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Study On Performance And Durability Of Polymer Matrix Composites With Basalt As A Reinforcement- A Review Paper

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Abstract: Polymer matrix composites (PMCs) augmented with basalt fibers have attracted significant scholarly interest owing to their superior mechanical attributes, thermal resilience, and ecological durability. This review meticulously examines the performance and longevity of basalt-reinforced polymer matrix composites, emphasizing their mechanical, thermal, and chemical characteristics. Moreover, a comparative evaluation with traditional reinforcements such as glass and carbon fibers is provided. In addition, this study addresses the constraints and prospective solutions to improve the practical applications of these composites.

***Index Terms* -** Polymer composites, performance, durability, basalt

I. Introduction

The aerospace industry together with automotive and civil engineering and marine sectors extensively apply polymer matrix composites because of their beneficial strength-to-weight ratio and their resistance to corrosion .Basalt fibers represent a promising option over glass and carbon fibers as reinforcement because of their favourable cost structure along with high heat tolerance and their sustainable profile.

The production of basalt fibers starts from volcanic rock through fiberization after melting it into fibers thus enabling their natural abundance and environmental sustainability. Basalt fibers need minimal production steps because of which they contribute to lower carbon emissions through their manufacturing process according to Johnson & Carter. Basalt fibers represent a practical solution for various applications because they exist in ample supply and cost less than carbon fibers.

The strongest aspect of basalt fibers emerges from their ideal balance between mechanical properties and thermal stability as well as resistance against chemicals. The strength and stiffness level of basalt fibers surpasses that of glass fibers which makes them more suitable for building structures. The fibers demonstrate optimal resistance to environmental harm and higher melting temperature since these features make them perfect for industrial high-temperature situations and marine use and fire-resistant building construction. [1,2,4]

The research advancement of basalt fiber-reinforced composites strengthened because of the rising interest in environmentally friendly materials. Basalt fibers serve as an effective alternative to typical PMCs reinforcement materials because they present lower environmental impact and recycling capability and chemical resistance benefits. This review details the mechanical traits along with durability and practical issues affecting basalt fiber-reinforced polymer composites (BPCs).[1,2,4]

II. MECHANICAL PROPERTIES

Basalt fibers are distinguished for their mechanical behaviour, which includes batter tensile strength, toughness and flexure properties. Basalt fibers have a tensile strength ranging from 2.8 to 4.8 GPa and higher than conventional E-glass fibers, which presents a good option as a replacement material especially in high-strength applications . The mechanical properties of BPCs are significantly influenced by fiber volume fraction, fiber alignment, fiber-matrix adhesion, and composite processing methods [5,6].

2.1 TENSILE STRENGTH AND ELASTIC MODULUS

Tensile strength is one of the most critical parameters of structural materials, and basalt fibers have a significantly larger tensile strength than that of glass fibers while being less expensive than carbon fibers. Due to the modulus of the basalt fibers, which is known to be between 89 and 110 GPa, the stiffness of the composite increases, thus increasing the load-bearing capacity. Such characteristics make BPCs highly attractive in aerospace, automotive and infrastructure applications[6].

2.2 FLEXURAL STRENGTH AND IMPACT RESISTANCE

The resistance of composite materials against bending forces strongly relies upon their flexural strength properties. Basalt fiber composites perform better than glass fiber composites in structural applications because their exceptional flexural properties. The shock-absorbing performance and sudden mechanical load resistance of basalt composites make them suitable materials for safeguarding vehicles and equipment. [9]

2.3 FATIGUE AND CREEP RESISTANCE

Materials consisting of BPCs retain their structural integrity at high levels during cyclic loading sessions. The property allows the successful implementation of basalt polymers in bridge reinforcements along with wind turbine blades and aerospace components needing repeated stress accumulation [7,8]. Constant stress loads do not affect dimension stability because basalt fibers show better performance in creep deformation than glass fibers.of five years. The time series monthly data is collected on stock prices for sample firmsand relative macroeconomic variables for the period of 5 years. The data collection period is ranging from January 2010 to Dec 2014. Monthly prices of KSE -100 Index is taken from yahoo finance.

III. INTERLAMINAR SHEAR STRENGTH AND TOUGHNESS

Interlaminar shear strength (ILSS) serves as the essential test parameter to determine composite failure under shear loads because it measures their resistance to delamination failures. BPCs outperform glass fiber composites because of stronger fiber-matrix bond strength which makes them more reliable in structural applications. Basalt fibers present built-in strength which helps them resist cracking damage while facing mechanical stress according to Wilson and Taylor and Kim [9,10].

IV. THERMAL AND CHEMICAL RESISTANCE

At temperatures reaching 800°C basalt fibers maintain their structural strength because of their superior thermal stability. The reduced thermal expansion of basalt fibers makes them optimal for use in high-temperature applications including aerospace components and fire-resistant structures according to Johnson et al. 2018, Nguyen & Tran 2023 and Reddy et al. 2023[6,7,8] Process chemical solutions resist change on basalt fiber structures because of their exceptional chemical resistance characteristics. The chemical agents cause no harm to basalt fibers because these fibers show stronger resistance against various chemicals compared to glass fibers. BPCs demonstrate high durability for use at chemical processing facilities alongside marine structures as well as underground pipelines according to Taylor & Kim[11]

V. MOISTURE AND ENVIRONMENTAL EFFECTS

Environmental degradation resistance stands as a primary durability factor for composites which mainly affects their moisture absorption and hydrothermal aging performance. Basalt fibers absorb less water content than glass fibers which reduces the susceptibility to hydrothermal damage [7,8]. Extensive research indicates basalt fiber composites maintain 90% of their mechanical properties under humid environments outlasting glass fiber composites by as much as 90% [10].

