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Impact Properties and Quasi-Static Indentation of Basalt and Glass Fibre Reinforced Polymer Composite Filled With Nano Silica

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ABSTRACT

Granite waste increased rapidly throughout the year with the increase in manufacturing industries. nan0-silica extracted from granite waste can be used as filler in the composite to improve mechanical properties and efficiency of the logistic industries based on fuel efficiency that can be used in transferring the product. The truck body panel industry is crucial in the automotive sector, providing components that ensure commercial vehicles' structural integrity, safety, and functionality. This study aims to create a new developed composite that can replace metal with a light and strong composite while exploring the advantages of adding nano-silica to these composites, particularly in impact scenarios. Different concentrations of nano-silica (1%, 3%, 5% wt.) were added during fabrication, and their impact properties were tested. Results were compared to a Carbon Tech Global (CTG) industrial sample. Incorporating up to 1wt% nano silica improved energy absorption, impact strength, and Quasi-static indentation (QSI) resistance. A composite with 1wt% nano-silica performed the best, significantly increasing the energy absorption, impact strength, and QSI value. The comparison between CTG and 1wt% nano silica in Basalt Fibre Reinforced Polymer Composite (BFRPC) displayed a remarkable 430% variation, showcasing a 128.2% boost in impact strength. These enhancements suggest the composite's potential for commercial applications, especially as a material for truck body panels.

Keywords: Vacuum silicon mould; nano silica; polyester, impact properties; quasi-static indentation

INTRODUCTION

Granite, an igneous rock formed over millions of years from molten magma, is extracted from quarries and processed into various products. However, significant amounts of granite waste, comprising off-cuts, broken pieces, and dust, are produced during the extraction and manufacturing. This waste poses environmental concerns. Quarrying activities often disrupt ecosystems, lead to soil erosion, and can result in biodiversity loss (Nayak et al. 2022).

As the world grapples with sustainability and environmental preservation challenges, innovative solutions that harness the untapped potential of industrial waste have become the focal point of scientific research and industrial endeavours (Shilar et al. 2022). One such marvel from the granite industry's waste is nano-silica, which promises to revolutionise various sectors with its unique properties and eco-friendly characteristics (Liu et al. 2023).

Nano silica, also known as nano silicon dioxide (S_iO_2), is a finely divided form of silica with particle sizes at the nanoscale. It is extracted from granite waste through specialised processes and has properties that set it apart from conventional silica (Erkliğ et al. 2022). Its high surface area, enhanced reactivity, and unique structure make it a sought-after material for various applications.

Besides that, Basalt and glass fibre-reinforced polymer (FRP) composites have become increasingly popular as lightweight and high-performance materials in numerous industrial applications. These composites offer excellent mechanical properties and corrosion resistance, making them ideal candidates for automotive parts, aerospace components, marine structures, etc. However, the quest for further enhancement in their mechanical characteristics has led researchers to explore the realm of nanotechnology, with nano-silica emerging as a promising filler that can propel these composites to new heights (Jenish et al. 2022).

Beyond the performance benefits, integrating nano silica into FRP composites introduces the new composite with higher mechanical properties, especially impact and QSI properties, for lighter and more fuel-efficient structures, making it an attractive option for the transportation industries. Moreover, using nano-silica as the filler will improve mechanical properties (Zeng et al. 2022). In this research, nano silica was derived from waste sources, lends an eco-friendly dimension to these advanced composites, contributing to sustainability efforts and responsible waste management practices (Cionita et al. 2022; Abdul Halim et al. 2022; Sampath & Santhanam, 2019; Raja et al. 2022).

Furthermore, research will explore the effect of incorporating nano-silica and optimising filler loading levels to achieve the desired composite properties of impact loading, energy absorbed and residual impact strength.

METHODOLOGY

The manufacturing process involved creating basalt and glass composites using different weight percentages (1, 3, and 5wt.%) of nano silica as the filler material. The matrix material in this investigation comprised woven glass fibre, woven basalt fibre, and a polyester resin known as CRYSTIC® 272E Isophthalic Polyester Resin. Carbon Tech Global (CTG) Sdn Bhd. in Rawang, Selangor, supplies the resin and hardener, which were mixed in a 100:2 ratio, following the manufacturer's instructions, with the resin amount being twice that of the hardener. The woven basalt and glass fibre were supplied from Vistec Technology, a company located in Puchong, Malaysia. The Department of Public Works in Malaysia supplied the granite dust used in this study. On the other hand, the nano-silica was extracted from granite dust through a process conducted at UiTM Shah Alam. The material used is in Figure 1.

The preparation of the fibre layers is the first stage in producing basalt and glass composites. The woven glass and basalt fibre were cut with the size of 300 mm x 300 mm and stacked by layer with 14 layers. The polyester resin and the nano-silica were mixed with a mechanical stirrer at a rotational speed of 400 rotations per minute (rpm). They were stirred for 120 minutes to mix thoroughly and to ensure the nano-silica filler was evenly distributed throughout the resin (Bhalla et al. 2022).

