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Improved Mechanical Properties of Basalt and Glass Fibre Reinforced Polymer Composite by Incorporating Nano Silica

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ABSTRACT

Granite waste that increasingly accumulates yearly is significant with granite industry growth. This research aims to use nano silica extracted from granite dust to identify the effect of nano silica on the mechanical properties of Basalt and Glass Fibre Reinforced Polymer Composite. The approach encompassed three distinct weight percentages of nano silica, specifically 1 wt%, 3 wt%, and 5 wt%, seamlessly blended into a polyester resin matrix. The evaluation of composite mechanical attributes was conducted through compression and Izod impact tests by following ASTM D3410 and ASTM D256. Remarkably, the pinnacle of this enhancement materialises at the 1 wt% threshold,

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signifying the impact strength and compression strength values. Beyond this point, a decline was observed, underscoring the critical importance of judicious weight percentage selection. This novel composite configuration holds promising implications, particularly for components within container trucks, where the fusion of exceptional impact and compression strength is paramount.

Keywords: *Vacuum Silicon Mould; Nano Silica; Polyester, Basalt Fibre; Glass Fibre*

Introduction

Basalt fibre is made from natural basalt rock, which is abundant and does not require energy-intensive processing like glass or carbon fibre. The awareness and adoption of basalt fibre in various industries are still relatively low compared to more established materials like fibreglass and carbon fibre. Basalt fibre has several advantages, including high strength, durability, and resistance to high temperatures and chemicals [1]-[2]. However, its adoption may be limited by higher costs and processing challenges. Its suitability for a particular application depends on the specific requirements and budget constraints.

Granite waste is generated during the quarrying, cutting, and processing of granite stone. It comprises various types of waste, including sawdust, sludge, and leftover stone blocks. The extraction and processing of granite can have environmental consequences, such as habitat disruption, soil erosion, and water pollution [3]-[5]. Managing granite waste is critical to mitigate these impacts. However, there are opportunities to reduce its environmental footprint by recycling and reusing the waste in various applications.

Nano silica particles are microscopic, typically in the nanometer range, which results in a high surface area. This property can enhance their reactivity and effectiveness in various applications. Nano silica is used as a reinforcement filler in polymer composites, concrete, and rubber, which enhances its mechanical properties and durability. When incorporated into materials, nano silica can significantly enhance their strength, stiffness, and abrasion resistance [6]-[9]. Nano silica offers many advantages in terms of enhancing material properties and enabling various applications, but it also raises concerns related to cost, health, and environmental impact.

Nano silica, when properly dispersed and integrated into composite materials, has shown the potential to enhance impact resistance. Its high surface area and compatibility with various matrices can improve the material's ability to absorb and dissipate impact energy. Nano silica can enhance the compression strength of composites by reinforcing the matrix material, thereby reducing the risk of compressive failure. Incorporating nano silica can significantly improve composites' mechanical properties, including increased strength, stiffness, and toughness [10]-[12]. Nano silica is lightweight, and its addition to composites can enhance its performance without adding excessive weight, making it attractive for applications where weight is critical. Achieving uniform dispersion of nano silica within the composite matrix can be challenging. Agglomeration or poor dispersion can lead to inconsistent performance [6], [13]. The optimal loading level of nano silica depends on the specific application and desired performance characteristics. Higher loading levels may improve mechanical properties but could also lead to processing difficulties.

In conclusion, nano silica can be an adequate filler in composite materials for impact and compression applications, offering improved mechanical properties and durability. However, dispersion, cost, and processing complexity challenges should be carefully considered. The success of using nano silica in composites depends on factors such as surface treatment, loading level, and thorough testing to ensure that the desired performance improvements are achieved.

Materials and Methodology

Materials

Composite materials were produced by incorporating varying amounts of nano silica, woven glass fibre, woven basalt fibre, and polyester resin as the matrix material. The polyester used, known as CRYSTIC® 272E Isophthalic Polyester Resin, is a low-viscosity organic-mineral resin, and it was supplied by Carbon Tech. Global Sdn. Bhd., located in Rawang, Selangor. The resin and Butanox M60 hardener were combined in a 100:2 ratio to create the resin mixture. The woven basalt fibres were sourced from Zhejiang GBF Basalt Fibre Co. Ltd. in Dongyang, China, while the woven glass fibres were provided by Vistec Technology in Puchong, Malaysia. The nano silica was extracted from granite fine powder and obtained from the Kelantan Branch of Jabatan Kerja Raya (JKR), Malaysia.

