Polymer Matrix Composite of Basalt Fiber – A Review

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Abstract

In recent years increase in the use of eco-friendly, natural fibers as reinforcement for the fabrication of lightweight, low cost polymer composites can be seen globally in many applications. In particular, both industrial and academic world are focusing their attention toward the development of sustainable composites, reinforced with natural fibres. Among the natural fibres basalt ones represents the more interesting properties, which is cost-effective and offers exceptional properties over glass fibers. This article presents a review on basalt fibers used as a reinforcement material for polymer matrix composites and as an alternative to the use of glass fibers.
Keywords: Basalt Fiber, TGA, LCM

I. Introduction

A. Basalt Fiber

Basalt is a natural material that is found in volcanic rocks. It is mainly used (as crushed rock) in construction, industrial and high way engineering. One can also melt basalt (1300-1700°C) and spin it into fine fibers.

Table - 1
Comparison of mechanical properties of basalt fiber with other fibers

Properties	*Basalt fiber*	*Glass fiber*	*Carbon fiber*
Breaking strength (Mpa)	*3000-4800*	*4020-4650*	*3500-6000*
Modulus of elasticity (Gpa)	*79.3-93.1*	*83-86*	*230-600*
Breaking extension (%)	*3.1*	*5.3*	*1.5~2.0*
Fiber diameter (μm)	*6-21*	*6-21*	*5-15*
Linear density (tex)	*60-4200*	*40-4200*	*60-2400*
Temp. Withstand (˚C)	*-260….+700*	*-50…..+300*	*-50……+700*

Table – 2
Comparison of thermal properties of basalt fiber with other fibers

Thermal properties	*Basalt*	*E-glass*
Maximum operating temperatures (ºC)	*980*	*650*
Sustained operating temperatures (ºC)	*700*	*480*
Minimum operating temperatures (ºC)	*-260*	*-60*
Thermal conductivity (W/m k)	*0.031-0.038*	*0.034-0.04*
Melting temperature (ºC)	*1280*	*1120*

When used as (continuous) fibers, basalt can reinforce a new range of (plastic and concrete matrix) composites. It can also be used in combination with other reinforcements (e.g. basalt/carbon). This wide range of possible applications results from its wide range of good properties.

II. Polymer Matrix Composites

Most commonly used matrix materials are polymeric. The reasons for this are two-fold. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers. Secondly the processing of polymer matrix composites need not involve high pressure and doesn't require high temperature. Also equipment's required for manufacturing polymer matrix composites are simpler. For this reason polymer matrix composites developed rapidly and soon became popular for structural applications. Composites are used because overall properties of the composites are superior to those of the individual components for example polymer/ceramic. Composites have a greater modulus than the polymer component but aren't as brittle as ceramics.

III. LITERATURE REVIEW

Lopresto et al. has compared the Mechanical properties of basalt fibre and E-glass fiber reinforced plastics manufactured by vacuum bag method. By comparing the results of the mechanical tests carried out on equivalent basalt and E-glass fibre reinforced plastic laminates, the author concluded that it was possible to replace glass fiber with basalt fiber in the epoxy matrix. The results showed that basalt material has high performance in terms of young modulus, compressive bending strength, impact force and energy. Also the short-beam strength tests has been carried out and results confirmed that a quite good interfacial adhesion between basalt fibres and epoxy matrix are not worse than the one between E-glass and epoxy matrix.

Dorigato et al. has studied the effect of Fatigue resistance of basalt Fibers reinforced laminates. Hand layup process is used to prepare the epoxy laminates were Carbon, basalt, and E-glass balanced woven fabrics has been utilized. Mechanical characterization of laminates reinforced with fabrics having the same areal density demonstrated that Basalt Fiber composites possess an elastic modulus higher than the corresponding glass fiber laminates, while their tensile strength approaches that of corresponding Carbon fibers laminates. The investigation of the fatigue behaviour confirmed the better performances of basalt Fiber laminates with respect to the corresponding glass fiber laminates, with a higher stiffness retention at low fatigue loads and better damping properties. It was concluded that the potential of basalt Fiber as replacement of glass fibers for the production of structural composites combining good mechanical performances and interesting energy dissipation capabilities.

