AN INTRODUCTION TO BASALT ROCK FIBER AND COMPARITIVE ANALYSIS OF ENGINEERING PROPERITES OF BRF AND OTHER NATURAL COMPOSITES

Piyush Sharma

Department of Civil Engineering, Amity School of Engineering & Technology

Amity University, Haryana, India

Email: piyushsharma1015@gmail.com

***Abstract* - Basalt is a common extrusive volcanic rock. An inert rock found worldwide, basalt is the generic term for solidified volcanic lava. Safe and abundant, basalt rock has long been known for its thermal properties, strength and durability. It is formed by decompression melting of the earth's mantle. It contains large crystals in a fine matrix of quartz. It is a material made from extremely fine fibers of basalt. Extruded basalt stone is formed into a metal like wool composed of pyroxene, plagioclase and olivine minerals. It is similar to carbon fiber and fiberglass, having better physic mechanical properties than fiberglass, and being significantly cheaper than carbon fiber. This paper deals with the wide applications of basalt fiber in construction. Basalt fiber (BF), known as "the green industrial material of the 21st century", combines ecological safety, natural longevity and many other properties.**

***Keywords:* basalt rock, basalt fiber, strength, durability using BRF, thermal properties, mechanical properties.**

1. INTRODUCTION

1.1. GENERAL ANALYSIS

The first attempts to produce basalt fiber were made in the United States in 1923 by Paul Dhe who was granted US patent. These were further developed after World War II by researchers in the USA, Europe and the Soviet Union especially for military and aerospace applications. Since declassification in 1995 basalt fibers have been used in a wider range of civilian applications.

Basalt is well known as rock found in virtually every country around the world. Its main use is as a crushed rock used in construction, industrial and highway engineering. However it is not commonly known that basalt can be used in manufacturing and made into fine, superfine and ultra fine fibers. Comprised of single-ingredient raw material melt, basalt fibers are superior to other fibers in terms of thermal stability, heat and sound insulation properties, vibration resistance and durability. Basalt continuous fibers offer the prospect of a completely new range of composite materials and products.

Basalt products have no toxic reaction with air or water, are non-combustible and explosion proof. When in contact with other chemicals they produce no chemical reactions that may damage health or the environment. Basalt replaces almost all applications of asbestos and has three times its heat insulation properties. Basalt based composites can replace steel and all known reinforced plastics (1 kg of basalt reinforcement equals 9.6 kg of steel). The life of basalt fiber pipes, designed for a variety of applications, is at least 50 years without maintenance or electrical or technical protection.

Basalt fibers together with carbon or ceramic fibers as well as various metals is the most advanced and exciting area of application, as they can develop new hybrid composite materials and technologies.
Basalts special properties reduce the cost of products while improving their performance. More than hundred specific unique manufacturing techniques using basalt fiber materials and products have been developed and patented in Russia.

Low cost, high performance fibers offer the potential to solve the largest problem in the cement and concrete industry, cracking and structural failure of concrete. Because of the higher performance (strength, durability and temperature range) and lower production cost predicted for basalt fibers, they have the potential to cost effectively replace fiberglass, steel fiber, prop ethylene, poly propylene, polyester, aramid and carbon fiber products in many applications.

1.2 PRODUCTION OF BASALT FIBER

Basalt fiber is made from crushed lava rocks with specific chemical compositions mined from chosen quarries. Unlike glass fiber no other materials are added and the basalt rock is simply cleaned and then melted down to around 1,450 °C. The molten rock is then extruded through small orifices (as shown in figure 1) at different speeds to produce continuous filaments of basalt fiber. The fibers typically have a filament diameter of between 9 and 20 µm.