Methodology

The fabrication began with cutting and measuring the desired thickness for the woven glass and basalt fiber. Subsequently, these fibers were systematically stacked layer upon layer. The polyester resin was then combined with the nano silica, with the proportions determined by weight percentage. In addition, four different percentages on nano silica weight percents, 0 wt%, 1 wt%, 3 wt%, and 5 wt%, were added to determine the most effective modified resin within basalt and glass fiber-reinforced polymer composites. To achieve a homogeneous mixture, a mechanical stirrer was employed, stirring at a rate of around 400 rotations per minute for approximately 120 minutes. As the supplier recommended, the polyester resin was blended with a hardener in a

100:2 weight ratio to ensure thorough composite curing. The resulting resin, filler, and hardener mixture was poured onto the fiber layers. This resin application was conducted layer-by-layer, ensuring a comprehensive saturation of the fibers. Once the resin had been applied, the specimen was sealed within a silicon mold. A vacuum was utilized to eliminate any trapped air within the specimen, thus ensuring a complete consolidation of the composite. Following this step, the sealed FRP (Fiber Reinforced Polymer) specimen was removed from the mold and left to cure naturally at room temperature for an approximate duration of 8 hours. During this period, a chemical reaction occurred within the resin, causing it to harden and ultimately resulting in the formation of a solid composite structure.

Izod impact test

The Izod impact test is a recognised norm that quantifies the impact energy required to fracture a material. This test assists engineers and scientists in evaluating the fracture properties of a given component or element. The results were used to determine how various materials responded to impact loading. The dimensions of sample 64 x 13 x 2.5 mm were prepared. Five identical samples with the exact measurement were used for each test. The test was conducted following the ASTM D256 standard. Figure 1 shows the machine involved during the test.

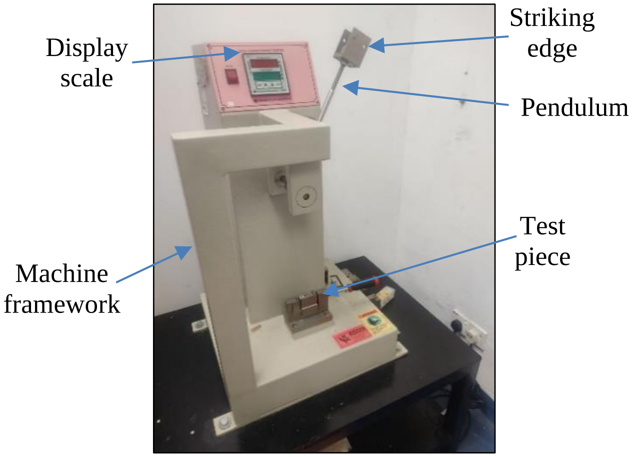

Figure 1: Izod Charpy machine used in this experiment

Compression test

The compressive test was performed according to ASTM D3410. The compressive properties were determined through compression experiments. The 110 x 10 x 2.5 mm sample was restrained in unique frames to prevent FRP composite samples from buckling. Each test used five identical samples following the standard ASTM D3410. Figure 2 shows how the compression test is performed.

Figure 2: Compression testing

Results and Discussion

The results derived in this investigation correspond to the average values obtained by examining five distinct samples for each composite laminate category. The observed variation in the sample pertains to the weight percentage of nano silica incorporated into the resin before the pouring phase in the hand lay-up manufacturing procedure. The laminates investigated in the study consisted of basalt fibre-reinforced polymer composite (BFRPC) and glass fibre-reinforced polymer composite (GFRPC).

Effect of nano silica on impact test of BFRPC and GFRPC

Analysing Figure 3 reveals a distinct trend for BFRPC and GFRPC in impact strength, as nano silica weight percentages are varied within the composite. Commencing at 0 wt% nano silica BFRPC, we note an impact strength of 3232 Jm^{-1}. As the nano silica content increases to 1 wt%, the impact strength experiences a notable surge, ascending to 4464 Jm^{-1}. However, the subsequent transition to 3 wt% nano silica leads to a decline in impact strength to 3680 Jm^{-1}. This downward trajectory persists at 5 wt% nano silica, with impact strength further falling to 3360 Jm^{-1}.

This sequence underscores an apparent pattern: impact strength augmentation up to 1 wt% nano silica, succeeded by a diminishing trend at 3 wt% and 5 wt%. This distinctive behaviour can be attributed to the agglomeration phenomenon observed with nano silica [7]-[8]. The expansive surface area of nano silica particles makes them prone to clustering, especially at elevated concentrations. In this context, the agglomeration effect becomes discernible at 3 wt% and 5 wt%, leading to a decrease in impact strength. This outcome aligns with experimental findings wherein the optimal impact strength, evidenced by the peak at 1 wt% nano silica, reflects the delicate balance between nano silica dispersion and agglomeration effects [14]-[15].