Chairman et al. has investigated the Mechanical and Abrasive Wear Behaviour of Glass and Basalt Fabric-Reinforced Epoxy Composites. Basalt fiber fabric and glass fiber fabric reinforced epoxy composites were prepared by hand layup technique. The experimental results showed that the basalt fiber fabric reinforced epoxy composite had better tensile, inter laminar shear strength and compressive property than glass fiber fabric reinforced epoxy composite. Young's modulus test shows that basalt fiber fabric reinforced composite had a positive/better influence on the abrasive wear behaviour. Whereas glass fiber fabric reinforced composites were detrimental to abrasive wear behaviour due to its poor bonding between fibres and resin.

Wang Mingchao et al. has investigated Chemical Durability properties and Mechanical Properties of Alkali proof Basalt Fiber and its Reinforced Epoxy Composites. In this work basalt fiber was boiled in distilled water, sodium hydroxide and hydrochloric acid, respectively. Then mass loss and strength change of the fibers has studied it shows that the alkali resistance of the basalt fiber is higher than that of acid resistance. Composites were investigated after being kept inside 8 kinds of chemical mediums for 15, 30 and 90 days. The composites corrosion behaviours differ greatly in acid and alkaline reactions. Also the mechanical properties of basalt fiber reinforced polymer and glass fiber reinforced polymer composite have been tested, and analysed contrastively. The tested results show that the basalt fiber reinforced epoxy has better interface than that of glass fiber reinforced epoxy.

Brahim Benmokrane et al. has stuieded the Characterization and Comparative Durability of Glass/Vinyl ester, Basalt/Vinyl ester and Basalt/Epoxy Fiber Reinforced Polymer Bars. The test results reveal that after conditioning in alkaline solution the Glass/Vinyl ester composite had the better physical and mechanical properties and lower degradation rate. The Basalt/Epoxy composite ranked second, while the Basalt/Vinyl ester composite had lower physical and mechanical properties and exhibited maximum degradation of its physical and mechanical properties after conditioning.

Sakthivel et al. has investigated the Drilling Analysis on Basalt/Sisal Reinforced Polymer Composites Using ANOVA and Regression Model. Drilling experimental trials were carried out on basalt/sisal polymer composites material using HSS twist drill. Then the data obtained from drilling are processed by using "Minitab 17" software package. The analysis of achieving the optimality condition to control thrust force and delamination factor are performed through Analysis of variance (ANOVA), regression model and response diagram (RD) to evaluate the best mathematical input models for making drilling in fabricated Basalt/Sisal Reinforced Polymer composite. The analysis result reveals the optimized condition to control thrust force and delamination factor in basalt/sisal Reinforced Polymer Composite is Drill bit diameter at 3mm, feed rate at 0.1mm/rev and speed at 300 rpm.

Sabet et al. has studied The Effect of Thermal Treatment on Tensile Properties of Basalt Fibers. In this paper author studies the tensile strength of basalt fibers at room temperature and also after exposure to 300 °C, 350 °C, 400 °C, 450 °C and 500 °C in a furnace for the durations of 5, 10, 15 and 20 min. The results indicate that the residual strength of basalt fibers were drastically decreased after 20 min exposure at 300 and 400 °C and it is only about 57% and 35% of that of fibers at room temperature, respectively. But at 450 and 500 °C, this drastic decrease occurs after 5 min of exposure. These results indicate the optimum conditions for processing of basalt fibers and the composites based on them.

Alexander et al. has studied the Effect of Combined Thermal and Microwave Curing of Basalt/epoxy Composites and its Mechanical Properties and Surface Hardness. In this fabrication is carried out by compression moulding process and post cured at thermal and thermal/micro wave environment. Results shows that due to micro wave post curing process the Surface harnesses is improved significantly in micro wave cured composites. The strength and stiffness properties also have improved significantly.

Amuthakkannan et al. has analysed delamination in drilling of basalt fiber reinforced epoxy composites. In this paper the delamination of basalt fiber reinforced epoxy composites was studied through drilling operation. Hand layup techniques is used to prepare the polymer Composites with unsaturated polyester. Taguchi design of experiment was used to investigate the effects of drilling parameters such as spindle feed rate (0.2, 0.4, 0.6 mm/rev), point angle (90°, 118°, 135°) and speed [2500, 2750, 3000 rpm].The resulting delamination factor was determined by Using CNC machine with a series of experiments based on L9 orthogonal arrays. The results showed that the delamination of the basalt fiber reinforced polymer composites were highly influenced by speed and point angles than feed rate.

