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Effect of Granite Fly Ash on Mechanical Properties of Basalt and Glass Fiber Reinforced Polymer Composite

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ABSTRACT

The granite processing industry generates a substantial volume of residual granite waste daily. This residue is collected through a filtration process during the drying and heating stages of concrete mixture production. Utilizing this residue, known as granite fly ash (GD), offers a promising avenue for mitigating adverse effects due to this waste material. The present study undertakes an experimental investigation into the potential utilization of granite fly ash as a filler to enhance the mechanical properties of basalt/glass composites (BFRC/GFRC). The research focuses on assessing the density and tensile characteristics of the developed fibre-reinforced polymer (FRP) composites. Composite samples were fabricated by incorporating GD at varying loadings, i.e., 1 wt.%, 3 wt.%, and 5 wt.%. The FRP laminates were produced using hand lay-up and vacuum silicon mold curing techniques. The outcomes show a slight increase in density, in which a maximum of 7% increment at 5 wt% of GD in BFRC. Meanwhile, tensile properties displayed

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significant enhancements, especially FRP with 3 wt.% GD content, for both BFRC and GFRC. Notably, the addition of 1 wt.% GD resulted in a 9% increase in tensile strength and a substantial 27% increase in modulus for the BFRC composite. In summary, the study underscores the advantageous influence of GD incorporation, particularly within the 1 wt.%, 3 wt.%, and 5 wt.%, on the mechanical properties of both BFRC and GFRC composites.

Keywords: *Tensile properties; Granite Fly Ash; Basalt Fiber; Glass Fiber; Polyester*

Introduction

In the present era, the concept of sustainability has emerged as a highly engaging subject across various domains of expertise, including civil and environmental engineering on a global scale [1]. Fiber-reinforced composites (FRCs) are extensively studied materials in engineering, encompassing a diverse array of reinforcing fibers and matrix properties [2]. The choice of both the fiber and matrix within an FRC is contingent upon the specific usage and the targeted mechanical potency of the composite [3].

Granite fly ash, a byproduct substance, holds the potential for reinforcement utilization because of its impressive attributes, including a high modulus of elasticity and strength [4]. Furthermore, granite fly ash is categorized as industrial waste, presenting a substantial environmental hazard [1], [5]-[6]. As granite stones undergo processing within the realm of granite processing, a considerable volume of granite waste holds the capacity to generate colloidal waste upon contact with water, exacerbating the environmental concern. In the global effort to tackle sustainability and safeguard the environment, creative remedies that tap into the overlooked capacities of industrial byproducts have gained prominence in both scientific investigation and industrial endeavors [7]. A noteworthy illustration emerging from the realm of granite waste is micro scale, an extraordinary substance possessing the ability to transform multiple sectors thanks to its unique qualities and environmentally conscious characteristics.

The main constituents of granite fly ash consist mainly of alumina, silica, and potassium, alongside minor quantities of magnesium and calcium. Because of its chemical makeup, specifically the presence of alumina, silica, and magnesium which serve as effective fillers, granite fly ash shows promise for utilization in polymer composites.

Basalt and glass fiber-reinforced polymer (FRP) composites have gained momentum as lightweight and high-performance materials in a variety of industries [8]. These composites display remarkable mechanical characteristics and resistance to corrosion, positioning them as viable choices for applications like automotive elements, aerospace components, and marine constructions. Yet, the pursuit of enhancing their mechanical and thermal properties has driven researchers toward the realm of nanotechnology, where the introduction of granite fly ash stands out as a promising enhancer capable of propelling these composites to new thresholds.

Beyond the performance benefits, the incorporation of granite fly ash as filler into basalt and FRP composites offers the potential for even lighter and more fuel-efficient structures, making them attractive options for the aerospace and transportation sectors [9]-[10]. The addition of fillers increased the stiffness of the polymeric composite, however, this effect peaked at a filler ratio above which a particle accumulation problem emerged. As a result of this buildup, the link between the matrix and the fillers became weaker, which decreased the composite's overall mechanical strength [11]. Additionally, the utilization of waste-derived granite fly ash, such as from the granite industry, introduces an environmentally friendly dimension to these advanced composites, contributing to sustainability initiatives and responsible waste management practices.

