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A short review on basalt fiber reinforced polymer composites

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ABSTRACT

A recent increase in the use of ecofriendly, natural fibers as reinforcement for the fabrication of lightweight, low cost polymer composites can be seen globally. One such material of interest currently being extensively used is basalt fiber, which is cost-effective and offers exceptional properties over glass fibers. The prominent advantages of these composites include high specific mechano-physico-chemical properties, biodegradability, and non-abrasive qualities to name a few. This article presents a short review on basalt fibers used as a reinforcement material for composites and discusses them as an alternative to the use of glass fibers. The paper also discusses the basics of basalt chemistry and its classification. Apart from this, an attempt to showcase the increasing trend in research publications and activity in the area of basalt fibers is also covered. Further sections discuss the improvement in mechanical, thermal and chemical resistant properties achieved for applications in specific industries.

1. Introduction

Since its discovery in 1923 by American scientists, basalt was a classified material of choice for military research and was extensively used in defense and aeronautical applications during World War II by the United States (US), Europe and the Soviet Union [1–3]. Fig. 1 shows basalt fiber and carbon woven fabrics, which are extensively used. In recent decades, an increasing research interest in the use of basalt fibers due to their enhanced mechanical properties has taken the polymer industry by storm. These fibers are now used in fabricating light, high-end hybrid composite materials for infrastructural and civil applications [4].

In general, hybrid nanocomposites are fabricated when two or more combined foreign materials are embedded or reinforced within a common host matrix. With this mixing of two or more materials, a synergistic effect is realized, which provides new and superior properties within the material like improved elastic modulus, ductility, light weight, and flame retarding ability [5–7]. These qualities are already present in carbon-fibers (CFs), which are useful in a plethora of large scale engineering applications like aircraft (civil and defense), automobiles, shipping, sports equipment and construction [8–11]. CF-based composites are, however, pliable to stress concentrations owing to the brittleness of the carbon fiber [8]. The major drawback in the carbon composite industry is the expense of production, resulting in the use of very low loadings. The problems of weakness and brittleness in the composite (carbon fiber reinforced plastic-CFRP) can be resolved by a hybridization technique, that is, by replacing the layers of the carbon fibers with ductile fibers. This may result in cost benefits and improvement in the physical and mechanical properties.

By using this technique, novel types of materials can be synthesized and fabricated. For example, Park and Jang [12] introduced fibers of polyethylene (PE) along with carbon fibers within an epoxy matrix to fabricate a hybrid laminated composite material. In their experiment, they chose PE fibers because of the high elongation at break followed by its high specific-strength and stiffness. Based on their observations, it was concluded that the superior mechanical properties of the hybrid-based composite depends strongly upon the position of the reinforcing fiber. So, whenever the CF was placed at the peripheral (outermost) layer, the composite delivered a high degree of flexural strength.

Based on the above observations, strong, lightweight, durable and economically viable fibers are currently required for fabricating the hybrid composites. Presently, several organic and inorganic fibers are available in the market, but many of them either lack structural strength or durability, or are extremely costly for use in moderate loadings. Basalt fiber is the material of choice presently and is an inorganic fiber with extremely good modulus, high strength, improved strain to failure, high temperature resistance, excellent stability, good chemical resistance, and it is easy to process, non-toxic, natural, eco-friendly and inexpensive [13–18]. Basalt fiber is obtained after extrusion from basalt-based molten igneous volcanic rock, which is found in flowing lava [19]. The

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extrusion process of basalt fiber is very energy efficient and simpler than that of any competing fibers. The fiber dimensions are generally in the range of 10–20 μm [16,19]. Several of these properties (like tensile and compressive properties of basalt) are better than the fibers of E-glass and are also far cheaper than their carbon counterparts [20–22]. Hence, basalt fibers have received increasing attention as a novel type of reinforcement material for the fabrication of hybrid composites/laminates.

Based on the merits of basalt fiber, potential applications exist in the fabrication of basalt-epoxy composites, which are also lightweight and have strong load-bearing properties useful in the heavy automobile industry. Currently, the CF composites are being extensively adopted in the automotive industry due to their superior mechanical properties. By utilizing this reinforcing material, one could decrease vehicle body weight by 40–60%, but the cost of the whole process is not currently economically viable [23]. Thus, the need for lowering the production and delivery cost without enduring a loss in CFRP-based composite mechanical properties is important. As stated above, the promising nature, low cost and effective properties of basalt fibers could make basalt a prospective candidate for reinforcement in CFRP based composites. Several accounts of reports are available which report the introduction of basalt fibers with different reinforcements within composite laminates. Lopresto et al. [13] investigated and compared the compressive strength, Young's modulus and flexural behavior of basalt fiber reinforced plastics or polymers (BFRP) with glass fiber reinforced plastics (GFRP), and they found that basalt was superior and has the potential to replace glass. A similar report was prepared by Manikandan et al. [24]. On the other hand, the mechanical, physical and physico-chemical properties of the fiber reinforced plastics or polymer were further improved by the introduction of foreign fillers like nanoparticles [25–27], fiber fillers [6,28], and by surface alterations [29] of the fibers. At present, very few researchers have carried out surface treatments of the basalt fibers to enhance its properties. Another possible alternative to enhance the properties of basalt as discussed previously is to hybridize it with carbon fibers. This would make it extremely light weight, durable, cost effective and also opens numerous opportunities in the hybrid composite world [30].