Fatimat et al. has studied the Thermomechanical properties of bio-based composites made from a lactic acid thermoset resin and flax and flax/basalt fibre reinforcements. Compression moulding process at elevated temperature is used to produce flax and flax/basalt fibre reinforced polymer composites. The mechanical properties of composites were determined by flexural test, tensile test and Charpy impact test whereas thermogravimetric analysis (TGA) and dynamic mechanical thermal analysis (DMTA) were used to analyse thermal properties. The results showed that due to insufficient fibre wetting for a neat flax composite mechanical properties were decreased with increase in fibre load after 40 wt.% and for the flax/basalt composite mechanical properties were increased with increase fibre load up to 60 wt.%. The results of the ageing test showed that the flax/basalt polymer composite had higher/better mechanical properties after ageing than the flax polymer composite before ageing.

Wang et al. has studied the Low velocity impact properties of 3D woven basalt/aramid hybrid composites. Inter ply and intra ply hybrid composites has been fabricated by using Aramid (Kevlar 129), basalt fibers, and epoxy resin. Impact test has been carried out in the composite at 2 m/s and 3 m/s impact velocities along warp and weft directions. Due to a layer-by-layer fracture mode for the inter ply hybrid composite the inter ply hybrid composite showed higher ductile indices (8–220%), lower peak load (5–45%), and higher specific energy absorption (9–67%) in both warp and weft directions than that of the intra ply hybrid composite.

Bashtannik et al. has investigated the effect of adhesion interaction on the mechanical properties of thermoplastic basalt plastics. Based on a high-density polyethylene and a copolymer of 1,3,5-trioxane with 1,3-dioxolan the mechanical properties of thermoplastic basalt plastics has been investigated. An extreme dependence for the adhesive strength in a thermoplastic basalt fiber system is established and its effect on the mechanical properties of basalt plastics. The surface modification of basalt fibers in acidic and alkaline media intensifies the adhesion of thermoplastics to them owing to a more developed surface of the reinforcing fibers after etching. It is found that the treatment in the acidic medium is more efficient and considerably improves the mechanical properties of basalt plastics.

Akinci et al. has investigated the Wear Behaviour of Basalt Filled Low Density Polyethylene Composites. The friction and wear performance of pure Low Density Polyethylene and 10%, 30%, 50% and 70% weight fraction basalt filled Low Density Polyethylene composite were comparatively evaluated under dry sliding conditions. Wear tests were carried out at room temperature under 5, 10 and 20N loads and at 0.5, 1.0 and 1.5 m/s sliding speeds. The coefficients of friction of the composites were significantly influenced with increase in basalt content. Friction coefficient of the Low Density Polyethylene was getting decreased from 0.51 to 0.13 with increase in basalt content, depending on applied loads and sliding speeds. The results show that the wear rates for pure Low Density Polyethylene and basalt filled composites increase with increasing loads and sliding speeds. The wear rates of the basalt filled composites were significantly affected from the basalt content. Wear rates of the Low Density Polyethylene was decreased from 2.596×10^{-3} to 6.8×10^{-5} mm^3/m with increase in basalt content, depending on applied loads and sliding speeds.

Dorigato et al. has studied the effect of Flexural and impact behaviour of carbon/basalt fibers hybrid laminates. Basalt and E-glass fibers fabrics were combined with carbon fiber fabrics in order to prepare epoxy-based inter-laminar hybrid composites. Charpy impact tests evidenced a strength increase as basalt and glass fibers content increased. Due to an enhancement of the fracture propagation component hybridization with basalt fibers promoted an increase of the adsorbed impact energy.