Conversion of Rock to Fiber

As crushed basalt enters the furnace, the material is liquefied at a temperature of 1500°C/2732°F (glass melt point varies between 1400°C and 1600°C). Unlike glass, which is transparent, the opaque basalt absorbs rather than transmits infrared energy. Therefore it is more difficult for the overhead gas burners used in conventional glass furnaces to uniformly heat the entire basalt mix. With overhead gas, the melting basalt must be held in the reservoir for extended periods of time — up to several hours — to ensure a homogenous temperature. Basalt producers have employed several strategies to promote uniform heating, including the immersion of electrodes in the bath. Normally, a two-stage heating scheme is employed, featuring separate zones equipped with independently controlled heating systems. Only the temperature control system in the furnace outlet zone, which feeds the extrusion bushings, requires great precision, so a less sophisticated control system may be used in the initial heating zone.

Like glass filaments, basalt filaments are formed by platinum-rhodium bushings. As they cool, a sizing agent is applied and the filaments are moved to speed-controlled fiber stretching equipment and then on winding equipment, where the fiber is spooled.

Because the basalt filament is more abrasive than glass, the expensive bushings once needed more frequent refurbishing. As bushings wear, their cylindrical holes wear unevenly, degrading process control. Without timely maintenance, the out-of-round apertures form filaments with an unacceptably wide diameter range, producing a roving with unpredictable breaking loads, explains Nolf. While glass fiber bushings last six months or more before they need to be melted, reformed and redrilled, a bushing used for basalt fiber production previously lasted anywhere from three to five months