Carmisciano et al. [20], reported higher flexural modulus and seemingly higher inter-laminar shear strength for their basalt woven fiber reinforced composites (BWFRC). They also found that their fabricated BWFRC had similar electrical properties in comparison with E-glass composites. As for the structural properties of the basalt fiber, several reports are available which show promising capacities of the material. Previously, basalt was a preferred choice of material (as fibers) in the construction industry, and has been in extensive use since as an external or internal reinforcement within concrete materials [18,31,32]. Moreover, basalt can also be used in other applications like marine [16], impact or ballistic resistance applications [6,32]. Eslami-Farsani et al. [33] fabricated a composite by chopping the basalt fiber and mixing it in a polypropylene–clay mixture. This approach not only improved the yield strength but also the elastic modulus of the composite dramatically. As basalt is more utility-friendly and ductile, basalt can be introduced as a reinforcement within the matrix in various shapes other than fibers. Shapes like rods, bars and textile fabrics are possible [6,18,19,25,34–50].

The present review focuses on the extensive use of basalt fibers as stable, inert, eco-friendly and non-reactive reinforcement material used in the synthesis and production of light-weight composites with highly improved mechanical properties. Also, the present review highlights the applications of the composites made by using a polymer matrix reinforced with basalt fiber.

1.1. Chemistry of basalt

Basalt is chemically rich with oxides of magnesium, calcium, sodium, potassium, silicon and iron, along with traces of alumina. Fig. 2 depicts the overall percentage distribution of the chemical constituents in basalt. The chemical content may differ based on the geographical distribution. Basalt is abundant and comprises up to 33% of the earth's crust. Basalt fibers are manufactured from finely powdered basalt, which is melted at around 1500–1700 °C to yield a glassy molten liquid, which is then extruded in the form of thin threads.

The fibers are chemically composed of pyroxene, clinopyroxene, olivine, and plagioclase minerals [51]. Based on the above chemistry, if the basalt is rich in silica and poor with sodium it is categorized as tholeiitic basalt. If the basalt is rich in sodium and deficient in silica then it is categorized as alkali basalt. Further, if the mineral is rich in alumina with a concentration over 17%, then the basalt is

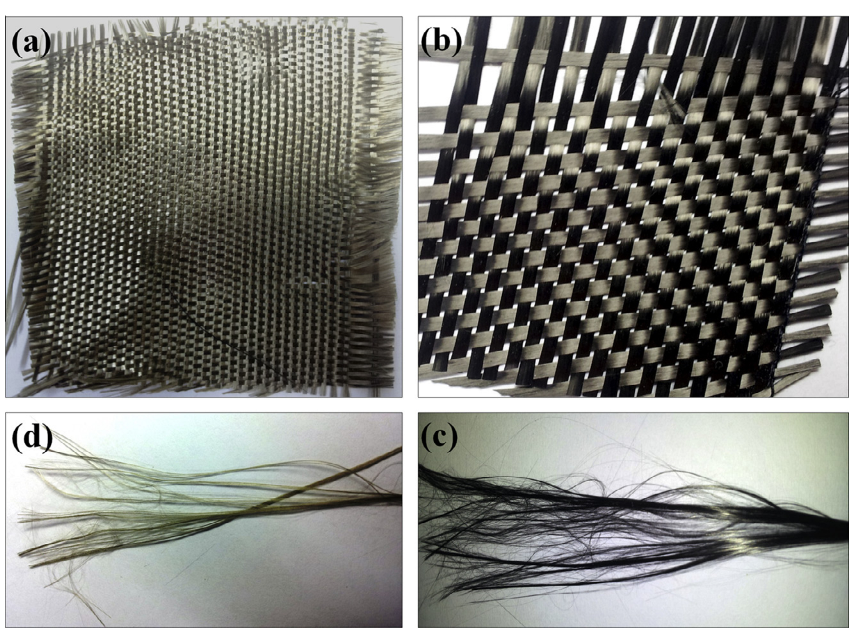

Fig. 1. Woven fabrics: (a) basalt fiber fabric, (b) carbon fiber fabric, (c) strands of carbon fiber, (d) strands of basalt fiber.