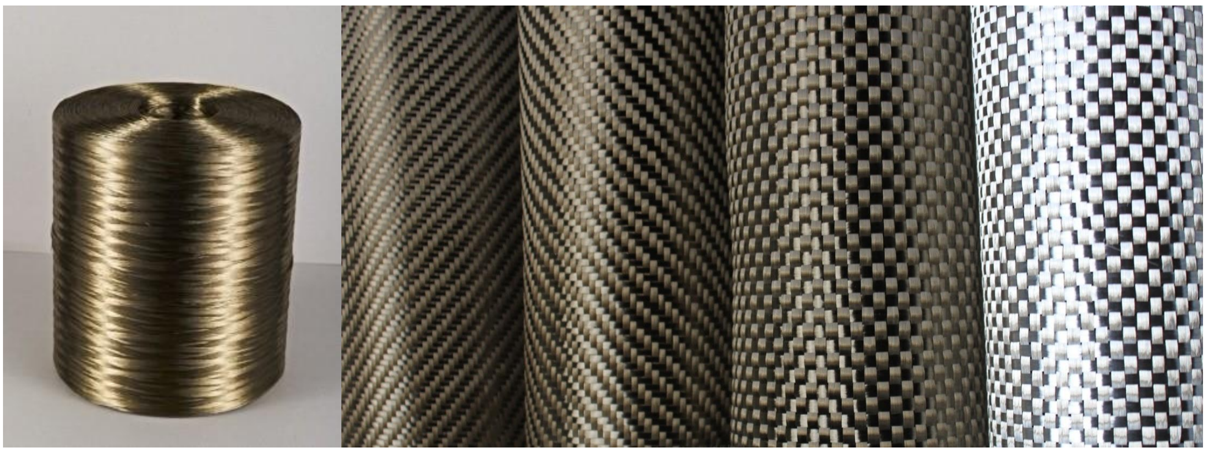
Basalt Fibre (BF)

The objectives of future researches on basalt fibres can be focused in the determination of feasibility and practicability in the exploitation of basalt fibre in reinforced polymer composites as beneficial material alternative for applications in which at the moment only glass, carbon and aramid fibres have a real market.

No significant differences in stiffness and strength were found between basalt fabric reinforced polymer composites and glass composites reinforced by fabrics of similar weave patterns, and the performance of these materials were also assessed not so far from carbon fibre reinforced polymer composites. What is really interesting in **basalt fibre** is that it **combines ecological safety, natural longevity, good mechanical properties, and high level thermal characteristics**. It is not a new material, but its applications are surely innovative in many industrial and economic fields, from building and construction to energy efficiency, from automotive to aeronautic and space, thanks to its good mechanical and chemical and thermal performances.

FEATURE	**BF**	**E-glass**	**S-glass**	**C-fibre**
Tensile Strength (MPa)	3000/5000	3100/3800	4020/4650	3500/6000
Elastic Modulus (GPa)	79/95	72.5/75.5	83/86	230/600
Elongation at break (%)	3.1	4.7	5.3	1.5/2
Diameter of filament (µm)	6/21	6/21	6/21	5/15
Textile title (tex)	60/4200	40/4200	40/4200	60/2400
Temperature of use (°C)	-270/+700	-50/+380	-50/+300	-50/+700
Price (USD/kg)	2.5	1.1	1.5	30