Going beyond the advantages in terms of performance, integrating granite fly ash into basalt and FRP composites not only promises enhanced performance benefits but also holds the potential to create structures that are notably lighter and more fuel-efficient. This quality renders these composites exceptionally appealing for pivotal sectors like aerospace and transportation [12]. Furthermore, the utilization of granite fly ash sourced from waste, particularly from the granite industry, introduces an added environmental dimension to these cutting-edge composites. This strategic choice aligns with sustainability initiatives and underscores responsible waste management practices, amplifying the overall appeal and impact of these advanced materials.

A survey of existing literature revealed an absence of specific investigations into the impact of granite fly ash incorporated into the polyester matrix on the mechanical properties of basalt/glass composites. Prior research on granite fly ash predominantly concentrated on diverse construction applications and building materials. This encompassed employing fine granite aggregate to replace natural sand and cement in concrete, using it as filler material for roads, and fabricating construction elements like bricks and tiles for infrastructure and building purposes [9], [12]. As a result, this study aims to leverage granite fly ash as a reinforcing filler to enhance the mechanical performance of basalt/glass composites, thus realizing a comprehensive utilization of granite fly ash.

The designed granite fly ash-infused basalt/glass composites adopt a distinct configuration, intended for repairing damaged or cracked surfaces and pipelines, serving as a substitute for carbon fiber-reinforced composite patches. The investigation examines varying levels of granite fly ash loading to assess its influence on tensile strength, alongside considerations for the form and type of fibers, which are specified as woven-type basalt fiber and glass fiber. The incorporation of granite fly ash incurs no additional cost, as it is a byproduct of the granite processing industry, thereby offering a solution to waste disposal challenges. Furthermore, this research seeks to expand the potential of incorporating granite fly ash into composites based on natural materials.

Methodology

The experiment utilized natural basalt fiber sourced from Innovative Pultrusion Sdn. Bhd., located in Seremban, Negeri Sembilan. Unsaturated Isopolyester (CRYSTIC® 272E Isophthalic Polyester Resin) and Butanox M60 hardener were supplied by Carbon Tech Global Sdn. Bhd., situated in Rawang, Selangor, Malaysia. Woven roving glass fibers were provided by Vistec Technology in Puchong, Malaysia. The granite fine powder used in the research was obtained from the Kelantan Branch of Jabatan Kerja Raya (JKR), Malaysia, as depicted in Figures 1 and 2. The polyester and hardener were combined in a mass ratio of 100:2, following the manufacturer's recommendation.

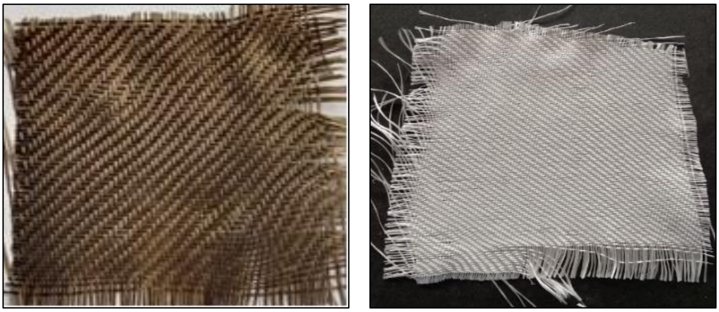

(a) (b)

Figure 1: Type of fibre used in this study; (a) Basalt fibre, and (b) Glass fiber

The manufacturing process involved fabricating composite materials using varying weight proportions (1 wt%, 3 wt%, and 5 wt%) of granite fly ash as the filler substance. The research focused on using a combination of woven glass fiber, woven basalt fiber, and a specific polyester resin as the matrix.