Sarasini et al. has studied the Effect of basalt fiber hybridization on the impact behaviour under low impact velocity of glass/basalt woven fabric/epoxy resin composites. E-glass/basalt reinforced hybrid laminates were manufactured by resin transfer moulding technique was investigated. Specimens prepared with different stacking sequences were tested at three different impact energies, namely 5 J, 12.5 J and 25 J. Residual post-impact mechanical properties of the different configurations were characterized by quasi static four point bending tests. Post-impact flexural tests have been also monitored using acoustic emission in order to get further information on failure mechanisms. Results showed that basalt and hybrid laminates with an intercalated configuration exhibited higher impact energy absorption capacity than glass laminates, and enhanced damage tolerance capability. Conversely, the most favourable flexural behaviour was shown by laminates with symmetrical sandwich-like configuration (E-glass fiber fabrics as core and basalt fiber fabrics as skins).

Dehkordi et al. has studied the Low velocity impact properties of intra-ply hybrid composites based on basalt and nylon woven fabrics. Epoxy resin was used as matrix material. Five different types of woven fabrics were used as reinforcement with different volume percentages of nylon (0%, 25%, 33.3%, 50% and 100%). The effect of nylon/basalt fiber content on maximum force, maximum deflection, residual deflection, total absorbed energy, elastic energy, size and type of damage were studied at several low velocity impact nominal energy levels (16, 30 and 40 J). The results indicate that impact performance of these composites is significantly affected by the nylon/basalt fiber content. The visual inspection and ultrasonic C-scan of the impact damaged specimens reveals that content of nylon/basalt fiber controls the type and size of damage.

Torres et al. has Manufactured Green-Composite Sandwich Structures with Basalt Fiber and Bio epoxy Resin. This material system was combined with cork as core material for the fabrication of fibre composite sandwich structures. Mechanical properties of both skin and core materials were assessed through flexural and tensile tests. Permeability measurements of the basalt fabrics were carried out in order to perform numerical simulations of liquid composite moulding (LCM) processes on the PAMRTM software. Finally, the load-bearing capacity of the board was studied by means of FEM simulations, and the presented design proved to be acceptable for service.

Khalili et al. has investigated the Mechanical behaviour of basalt fiber-reinforced and basalt fiber metal laminate composites under tensile and bending loads. To study the effect of fillers in epoxy, the micro glass powder (MGP) was only added into the

epoxy resin in BFRE composites at various volume fractions. It was found that the micro glass powder had no significant effect on tensile strength, but it raised the stiffness and decreased the failure strain of BFRE. On the other hand, bending strength increased by adding MGP. BFML showed superiority in energy absorption via tensile strength. This FML had flexibility much higher than that of BFRE. Adding MGP or metal layer to basalt-reinforced composites improved the mechanical properties in tensile and bending loads. Selective bending specimens of BFRE are studied by SEM to show the positive role of MGP in raising the bending strength and further analysis of the nature of fracture surfaces. High fragmentation of matrix was obvious.
Chelliah et al. has studied Mechanical and Abrasive Wear Behaviour of Glass and Basalt Fabric-Reinforced Epoxy Composites Basalt and glass fabric-reinforced epoxy composites have been fabricated by hand layup technique. The mechanical properties of basalt and glass fabric reinforced epoxy composites were evaluated. Abrasive wear performance was evaluated at ambient temperature using 400 grade Silicon Carbide paper as a counter face. The outcome of the results suggested that basalt fabric-reinforced epoxy composites has the possible application in abrasive wear situation, owing to its better abrasive wear resistance and good mechanical properties. However, this situation may differ from other resins.

Wei et al. has investigated Degradation of basalt fibre and glass fibre/epoxy resin composites in seawater with different periods of time. Both the mass gain ratio and the strength maintenance ratio of the composites were examined after the treatment. The tensile and bending strengths of the seawater treated samples showed a decreasing trend with treating time. In general, the anti-seawater corrosion property of the basalt fibre reinforced composites was almost the same as that of the glass fibre reinforced ones. Based on the experimental results, possible corrosion mechanisms were explored, indicating that an effective lowering of the Fe^{2+} content in the basalt fibre could lead to a higher stability for the basalt fibre reinforced composites in a seawater environment.

IV. CONCLUTION

From the literature review it is understood that basalt fiber will be a potential replacement for glass fibers and other synthetic fibers. It is cost effective and eco-friendly material. Basalt fiber reinforced polymer having wide range of applications due to their great mechanical property and thermal stability.

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