III COMPARATIVE ANALYSIS WITH GLASS AND CARBON FIBER COMPOSITES

BPCs succeed in providing an intermediate solution between GFRP and CFRP composites suitably blends their characteristics. The analysis compares BPCs regarding mechanical performance together with expenses and thermal endurance and environmental friendliness.[1,2].

3.1 MECHANICAL PERFORMANCE

Basalt fibers maintain better tensile strength as well as flexural strength than glass fibers while demonstrating inferior mechanical qualities compared to carbon fibers. The tensile strength of basalt fibers spans between 2.8 to 4.8 GPa whereas E-glass fibers measure between 2.0–3.5 GPa and carbon fibers exhibit 4.8–7.0 GPa tensile strength [6,18]. Their elasticity modulus (89–110 GPa) stands higher than glass fibers (70–85 GPa) while remaining lower than carbon fibers (230–600 GPa) [3,4].

Basalt fibers demonstrate greater impact resistance than glass fibers because they possess superior energy absorption ability which makes automotive crash structures and ballistic protection applications beneficial for them [9] Carbon fibers hold superior fatigue and wear resistance when compared to all other materials in this list [10]. The following factors contribute to the increase in mechanical properties, • Physical Interactions: Basalt fibres reinforce PLA by transferring load, with their orientation, length, and volume fraction impacting the composite's properties [2,3,4]. Chemical Interactions: Strong interfacial adhesion between basalt fibres and PLA, enhanced by coupling agents or surface treatments, is crucial for optimal composite performance. Polymer matrix compatibility also affects interaction strength.

3.2THERMAL STABILITY AND FIRE RESISTANCE

Basalt fiber-reinforced polymer composites (BFRPs) have high thermal stability and resistance to fire as a result of the natural characteristics of basalt fibers. Basalt fibers melt at around 1450 °C, with a softening point at around 1050 °C, and retain structure at 800 °C. BFRPs demonstrate better ignition resistance and emit no toxic fumes upon combustion, with a limiting oxygen index (LOI) of around 41%, which is far above that of most traditional composites. Research has indicated that BFRPs maintain as much as 90% of their tensile strength at 400 °C, surpassing glass fiber composites, which start degrading at temperatures above 300 °C. These properties make BFRPs extremely well-suited for use in applications that need flame retardancy and heat resistance, including fireproof panels, car shields, and structural insulation.[3,4]

3.3 ENVIRONMENTAL SUSTAINABILITY

Basalt fiber demonstrates superior environmental benefits than both glass and carbon fiber products. Basalt fibers prove superior to carbon fibers in environmental friendliness because of their source from natural materials through straightforward processing requirements [2,3].

The hazardous substances present in glass fiber dust make their disposal difficult while basalt fibers establish themselves as non-toxic as well as recyclable [20]. The degradation resistance of basalt fibers surpasses glass fibers so they function well in marine and chemical and underground environments [3,4].

IV SUMMARY OF COMPARATIVE ANALYSIS

Table1. COMPARATIVE ANALYSIS OF VARIOUS FIBERS

Property	Basalt Fiber	Glass Fiber	Carbon Fiber
Tensile Strength (GPa)	2.8–4.8	2.0–3.5	4.8–7.0
Elastic Modulus (GPa)	89–110	70–85	230–600
Impact Resistance	High	Moderate	Low
Cost	Moderate	Low	High
Thermal Stability (°C)	800	600	>1000
Environmental Impact	Low	Moderate	High

The properties of various fibers are as shown in the table 1.The mechanical properties of basalt fibers including low cost and sustainability along with thermal resistance serve as an outstanding balance for_components. Applications in structural and automotive together with aerospace industries have indicated their potential to supplant glass fiber composites since basalt fibers demonstrate both affordability and effectiveness in replacing carbon fibers.[2,3]

V Conclusion

- The processing techniques used during the fabrication of basalt-polymer composites (BPCs) have a major impact on their mechanical performance. Important processing variables that affect the final properties of the composite include matrix viscosity, fiber dispersion, fiber-matrix adhesion, and void content.[21,22]
- An important factor in the impregnation of basalt fibers is the viscosity of the polymer matrix. Reduced mechanical properties and poor fiber-matrix interaction can result from matrices with higher viscosities that prevent fibers from being thoroughly wet. The strength and stiffness of the composite are increased by matrices with lower viscosity, which enable better fiber impregnation. Achieving high-quality BPCs requires processing techniques that maximize matrix viscosity. [12,13]
- Uniform alignment and dispersion of basalt fibers in the polymer matrix are critical for efficient load transfer and mechanical performance. Poor dispersion may lead to fiber agglomeration, causing stress

concentrations and failure sites. Processing methods that provide uniform fiber distribution and alignment are vital to achieving the maximum mechanical properties of the composite. [12,13].

- Interfacial adhesion of BPCs between the polymer matrix and the basalt fibers is a key aspect that can facilitate successful stress transfer. Processing techniques that strengthen the adhesion, like the application of compatibilizers or proper curing cycles, can strongly improve the mechanical properties of BPCs. Enhanced fiber-matrix adhesion results in efficient load transfer and higher composite strength. [12,13]
- The presence of voids and defects within the composite can act as stress concentrators, leading to premature failure. Processing techniques that minimize void formation, such as controlling processing temperatures and pressures, are vital for achieving high-quality BPCs with superior mechanical performance. Reducing void content enhances the composite's structural integrity and durability. [12,13].

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