The fabrication process for composite laminate begins by preparing the necessary materials and tools. It is crucial to establish the accurate size and required thickness of the composite at the outset to ensure it aligns with the prerequisites for mechanical testing. Initially, the basalt fiber, provided in roll form, undergoes a meticulous transformation, being carefully shaped into a square measuring 300 x 300 mm. This achievement results from carefully accumulating interconnected layers.

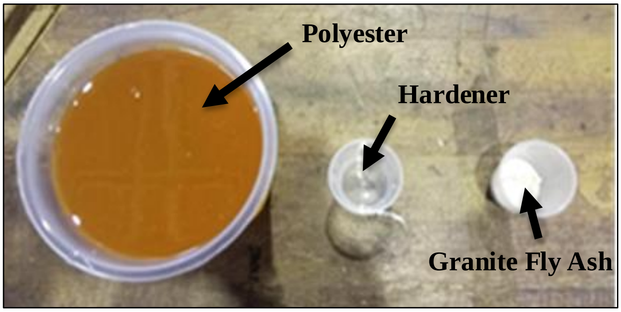


Figure 2: Polyester, hardener, and granite fly ash

The matrix of the composite comprises polyester (PE) resin infused with a mixture of hardener and granite fly ash, enabling effective room-temperature curing. To prevent premature resin hardening throughout the process, a specialized slow hardener is employed. This slow hardener is thoroughly mixed in a weight ratio of 100 parts resin to 2 parts hardeners, ensuring precise control and optimal outcomes.

The equipment ensemble includes essential components: a robust base plate with a substantial 10 mm thickness, a reliable vacuum pump, a network of vacuum tubing for seamless communication, a flexible silicon mold bag that conforms to innovative contours, and a dependable roller ensuring precision and uniformity at each step of the process.

The fabrication of the composite laminates involves a combination of hand lay-up and silicon vacuum mold methodologies. The base plate undergoes meticulous cleansing, with its surface gently coated in mold release wax to eliminate impurities. Subsequently, seven layers are sequentially assembled, each carefully placed on top of the other. With deliberate precision, a symmetrical flow of resin mixture is poured onto each layer, ensuring consistent distribution – a meticulous dance of balance and uniformity that harmonizes the layers into a coherent whole. This systematic layering process results in a substantial composite thickness of 2 mm.

The silicone vacuum bag is then gently and precisely secured around the intricate assembly of the seven layers as shown in Figure 3. After completing the vacuum bagging process, the samples are left at ambient temperature for a 24-hour curing period. This stabilization period guarantees thorough and complete curing of the samples, reaching a 100% cured state. Upon completion of the curing phase, the composites undergo a precision cutting process to achieve the desired dimensions in accordance with the ASTM standard. Figure 4 illustrates the comprehensive process flow of the composites.