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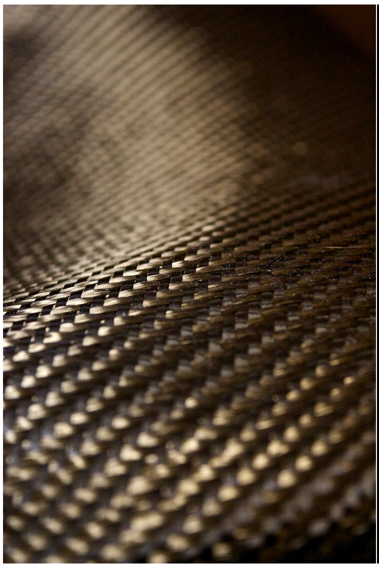
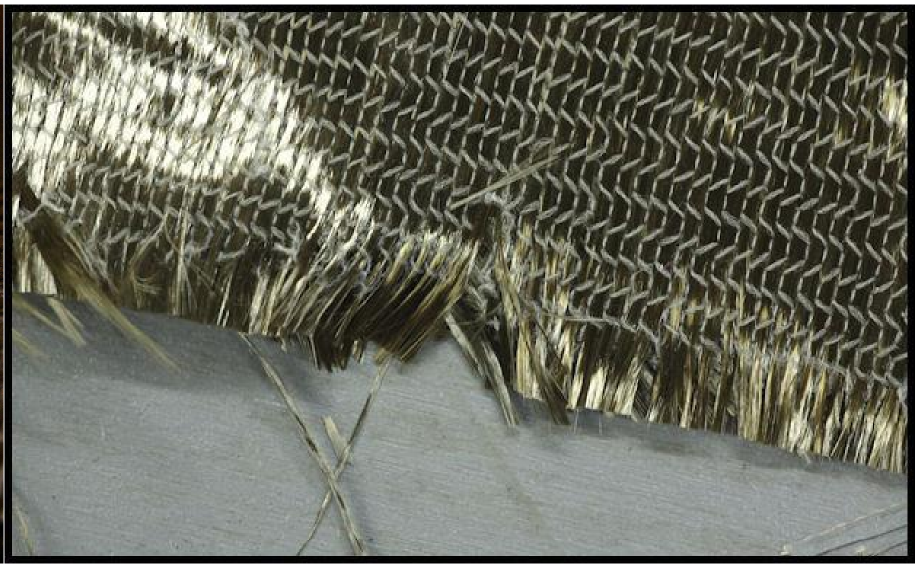




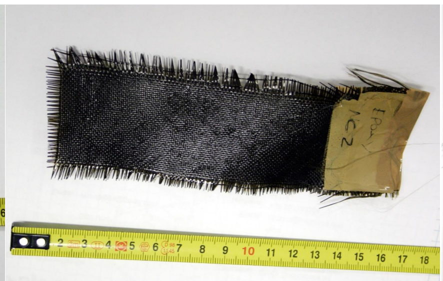
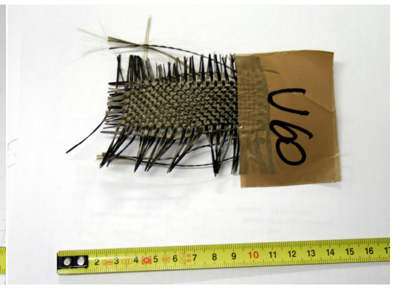
A significant and steady growth up to 10 % of manufacture of composite materials is observed in the world at the moment. One of the basic reinforcing elements of composite materials is fibres. Besides fibrous materials are widely applied in quality of thermal, sound-proof, and filtering materials. For this purpose glass fibres are widely applied, and for particularly responsible and expensive products carbon fibres are usually used. However these materials not completely meet the requirements of the present stage. Glass fibre has notable restrictions under its characteristics of use: specific durability, temperature of application, chemical stability, especially in alkaline environments and against acidic and salt attack/corrosion. By producing of good quality glass fibre it's essentially to use relevant quantities of other components - i.e., oxide boron (B2O3). In both insulation fibre glass (IFG) and reinforcement fibre glass (RFG), boron improves the fluxing capabilities of the batch, reduces glass batch melting temperatures and increases the fiberising efficiency by lowering the viscosity. It controls the relationship between temperature, viscosity and surface tension to create optimal glass fiberisation. Boron also reduces the tendency of crystallisation and increases the strength of the fibres and resistance against moisture. Carbon fibres at the other hand have a production cycle with a very high environmental impact, and their high cost have no big prospects of mass applications. Furthermore, compared to carbon and aramid fibre, basalt fibre has the features of wider application temperature range (-270°C/+700°C), higher oxidation resistance, higher radiation resistance, higher compression strength, and higher shear strength[1]. Aging results indicate that the interfacial region in basalt composites may be more vulnerable to environmental damage than in glass composites. However, the basalt/epoxy interface - for example, may also be more durable than the glass/epoxy interface in tension-compression fatigue test because the fatigue life of basalt composites is longer. **A wide disagreement between the literature properties of**

[1] Note that application temperatures of FRPs - Fibre Reinforced Plastics are limited by the glass transition temperature of the matrix, which is lower than the application temperature of the fibres.