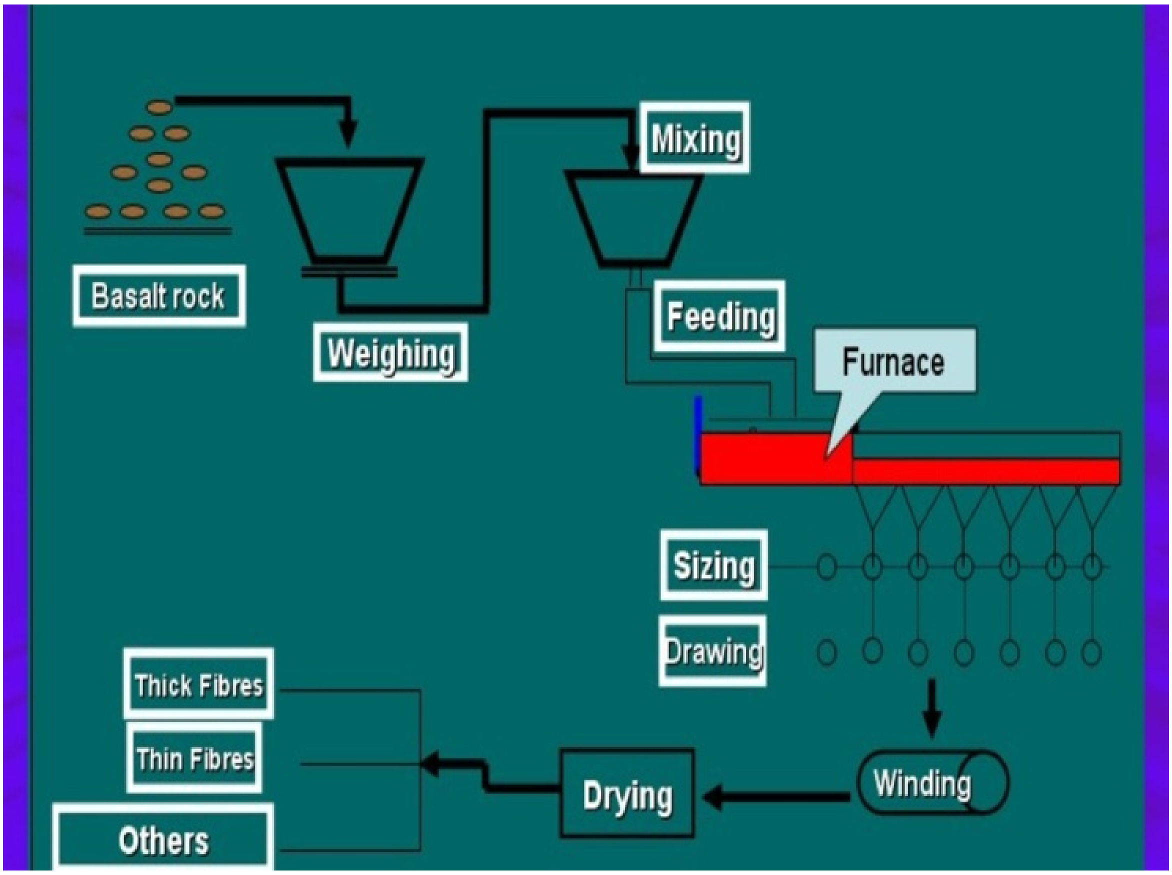


Figure 1: Production process of ballast fiber

1.3 CHEMICAL COMPOSITION

Not all basalt rocks can be good to make continuous filament fibers. The typical chemical constituents are SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, Fe_2O_3, and FeO. For instance, the following form shows the typical range of various constituents in basalt rock that would be suitable to make continuous filament fibers.

Components	Percentage (%)
SiO_2	50-60
Al_2O_3	14-19
CaO	5-10
MgO	3-5
$Na_2O + K_2O$	3-5
TiO_2	0.5-3
Fe_2O_3 + FeO	9-14

Table 1: Components of good basalt rock

Al_2O_3 increases the viscosity of the melt and chemical stability effects of the constituents on the properties of the fiber have been studied in the past, based on existing literature survey that can be generally summarized as below although there might be some different views amongst researchers:

- SiO_2 and Al_2O_3 affect tensile properties.
- Fe_2O_3 and FeO alter the melting parameters by increasing the homogenization period, crystallization temperature and thermal conductivity, high-temp performance of the final products.
- CaO, TiO_2, MgO increase water resistance and resistance to aggressive media.
- Na_2O and K_2O mainly increase the corrosion resistance in alkali.
- Ballast rock fiber proves to be an excellent material in construction due to its extraordinary properties.

2.0 MECHANICAL PROPERETIES OF BASALT ROCK FIBER

Fiber Type	Specific Gravity	Tensile Strength Ksi (MPa)	Elastic Modulus Ksi (Gpa)	Strain at Break
Basalt	2.7	40-695 (2800-4800)	12,500-13,000 (86-90)	0.0315

Table 2: Mechanical Properties of BRF

Basalt as a fiber used in FRPs and structural composites has high potential and is getting a lot of attention due to its high temperature and abrasion resistance. Compared to FRPs made from glass, aramid and carbon fiber, its use in the civil infrastructure market is very low. Basalt fibers are characterized by a good resistance against low and high temperatures and are superior to other fibers in terms of thermal stability, heat and sound insulation properties, ablation resistance, vibration resistance and durability.

Basalt fiber is raised, from a performance standpoint, between the carbon fiber and the glass fiber, even if among others, it has a great advantage: it is well-compatible with carbon fiber. The consequence is that high efficient hybrid materials can be manufactured by adding small (pre-determined) amount of carbon fibers to basalt fibers. The obtained thread, differing insignificantly in cost (owing to small content of expensive carbon fiber) will demonstrate considerably better elastic properties compared with basalt fiber (notice that elastic modulus of basalt fiber is around 11 kg/mm^2, whereas that of carbon fiber is between 22 to 56 kg/mm^2).

However, from a properties point of view, glass fiber, in its various form and chemical composition, can be considered as the reference material for a better understanding of basalt fiber properties. Both are inorganic but they are manufactured by different processes. Glass fibers are produced from melted charge (composed of quartz sand, soda, limestone, fluxing agents, etc.) to obtain glass, from which fibers are obtained by blow with steam, air or at centrifuge.

Although current research shows that the structural behavior, including long-term deflections due to creep and cyclical loading is similar to glass fiber, internationally recognized code authorities have yet to acknowledge basalt in their codes. This puts the use of basalt at a disadvantage until the American Concrete Institute, Canadian Standards Association, Fédération Internationale du Béton (International Federation for Structural Concrete), and others provide specific design guidance for its use. Recognition and engineering design of basalt composites should continue to climb as research substantiates current knowledge and code authorities adopt its strength characteristics.