In summary, the impact strength's interplay with nano silica weight percentages reveals a clear trend of enhancement up to 1 wt% and subsequent decline at 3 wt% and 5 wt%, attributable to nano silica's inclination to aggregate. This investigation underscores the significance of precise nano silica dispersion control in optimising composite properties [10], [16].

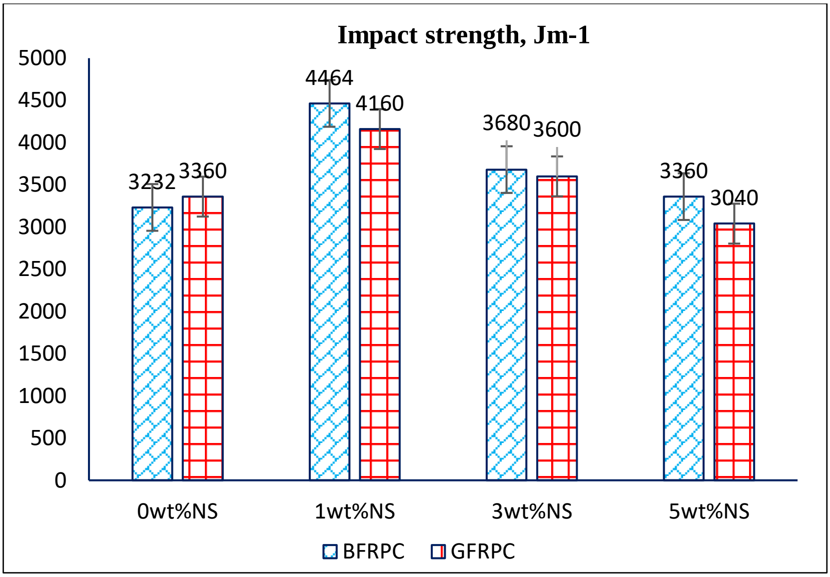

Figure 3: BFRPC and GFRPC impact strength vs. different wt% of nano silica

Meanwhile, for GFRPC, we can see from Figure 3 that a distinct trend emerges in impact strength variations across diverse nano silica weight percentages within the composite. Initiating at 0 wt% nano silica, the impact strength registers at 3360 Jm^{-1}. As the nano silica content advances to 1 wt%, a significant increase is observed, elevating the impact strength to 4160 Jm^{-1}. Subsequently, the transition to 3 wt% nano silica reduces the impact strength to 3600 Jm^{-1}, with the descending trajectory persisting at 5 wt% nano silica, leading to a further decline of 3040 Jm^{-1}.

This progression underscores a clear pattern: an initial augmentation of impact strength up to 1 wt% nano silica, succeeded by a decrement at 3 wt% and 5 wt%. This pattern aligns with observations across both composite types. Initially, nano silica's integration positively affects impact strength, a phenomenon witnessed from 0 wt% to 1 wt%. However, a converse trend emerges as impact strength wanes at elevated nano silica concentrations (3 wt% and 5 wt%) [17]-[18].

This intriguing behaviour stems from the inherent characteristics of nano silica. As nano silica is incorporated, a propensity for agglomeration emerges, particularly prominent at 3 wt% and 5 wt% due to the expansive surface area of nano silica particles [19]-[20]. Following the outcomes, this agglomeration effect is particularly prominent in this experiment at 1 wt% nano silica.

In summary, Figure 3 unravels a consistent trend wherein impact strength ascends until it reaches 1 wt% nano silica, then tapers off at 3 wt% and 5 wt%. The underlying mechanism attributed to nano silica agglomeration underscores judicious dispersion management's importance in optimising composite characteristics [21]-[22].

Generally, at each corresponding weight percentage of nano silica, NS-BFRPC tends to have slightly higher impact strength values than NS-GFRPC. Adding nano silica might positively impact the impact strength of the Basalt Fiber-Reinforced Polymer Composite. There is an optimal nano silica percentage that yields the highest impact strength for each composite type. For NS-BFRPC, the optimal percentage might be around 1 wt%, and for NS-GFRPC, it could be around 1 wt% to 3 wt% [23]-[24].

Effect of nano silica on compression test of BFRPC and GFRPC

Based on Figure 4, the compressive strength of the BFRPC composite with 0 wt% nano silica is 125.76 MPa. For the BFRPC composite with 1 wt% nano silica, the compressive strength increases to 153.88 MPa. The compressive strength for the BFRPC composite with 3 wt% nano silica is 128.97 MPa. For the BFRPC composite with 5 wt% nano silica, the compressive strength decreases to 106.21 MPa. The data show a trend where the compressive strength initially increases from 0 wt% to 1 wt% nano silica and decreases as the nano silica content rises [25]-[26].