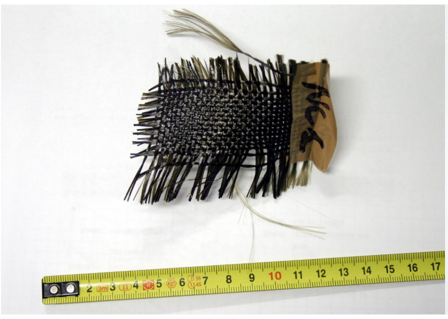
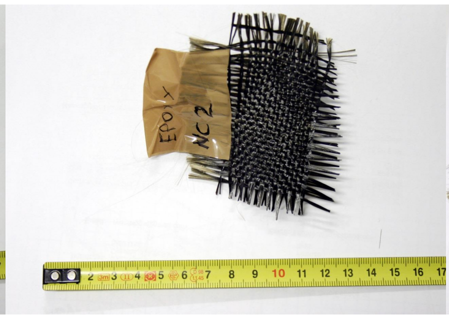
basalt fibres and properties measured in different studies renders any further consideration of basalt reinforced composites highly problematical.

1. **Basalt fibre can be suited for fire protective applications** and so it can replace almost all applications of hazardous materials (i.e., asbestos) without any impact on human health, thanks to the fibre's size that make it non-breathable.

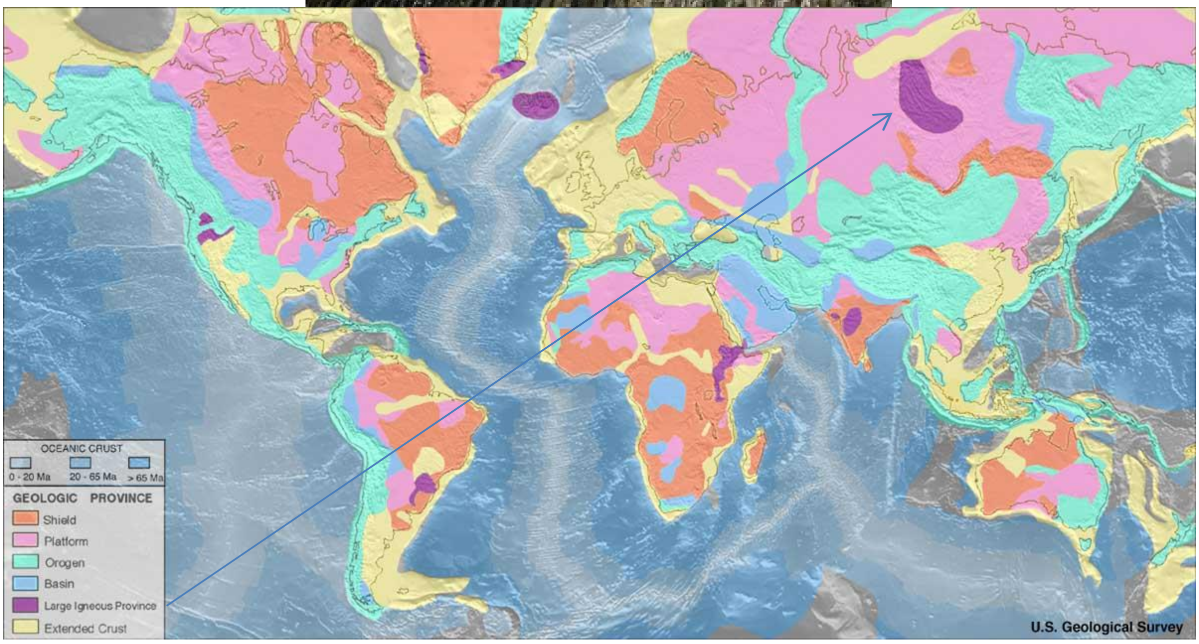
2. **Basalt fibre is an eco-compatible material**, characterized by an easier recyclability if compared, for example, to carbon, aramid or glass fibre. For the latter, the principal problem in glass fibres recycling is that they melt during incineration, sticking to the inside of the incineration chamber. The result is a costly clean-up effort and significant downtime. Basalt, instead, has a melting point of about 1400°C; this means that after some composite materials containing basalt fibres are incinerated, the only product left is an un-molten, fully usable basalt, that can be swept from the incineration. And this is naturally a considerable added value.