Comparative Analysis of Basalt Fiber and Glass Fiber

	Basalt Fiber	Glass Fiber
Working Temperature (°C)	-260 °C ~ 700 °C	-60 °C ~ 250 °C
Caking temperature (°C)	1100 °C	600 °C
Thermal Conductivity	0.031-0.038w/m.°K	0.038~0.042w/m.°K
Filament diameter(µm)	7 ~ 15	6 ~ 17
Tensile strength MPa	4150 ~ 4800	4150 ~ 4800
Chemical resistance (loss of weight) (%)	2N HCl 2.2	2N HCl 38.9
Water absorption (%)	0.02	1.7
Vibro resistance (loss of weight) (%)	0	12
Sound absorption coefficient	0.95~0.99	0.8~0.92

Table 3: Comparison of Various Properties of BRF and Glass Fiber

From the Table 3 it is possible to observe that:

- The modulus of elasticity of basalt fibers is higher at least 18% than that of glass fibers, particularly E-glass fiber, and, as known from literature, very closely approximates the modulus of elasticity of high-modulus and high-strength fibers made of magnesium - aluminosilicate glass (S-glass rovings).
- The application temperature of basalt fibers products are markedly higher (from -260 °C to 700 °C) compared to glass fibers (-60 °C to 250 °C).

- Vibration-resistance of basalt fiber is also much higher than that of glass fiber. 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 fibers were applied in aerospace military industry and shipbuilding), engineering, etc. Besides, basalt fiber 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.

- Among these various properties and characteristics, basalt fiber resistance in acidic and basic environments should be highlighted especially if compared with glass fiber, for the implications that this has in common applications of this material, such as concrete reinforcement in form of chopped or bars.

- Obviously, chemical resistance of basalt fibers principally depends upon their chemical composition even if it is very important to evaluate the fiber surface condition, especially in the case of surface-active media (alkali, some salt solutions, and so on); the ratio of silicon, aluminum, calcium, magnesium, and iron oxides is of great importance. For instance, the presence of iron oxides imparts to basalt fibers higher chemical and heat resistance as compared with glass fibers. In particular BF has high acid resistance, which is greater than the resistance of E-glass and S-glass fibers, but is somewhat less than the resistance of specific chemically resistant zirconium glasses.

- At short-term exposure in strong mineral acid solutions, no fiber 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 fibers 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 fibers and glass fibers 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 fibers 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 fibers are followed by relatively cheap basalt fibers having higher mechanical properties. Therefore, basalt fibers demonstrates a higher alkali resistance if compared with the majority of glass fibers. This is the reason why basalt fibers have been used as reinforcement of in Portland cement concrete, which is an alkaline medium, attracting the attention of researchers and users of these fibers.