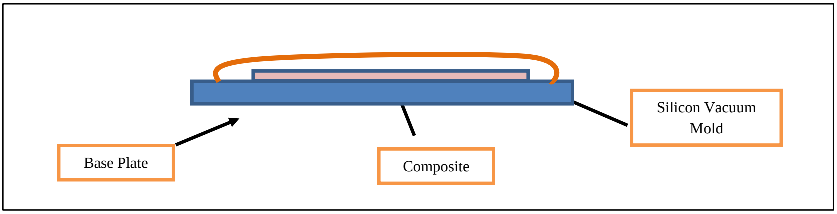


Figure 3: Schematic of vacuum bagging setup for composite fabrication

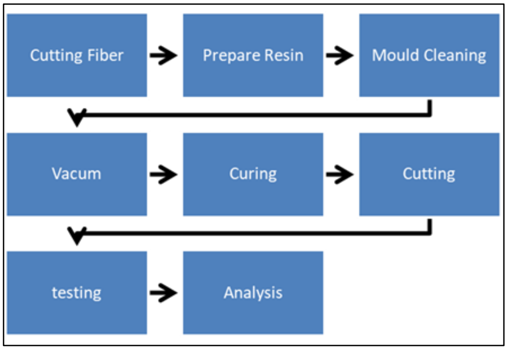


Figure 4: Composite fabrication process

Density test

Density analysis is a fundamental process that involves a comparative evaluation of an object's mass against its volume. The mass component is typically quantified using precision instruments such as balances or scales, while a range of methodologies is harnessed to deduce the volume, contingent upon the unique attributes of the material in question. The consequential density measurement yields invaluable insights into the material's intrinsic qualities, encompassing its degree of compactness, concentration, or even purity.

This study encompassed a meticulous density assessment, meticulously adhering to the standards stipulated by ASTM D792 [13]. To this end, distilled water was maintained at a temperature of 25 °C and was meticulously employed. The requisite water volume, carefully regulated within the range of 200 ml to 250 ml, was meticulously referenced against temperature-specific density values gleaned from established tables. The density of the composite samples is calculated using Equation (1).

$$\rho = \frac{m_1}{m_1 - m_2}\rho_{water} \tag{1}$$

where; ρ = density of composite specimen (g/cm^3), m_1 = mass of dry sample (g), m_2 = mass of sample in water (g), and ρ_{water} = density of water at room temperature (0.9982 g/cm^3).

The specimens designated for this comprehensive density examination were characterized by their precise dimensions, measuring 20 x 20 mm using analytical balance Gr-200 and the specialized apparatus employed for density measurement as illustrated in Figure 5. Each system underwent the testing regimen, entailing the meticulous examination of three distinct samples.

Figure 5: Density measurement using Archimedes' principle

Tensile test

The experimentation was conducted under standard ASTM D3039 conditions, ensuring room temperature consistency. Tensile properties of the composite laminates were evaluated using universal testing apparatus (UTM-SHIMADZU 3366), with a controlled cross-head speed of 2 mm/min and specimens measuring 250 x 25 mm as depicted in Figure 6. Rigorous testing involved a minimum of five specimens per hybrid composite laminate configuration. The SHIMADZU 3366 Universal Testing Machine and visual representation of the specimens are depicted in Figure 7.

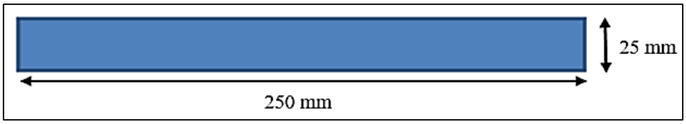
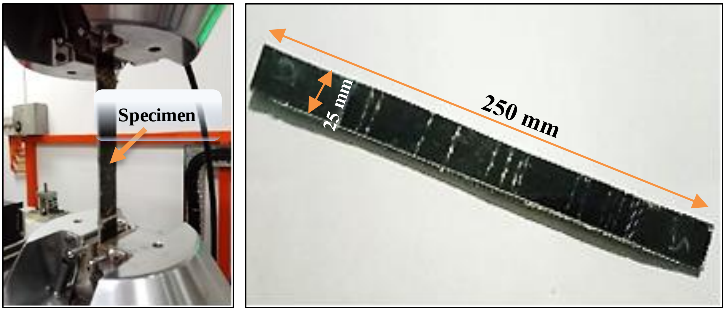


Figure 6: Dimensions of the tensile specimens



(a) (b)

Figure 7: Tensile testing machine and tensile specimen; (a) specimen setup (b) tensile sample

For BFRC and GFRC, all computations based on the values measured were performed in the same manner. Newton units (N) were used to present the applied load (F). Equation (2) is used to determine the tensile stress (σ), and the observed strain in the direction of the longitudinal is calculated using Equation (3).

$$\sigma = \frac{F}{A} \tag{2}$$

where; σ = tensile stress at data point, F = load data point, and A = cross-sectional area.

$$\in = \frac{\Delta L}{L_0} \tag{3}$$

where; $\in$ = strain, ΔL = change in length, and L_0 = original length.