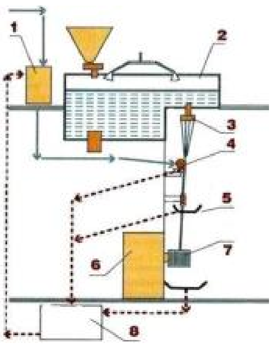
Basalt applications are well known from roman age where this material was used in its natural form as a paving and building stone: actually basalt can also be formed into a continuous fibre having unique chemical and mechanical properties, so that **it is ideally suited for demanding applications requiring resistance vs. high temperatures, insulation properties, acid and solvent resistance, durability, mechanical strength, low water absorption, etc.** Producing fibres from basalt was researched during the cold war by the old Soviet Union and limited commercial research and production was done also in the USA during the same period. The Soviets researched basalt as a source of fibre for **ballistic resistant textiles**.


Basalt is a type of **igneous rock** formed by the rapid cooling of lava at the surface of a planet. It is the most common rock in the Earth's crust. Basalt rock characteristics vary from the source of lava, cooling rate, and historical exposure to the elements. High quality fibres are made from basalt deposits with uniform chemical make-up.



Crushed basalt rock is the only raw material required for manufacturing the fibre. It is a continuous fibre produced through igneous basalt rock melt drawing at about 1500°C. Though the temperature required to produce fibres from basalt is higher than glass, it is reported by some researchers that production of fibres made from basalt requires less energy by due to the uniformity of its heating. Basalt fibres are produced from basalt rock using single component raw material by drawing and winding fibres from the melt (extrusion and spinning of the continuous fibre). Once the continuous basalt fibres have been produced, they are converted into suitable forms for particular applications. In many ways, basalt fibre technology production is similar to glass fibre one, but it requires less energy and no addition of other components. These aspects, together with an easy availability of raw materials all over the world, could justify a decrease in the cost of basalt fibres compared to



glass fibres. BF are extruded from basalt rocks through a melting process without the application of additives. The manufacturing process can be summarized as shown in the figure above: 1. Tank for sizing; 2. Furnace; 3. Bushing; 4. Sizing applicator; 5.Tray for used sizing collection; 6. Winder; 7. Spool; 8. Tank for used sizing.

Basalt rocks are firstly crushed, then washed and moved into melting baths in gas-heated furnaces under temperature of 1460-1500°C. Here, the process is simpler than glass fibre processing because the basalt fibre has a less complex composition. Molten basalt flows from furnace through a platinum-rhodium bushing with 200, 400, 800 or more holes and the fibres can be drawn from the melt under hydrostatic pressure. Then a sizing is applied to the surface of the fibres by a sizing applicator to impart strand integrity, lubricity, and resin compatibility. Finally, a winder allows to realize some large spools of continuous basalt filament. **The production process**, particularly temperature levels in the furnace, **is of considerable importance in relation to the final mechanical properties** of basalt fibrous materials (roving, etc.). Furthermore, it has been reliably determined that low variations in chemical composition of basalt rocks have a minor effect on the level of mechanical performance of the continuous basalt fibres, while the greatest effect comes from direct moulding conditions of the fibres (drawing temperature and the period of melt homogenization). For example, for the same basalt chemical composition, a fibre drawing temperature increase of 160°C (from 1.220 °C to 1.380 °C), increased its strength from 1.3 to 2.23 GPa and modulus of elasticity from 78 to 90 GPa. Great importance on

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final properties has also the fibre dimension: as the filament diameter increases of 3-4 µm, the strength value decreases from 2.8 to 1.8 GPa. The industrial production of basalt fibres on the basis of new technologies, can shift their cost as equal and even less than cost of glass fibre. Thus basalt fibres and materials on their basis have the most preferable parameter a ratio of quality and the price in comparison with glass and carbon fibres, and other types of fibres.

Basalt fibres are characterized by a good resistance vs. low and high temperatures and are superior to other fibres in terms of thermal stability, heat and sound insulation properties, ablation resistance, vibration resistance and durability, also with respect to carbon and aramid fibres. **High durability**: i.e., strength-to-weight ratio of a basalt fibre exceeds strength of alloyed steel 2.5 times, strength of fibre glass 1.5 times.