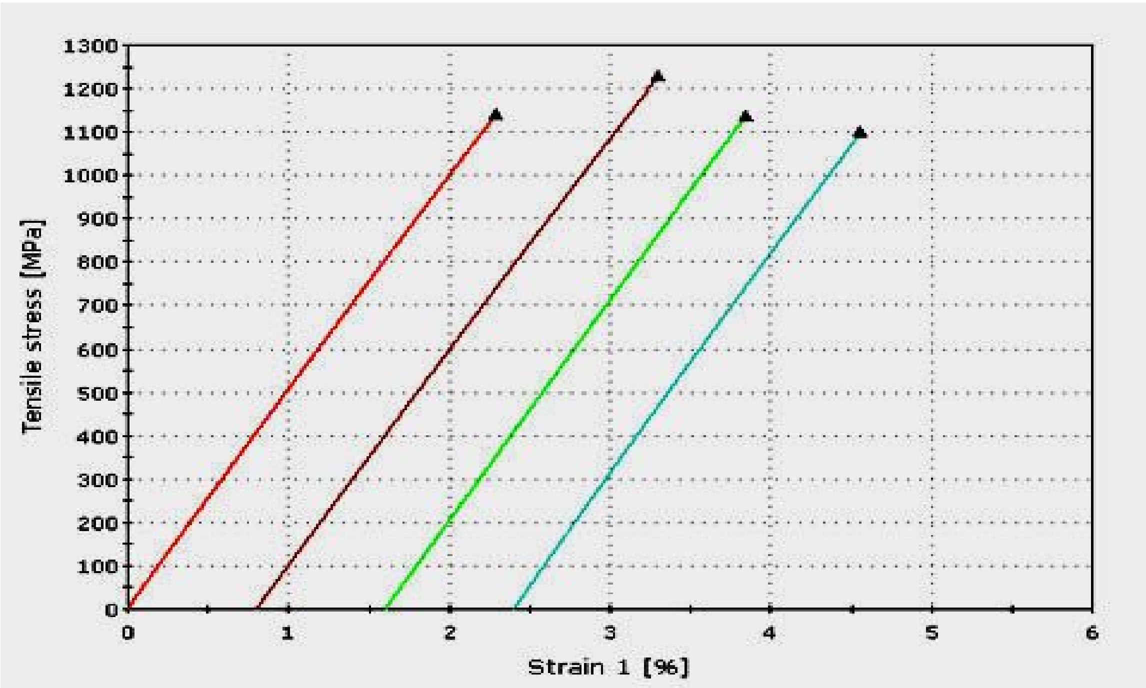


Figure 2: Tensile Stress-Strain Curve of BRF

2.1 COMPARITIVE THERMAL AND ELECTRICAL PROPERTIES OF BASALT FILAMENT, FIBERGLASS, SILICA FILAMENT

THERMAL PROPERTIES				
	SI Units	Basalt Filaments	Fiberglass	Silica Filament
Maximum application temperature	(°C)	650°	600°	1100°
Sustained operating temperature	(°C)	600°	480°	1000°
Minimum operating temperature	(°C)	-260°	-60°	-170°
Thermal conductivity	(W/m K)	0.031-0.038	0.034-0.04	0.035-0.04
Melting temperature	(°C)	1450°	1120°	1550°
Virtification conductivity	(°C)	1050°	600°	1300°-1670°
Glow loss	(%)	1.91	0.32	1.75
Thermal expansion coefficient	(ppm/ °C)	8.0°	5.4°	0.05°
ELECTRICAL PROPERTIES				
Specific volume resistance	(ohm.m)	1*10×12	1*10×11	1*10×11
Loss angle tangent frequency	(1 MHz)	0.005	0.0047	0.0049
Relative dielectric permeability	(1 MHz)	2.2	2.3	2.3
ACOUSTICS				
Sound absorption coefficient	(%)	0.9-0.99	0.8-0.93	0.85-0.95

Table 4: comparative analysis of basalt filaments, fiberglass and silica filaments

2.2 EXPERIMENTAL INVESTIGATION

Tests are carried out by various agencies primarily to understand and research on the properties of a material - basalt fiber - that is not widely used and known in the Western world. In many cases research is in progress and yet still limited to few applications. Basalt fiber has a potential in all its forms and applications, making it the reference point in a virtuous cycle linking producers to end-users through validation and research performed by an independent organization.

Particularly, the following tests are carried out in the laboratories of the Technical Unit for Technology Transfer of Trisaia Research Centre: mechanical characterization of basalt fiber rebar and durability tests; characterization of BF insulating panels (thermal conductivity); durability and destructive tests on basalt fabric for structural applications; and, more generally, study of material durability. Some of these tests are still in progress because they need long time – as in the case of durability tests– or in planning stage, such as BF rebars characterization; others have already been performed.

In this paper, experimental test for measuring the thermal conductivity of thermal insulation basalt fiber panel has been studied.