Results and Discussion

The outcomes of this investigation are based on the mean values extracted from the meticulous analysis of five distinct samples within each classification of composite laminates. The observed divergence among these samples is linked to the varying weight percentages of granite fly ash that were integrated into the PE resin prior to the pouring stage in the manufacturing process. This study conducted a thorough exploration of multiple attributes of composite laminates, embracing pivotal variables like density and tensile properties.

Effect of granite fly ash on the density of BFRC and GFRC

The assessment of density was crucial in determining the mass per unit volume of each specimen, aiding in understanding how the inclusion of granite fly ash affected the properties of PE polymer and FRP composites.

The collected data showed a consistent trend across all systems, with density values increasing as the weight percentage of granite fly ash in the PE polymer increased. Specifically, the BFRC configuration with 1 wt% granite fly ash exhibited a slight increase of 0.08% compared to the configuration with 0 wt%, as reported by Hashim et al. [14] and Chaves et al. [15]. This trend highlights the direct relationship between higher weight percentages of granite fly ash in the PE resin and increased density values. Notably, pure PE had the lowest density, emphasizing the impact of adding granite fly ash. As the weight percentage of the filler (granite fly ash) increased, so did the density of the composite material, as shown in Figure 8. These findings underscore a clear correlation between the rising weight percentage of granite fly ash and the corresponding increase in density.

Furthermore, insights from Figure 8 revealed a consistent pattern where the density increased proportionally with higher weight percentages of granite fly ash in both BFRC and GFRC composites. This aligns with previous observations that the density of basalt fiber surpasses that of both glass fiber, as indicated by Sapuan et al. [16], and unsaturated polyester, as highlighted in the previous research by Raajeshkrishna et al. [17] and Raajeshkrishna and Chandramohan [18].

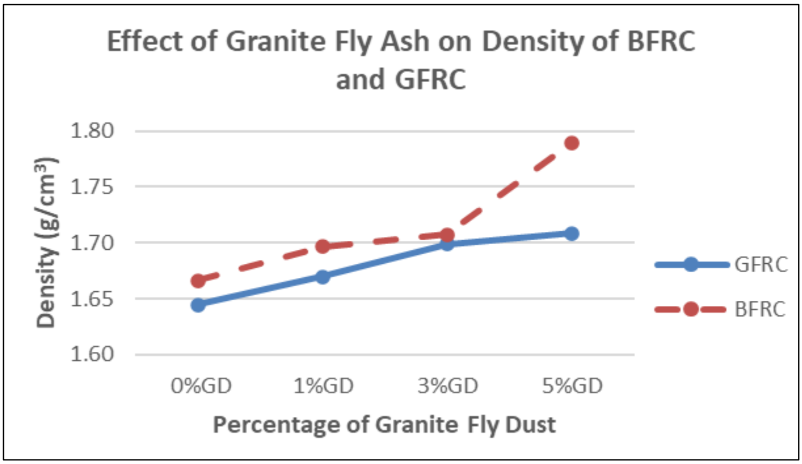


Figure 8: Density of FRP composites with different loading (wt%) of granite fly ash

Effect of granite fly ash on tensile strength and modulus of BFRC and GFRC

The impact of granite fly ash on tensile properties is presented in Table 1. Tensile strength is depicted in Figure 9, while its corresponding influence on modulus is illustrated in Figure 10. The examination revealed a remarkable pattern in the tensile strength of BFRC. Initially, with no incorporation of granite fly ash at 0 wt%, the tensile strength was measured at 255.89 MPa. Interestingly, the addition of just 1 wt% granite fly ash caused a significant increase to 270.25 MPa, indicating an increase of 5.3% which is in line with the findings of previous research by Kufel et al. [19], as well as Hashim et al. [14] where the presence of granite fly ash resulted in an enhancement of both tensile strength and modulus compared to the unmodified system.