Filament diameter (µm)	5	6	8	9	11
Strength-to-weight ratio of the elementary fibre (kg/mm²)	215	210	208	214	212

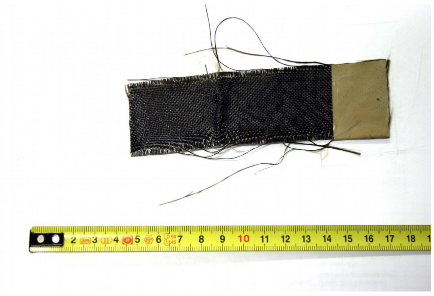
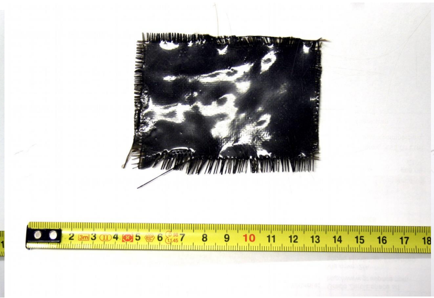
Fibre diameter (µm)	Tex	**Breaking strength** (N)
10	600	400
10	1200	700

Although current research shows that the structural behaviour, including long-term deflections due to creep and cyclical loading is similar to glass fibre, internationally recognized code authorities have yet to acknowledge basalt in their codes. Recognition and engineering design of basalt composites should continue to climb as research motivates and demonstrates current knowledge and coding authorities to adopt its strength characteristics. The price of fibres made from basalt is at the moment a little bit higher than those made of E-glass, but less than S-glass, aramid or carbon fibre and as worldwide production increases, its cost of production should reduce further.

Fibre diameter (µm)	H2O	0.5 n NaOH	2 n NaOH	2 n HCl
17	99.63	98.3	92.8	76.9
12	99.7	98.9	90.7	49.9
9	99.6	94.6	83.3	38.8

High chemical durability to impacts of water, salts, alkalis and acids. Unlike metal, BF is not affected by corrosion. Unlike fibre glass, BF is not affected by acids. BF possesses high corrosion and chemical durability qualities towards corrosive mediums, such as salts and acids solutions and, especially, alkalis.

High thermal resistance. A range of temperatures for BF long-time application is 200-700°C. Short-term impact of temperatures - up to 800°C. Single impact of temperatures - up to 1100°C. **Compatibility** of BF with other materials. High compatibility of BF with other materials (i.e., metals, plastic, glues) during different producing processes. Materials made on BF basis can be processed with application of different “cold” technologies, such as moulding, winding, pultrusion, sputtering, etc. Basalt fibre is raised, from a performance standpoint, between the carbon fibre and the glass fibre, even if among others, it has a great advantage: it is well-compatible with carbon fibre. The consequence is that high efficient hybrid materials can be manufactured by adding small (pre-determined) amount of carbon fibres to basalt fibres. The obtained thread, differing insignificantly in cost (owing to small content of expensive carbon fibre) will demonstrate considerably better elastic properties compared with basalt fibre (notice that elastic modulus of basalt fibre is around 11000 kg/mm2, whereas that of carbon fibre is 22000-56000 kg/mm2).


However, from a properties point of view, glass fibre, in its various form and chemical composition, can be considered as the reference material for a better understanding of basalt fibre properties. Both are inorganic but they are manufactured by different processes. Glass fibres are produced from melted charge (composed of quartz sand, soda, limestone, fluxing agents, etc.) to obtain glass, from which fibres are obtained by blow with steam, air or at centrifuge. Basalt fibre is obtained, as already shown, from melted of basalt rocks without any additives. There are different forms in which BFs can be processed: as continuous fibres, made of a bundle of parallel strands without twisting; thickness of a fibre usually ranges from 7 to 24 microns. It is the basic material, directly produced by the melting process of volcanic rock, from which it is then possible to get any other products with different manufacturing methods: chopper strands, produced by cutting continuous basalt fibre; it is used in reinforcing composite materials, as well as fabrics with different woven structures. **Composites manufacturing issues with basalt fabric need to be investigated, especially in relation to the woven architecture chosen and the resin permeability feature** for an effective use of basalt in FRP composites. Some measurement results of the in-plane permeability for basalt Twill 3×1 fabric material showed that a high correlation exists between the two principal permeability values for this fabric. This is in contrast to the lack of correlation found other weave patterns, and may point to an important material selection criteria for mass production of composites by liquid moulding (i.e., injection or resin transfer).

3. **The modulus of elasticity of basalt fibres is higher at least 18% than that of glass fibres**, particularly E-glass fibre, and, as known from literature, very closely approximates the modulus of elasticity of high-modulus and high-strength fibres made of magnesium - aluminosilicate glass (S-glass rovings).

4. **The application temperature of basalt fibres products are markedly higher** (from -270°C up to 700°C) **compared to glass** (-50°C up to 350/380°C).