The energy efficiency of the building depends primarily on the efficiency of the insulating material; the determination of its thermal characteristics is the first step towards the definition of a more efficient technological system. The experimental measurements were made by using the method of heat flow with the NETZSCH apparatus according to the standard procedure defined in compliance with UNI EN 12667. They showed that the basalt fiber panel tested – with a density of 240 kg/mc - has a thermal conductivity of 0.032 W/m K at the stated temperature of 10 °C, strictly comparable to that of traditional insulation materials such as fiberglass and rock wool having a much lower density.

The test results also showed the increase in thermal conductivity with temperature. If compared to other materials, probably cheaper, the added value of the basalt fiber insulating panel can be the fire resistance.

At the Materials Laboratory of Trisaia research Centre some more tests were performed on fabrics, normally used as external reinforcement for concrete in many structural systems. Main objective of the experimental activity was to investigate on the effectiveness of confinement based on basalt fibers pre-impregnated in epoxy resin (BFRP), and to compare the performance (in terms of peak strength and ultimate axial strain gains) of different confinement materials, in particular glass fiber reinforcement laminates jacketing (GFRP). The investigation was carried out on 18 concrete cylindrical specimens with a diameter of 150 mm and a height of 300 mm - 8 unconfined, 5 confined with uniaxial basalt laminates with unit weight of 200 g/m^2, 5 confined with uniaxial glass laminates with unit weight of 250 g/m^2.

	fca [Mpa]	εa	fc/fc0
Unconfined	27.1	0.0041	1
GFRP	37.3	0.010	1.38
BFRP	51.5	0.016	1.90

Table 5: Lab results showing the performance of GFRP, BFRP

It is important to emphasize the good behavior of basalt fiber fabric reinforcement. In this case the added value can be ecocompatibility of this material, it’s easier recyclability if compared to other material with similar mechanical characteristics.

2.3 APPLICATIONS

Core Construction

- Reinforcement of bridges, tunnels.
- Production of sandwich-panels based on basalt and carbon-basalt fibers.
- External and internal heat and sound insulation.
- Insulation of panel butt joints.
- Directional and dispersive reinforcement of concrete.
- Repair (healing) of cracks, local damage to buildings, bridges, building constructions.
- Soft roofing (of slate and tile type).
- Reusable shutters.
- Internal waste pipes.
- Reinforced structures
- Heat-supply systems, cable conduits.
- Hydraulic construction.

Engineering Networks

- Pipelines for heating and hot water supply.
- Pipelines for heat supply.
- Canalization.
- Oil and gas pipelines.

- Cable-conduit, telephone systems protected against electromagnetic fields and information leakage through electronic surveillance.
- Highly efficient seals and linings for pipelines.
- Pipes for chemicals production and transportation of aggressive media.
- Pumps for aggressive media.

Agriculture

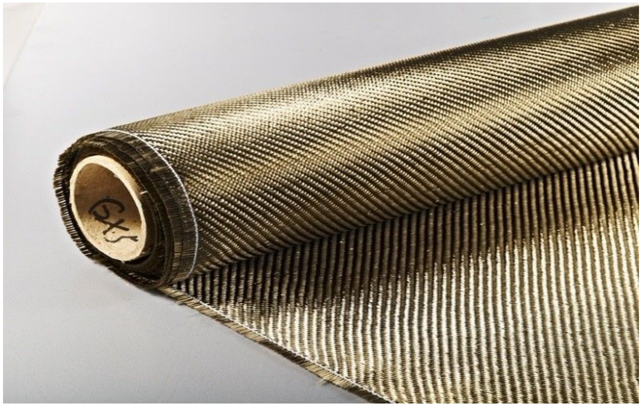
- Land drainage pipes.
- Pipes for irrigation and hosing.
- Raising vegetables and seedlings (hydroponics) (Basalt super thin fibers).
- Agricultural construction.
- Agricultural machine construction.