Table 1: Effect of GD inclusion (weight %) on tensile properties of BFRC & GFRC

Composite	Properties	0% GD	1% GD	3% GD	5% GD
BFRC	Tensile strength (MPa)	255.894	270.258	278.020	231.245
	Tensile strain (%)	2.453	2.700	2.889	2.611
	Tensile modulus (GPa)	11.742	12.266	14.911	11.035
GFRC	Tensile strength (MPa)	196.122	215.024	233.726	194.151
	Tensile strain (%)	2.366	2.503	2.600	2.425
	Tensile modulus (GPa)	11.415	11.964	13.058	11.074

As the concentration of granite fly ash increased to 3 wt%, an interesting trend emerged: the tensile strength exhibited a consistent upward trajectory, rising steadily to 278.02 MPa. This represents a significant increment of 2.9% from the initial concentration of 1 wt%. This observation underscores the positive correlation between the concentration of granite fly ash and tensile strength, highlighting its potential impact on material properties.

However, when the concentration of granite fly ash was increased to 5 wt%, a noticeable decline of 20% in tensile strength was observed. This decreasing trend was consistent for both GFRC and BFRC materials. Specifically, the addition of 5 wt% granite fly ash caused the lowest reduction in tensile value, around 10.7%, compared to the composite without any granite fly ash added.

A similar phenomenon has been previously reported by Sapiai et al. [4], Awad et al. [9], Awad et al. [20], and Hashim et al. [21]. In these studies, the agglomerated structure of the modified matrix resin led to stress concentration, ultimately resulting in composite failure. Additionally, higher filler loadings can also affect the dispersibility of fillers within the matrix resin during the fabrication process. This is because higher filler loadings can increase the viscosity of the modified resin, leading to improper bonding and reduced wettability. Consequently, this adversely affects interface adhesion between the fibers, fillers, and matrix resin.

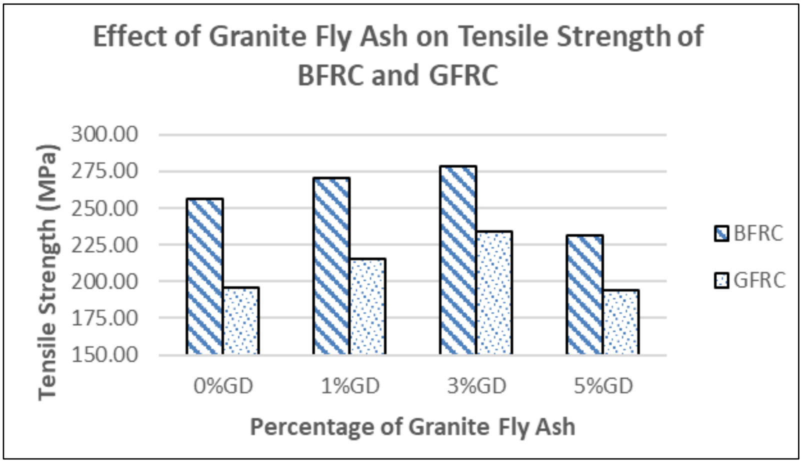


Figure 9: Tensile strength of FRP composites with different loading (wt%) of granite fly ash