In summary, these results indicate that adding nano silica to the Basalt Fiber-Reinforced Polymer Composite has varying effects on its mechanical properties. Compressive strength and modulus show initial improvements at 1 wt% nano silica but decline as nano silica content increases [27]. The strain at fracture generally increases with higher nano silica content, except at 5 wt%. This complex relationship between nano silica content and mechanical properties underscores the importance of carefully optimising composite formulations for the desired performance characteristics.

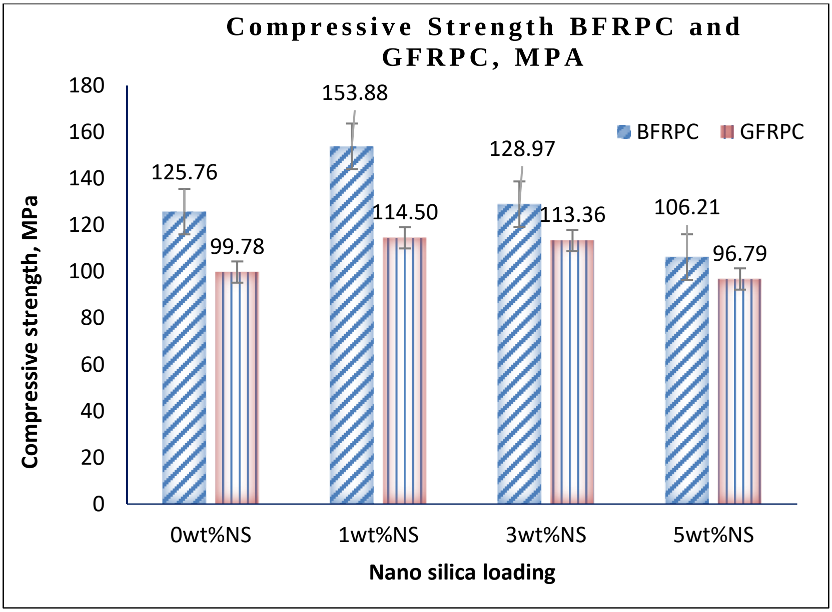

Figure 4: Compression strength of BFRPC vs. wt% of nano silica

Examining Figure 2 gives us a comprehensive grasp of the mechanical dynamics within composites, navigating the spectrum of varying nano silica weight percentages. A deeper analysis is warranted.

For the GFRPC composite with 0 wt% nano silica, the compressive strength is 99.78 MPa. Transitioning to 1 wt% nano silica introduces a remarkable surge, elevating the compressive strength to 114.50 MPa. The subsequent exploration of 3wt% nano silica content reveals a compressive strength of 113.36 MPa. As we venture further to 5 wt% nano silica, the compressive strength regresses to 96.79 MPa. This trajectory mirrors the observed pattern, affirming the correlation between nano silica content and compressive strength. The initial summit from 0 wt% to 1wt% nano silica harmonises with prior findings, while the ascent tapers fluctuate at higher nano silica proportions [18].

In synthesis, the mechanical property data for nano silica-glass Fiber-Reinforced Polymer Composite (NS-GFRPC) retraces the trends evident in prior instances. The compressive strength and modulus variances tied to nano silica content remain consistent, while strain at fracture escalates until a threshold and diminishes beyond [23], [28]. These patterns underscore the pronounced influence of nano silica on composite performance and the indispensability of refined composite formulations in attaining the desired mechanical attributes [17].

Conclusions

Following a meticulous analysis of the mechanical test data, it is evident that among the array of eight distinct FRP composite systems distinguished by varying weight percentages of nano silica, the composite system featuring 1 wt% of both Basalt Fiber-Reinforced Polymer Composite (BFPRC) and Glass Fiber-Reinforced Polymer Composite (GFRPC) emerges as the frontrunner in terms of compression properties, outshining the remaining systems. This finding underscores a crucial principle: the influence of nano silica in enhancing mechanical properties follows an apparent pattern wherein improvements are notable until a certain threshold, beyond which these enhancements taper.

The rationale underlying this phenomenon can be attributed to the inherent characteristics of nano silica itself. With its expansively broad surface area, nano silica’s propensity to enhance mechanical properties reaches an apex, beyond which it starts to exhibit signs of compression affiliated with crumpling. In this experimental context, the pivotal juncture is notably marked at the 1 wt% concentration level. Consequently, a coherent conclusion emerges - integrating nano silica can significantly elevate composites' mechanical attributes, encompassing impact strength and compression strength, up to a specific weight percentage threshold. Simultaneously, integrating nano silica presents a supplementary advantage - the reduction of granite waste, a burgeoning concern, as it is seamlessly incorporated into the composite fabrication process, thereby aiding in curbing the accumulation of daily produced waste.

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 conflicts of interest.

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