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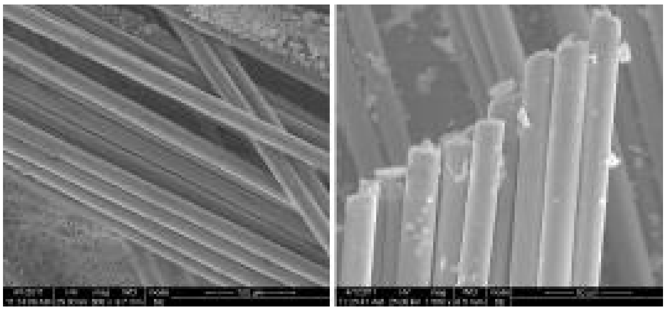
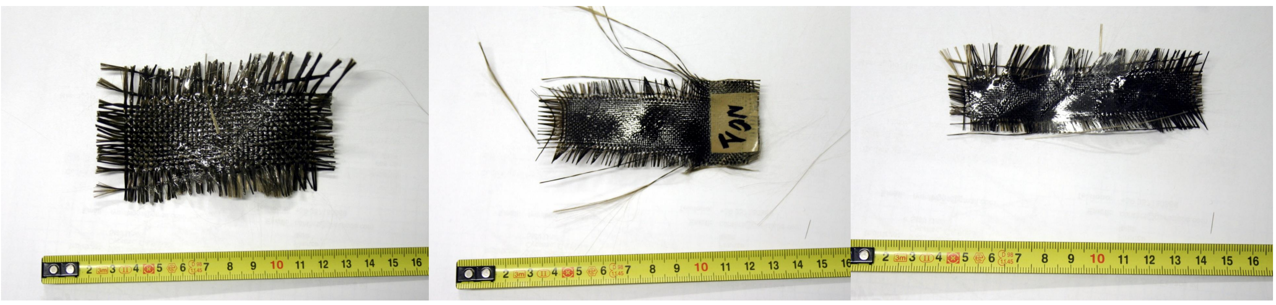
5. **Vibration-resistance of basalt fibre is also much higher than that of glass fibre as well as carbon fibre**. That is why BF finds widest application in wide range of constructions, subjected to heavy vibration and acoustic loads: transport vehicles (notice that initially basalt fibres were applied in aerospace military industry and shipbuilding), engineering, etc. Besides, basalt fibre articles serve as effective sound-insulator, which is not broken itself under effect of acoustic vibrations that owes, for instance, their exclusives application as insulation in aircrafts.

6. **Basalt fibre resistance in acidic and basic environments should be highlighted**, especially if compared with glass fibre or aramid fibre, for the implications that this can have in common applications with these materials, such as reinforcements in form of chopped or fibres.



Obviously, chemical resistance of basalt fibres principally depends upon their chemical composition even if it is very important to evaluate the fibre surface condition, especially in the case of surface-active media (alkali, some salt solutions, and so on); the ratio of silicon, aluminium, calcium, magnesium, and iron oxides is of great importance. For instance, the presence of iron oxides imparts to basalt fibres higher chemical and heat resistance as compared with glass and also carbon fibres. In particular BF have high acid resistance, which is greater than the resistance of E-glass, S-glass carbon, as well as aramid fibres, but is somewhat less than the resistance of specific chemically resistant zirconium glasses. At short-term exposure in strong mineral acid solutions, no fibre strength was observed while a long-term (more than 100 h) impact of hydrochloric acid solutions can cause strength reductions of 15%-20%.



This reduction proceeds more slowly for basalt rovings with smaller filament diameter than for glass rovings. Regarding the resistance of basalt fibres to the influence of various alkali media, it has been considered for different times and at different levels in many researches. Alkali resistances of basalt fibres and glass fibres having different chemical composition, in various model alkali media (alkali, alkali-free, quartz, and zirconium), were compared qualitatively. Analysis of the strength decrease enables to arrange the glass and basalt fibres studied, in the following descending sequence by alkali resistance: zirconium > basalt > quartz > alkali > alkali-free. As may be inferred from this sequence, expensive zirconium-containing glass fibres are followed by relatively cheap basalt fibres having higher mechanical properties. Therefore, basalt fibres demonstrate an higher alkali resistance if compared with the majority of glass fibres, and for sure if compared with carbon and aramid fibres.

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