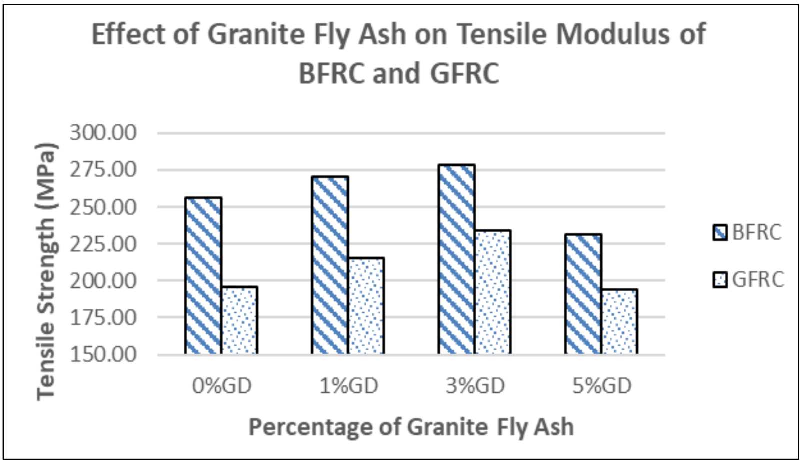
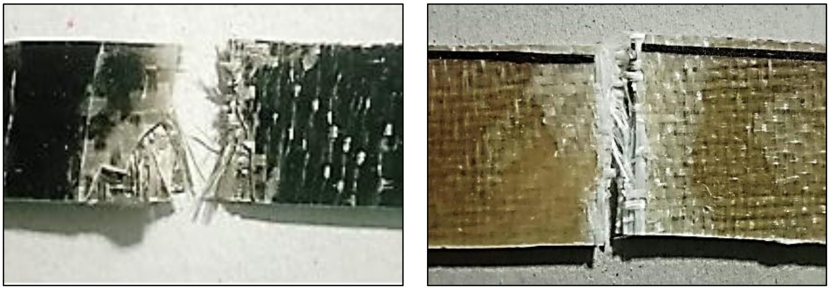


Figure 10: Tensile modulus of FRP composites with different loading (wt%) of granite fly ash

This occurrence originates from the inherent traits of granite fly ash, which exhibit a tendency to aggregate up to a specific limit [4]. Within the context of this trial, the ideal quantity for enhancing tensile properties has been precisely identified at 3 wt% [4]. This correlation corresponds to the point where the favorable effects of integrating granite fly ash reach a saturation point, influenced by its propensity to cluster beyond this threshold. The characterization of the damaged specimens following the completion of the tensile tests for both BFRC and GFRC is depicted in Figure 11.



(a) (b)

Figure 11: Images of (a) BFRC and (b) GFRC fractured specimens

A clear correlation exists between the tensile modulus and tensile strength of the composite samples. Elevated tensile modulus values indicate greater material rigidity, not elasticity. Based on the acquired results, both BFRC and GFRC exhibited their peak tensile strengths at a 3 wt% granite fly ash (GD) composition, with average values of 14.911 GPa and 13.058 GPa, respectively. Following this, the samples with a 1 wt% GD composition displayed the next highest tensile strengths, whereas the lowest tensile modulus was observed in the 5 wt% GD sample. The overall trend of average tensile modulus values for each sample is visually depicted in Figure 10.

To summarize, the results clearly show that adding granite fly ash to composite materials significantly improves their tensile properties, which peak at a concentration of 3 wt%. This result is an intricate consequence of the natural characteristics that exist between large surface areas of granite fly ash's powders and its tendency to aggregate. Therefore, this study shows that more than 3 wt% inclusion of GD resulted in agglomeration of GD powders, thus slightly reducing the FRP's tensile properties. The inherent properties of granite fly ash and its tendency to aggregate were also explained by Mohamad et al. [7] and Kanna et al. [11].

Conclusions

In conclusion, the inclusion and integration of granite fly ash into glass/basalt fiber-reinforced composites significantly enhances their density and tensile properties, thereby fortifying their mechanical properties to a considerable degree. This improvement is especially notable at a concentration of 1 wt% granite fly ash. Among the tested scenarios, the highest levels of density were distinctly observed in BFRC, particularly with a 5 wt% loading of granite fly ash (GD) filler. The highest tensile results, in terms of both strength and modulus, were exhibited by BFRC, specifically at a 3wt% inclusion of granite fly ash (GD) filler. Clearly, the introduction of GD filler within BFRC significantly outperformed its counterpart, GFRC, leading to superior outcomes in mechanical properties.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflict of interest.

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