Machine Construction

- Case and body parts.
- Heat-resistance body-containers.
- Refrigerators.
- Completely incombustible thermal sound insulation for cabins, motor compartments, metro carriages, vessels and aircrafts.
- Electro technical and electronic circuit boards.
- Brake pads for automobiles, aircrafts, metro carriages and coaches.
- Friction disks for auto tractor facilities.
- Frame sections.
- Reinforcement for industrial rubber and other articles.
- Acoustic systems and articles.
- Belts for heavy-loaded conveyers.

Environmental Safety

- Protection screens against electromagnetic radiation and information read-out.
- New generation body armor for individual and collective protection.
- Fireproofing and heat-protection working clothes.
- Containers for burial of extremely toxic waste.
- Basalt-carbon heaters for clothes, rooms, incubators etc.



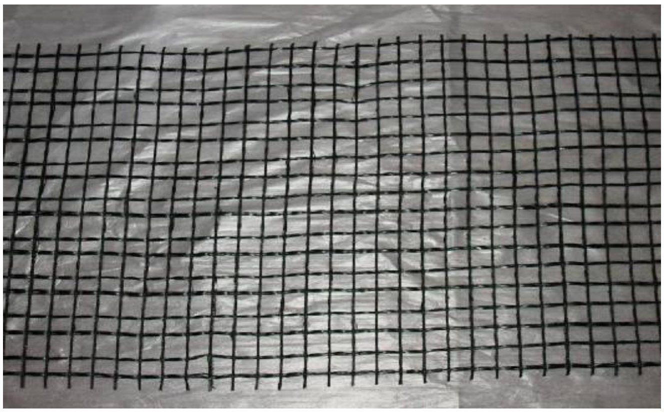


Figure 3: Basalt Rock Fiber Products

CONCLUSION

Due to the wide application of basalt fibers in markets such as building & construction, automotive, wind energy, electronics, marine, and others, the global basalt fiber market is expected to reach $200 million by 2020, growing at a rate of 13.1% from 2012 to 2020. Continuous basalt fiber is more efficient and eco-friendly than most glass & carbon fibers. Continuous basalt fibers can be processed to have higher tensile strength than steel and are rust free as they are chemically inert. Basalt as a fiber used in FRPs and structural composites has high potential and is expected to grow at a significant rate due to its high temperature resistance, abrasion resistance, ultraviolet resistance and high-energy electromagnetic radiation Basalt fibers are ideally suited for demanding applications requiring high temperatures, chemical resistance, durability, mechanical strength and low water absorption. Such structures combine the best properties of each component to possess enhanced mechanical & superconducting properties for advanced applications. Growing demand of basalt fiber from new application markets of the world is also expected to contribute to the growth of the basalt fiber market.

ACKNOWLEDGMENT

I would like to thank Prof. Meeta Verma, Prof. Sarah Khan, Prof. Sakshi Gupta, Dr. D.K Singh, Prof. R.C Sharma and Prof. M.K Sinha for their valuable discussions on basalt fibers and their properties.

REFERENCES

[1] T Czigány - Materials Science Forum, 2004 Basalt fiber_reinforced hybrid polymer composites.

[2] Jiri Militky, Vladimir Kovacic; 'Ultimate Mechanical Properties of Basalt Filaments', Text. Res. J. 66(4), 225- 229 (1996)

[3] Stephen Cater; 'Editorial', International Composites News, (40) March (2002)

[4] T Deák, T Czigány - Textile Research Journal, 2009; Chemical composition and mechanical properties of_basalt_and glass_fibers: a comparison.

[5] Tengiz Chantladze; 'Industrial assimilation of the effective type of fiber with multicomponent charge'

[6] LJYYY Meng, Z Yan - Industrial Construction, 2007; Experimental_Research_on the mechanical behaviour of chopped_basalt fiber_reinforced concrete.

[7] Sergeev et al.; 'Basalt Fibers – A Reinforcing Filler for Composites', Powder Metallurgy and Metal Ceramics, 33(9-10), 555-557 (1994)