The suggested weight ratio for combining the hardener and polyester resin is 100:2, followed by the manufacturer's instruction guide. The stacked fibre layers are then covered with the resin mixture, which includes nano-silica and hardener. A silicon mould was used to encapsulate the specimen to aid in the amalgamation of the composite. The vacuum technique was applied to remove any trapped air in the specimen, making the composite's best possible consolidation (Pappu & Thakur, 2017). After being sealed, the FRP (fibre-reinforced polymer) specimen was removed from the mould and the specimens were cured for roughly 8 hours at room temperature.

Basalt Fibre Glass Fibre

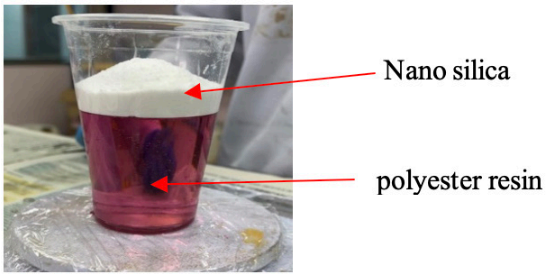

FIGURE 1. Material used: basalt fibre, glass fibre, nano silica, polyester

After fully cured, the composite specimens were subjected to exact measurements following ASTM standards (Vincent & Ramesh, 2015). The task is completed using a circular saw apparatus and adhering to the defined testing using these ready specimens, as shown in Figure 2.

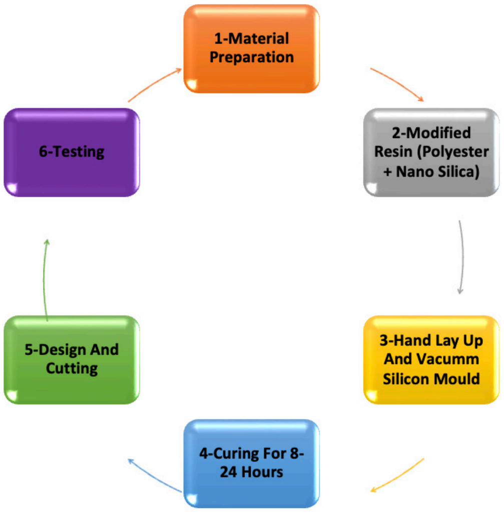

FIGURE 2. Fabrication process

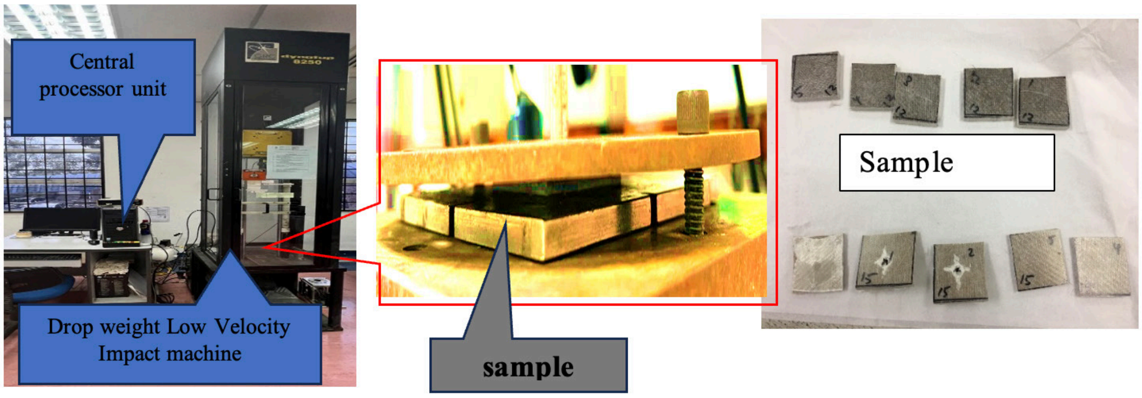

FIGURE 3. Instron machine and impact samples

DROP WEIGHT LOW-VELOCITY IMPACT

The drop weight impact test involves utilizing the gravitational force on a known weight to create energy, which is then used to fracture a beam or plate specimen. The specimen can be either supported at its ends or fixed. ASTM D7136 standard was followed to conduct this study an Instron Dynatup 8250 Drop Weight Impact was employed (Sarasini et al. 2014; Pingulkar et al. 2021). The specimens used in this experiment had dimensions of 50 mm x 50 mm x 5 mm. The drop tower had a 13 mm diameter hemispherical tip impactor weighing 13.24 kg. Dropping the weight from a height of 0.78 m and kinetic energy of 101.3 J was achieved with a constant gravitational speed of approximately 9.81 m/s. To ensure accuracy, five identical specimens of each system were prepared (Sari et al. 2023). From this test, the energy absorption and impact strength of the composite laminates can be determined.

QUASI-STATIC INDENTATION (QSI)

Like Low-Velocity Impact (LVI), the quasi-static indentation test evaluates FRP laminates. The quasi-static indentation test (QSI) followed ASTM D6264M to accurately assess the energy absorption and load-carrying capability (Engül & Ersoy, 2023). The damage tolerance of the FRP to the applied loads was also determined using this value. The specimen was subjected to an indentation force by progressively pushing a hemispherical indentation onto the surface. This test may also be used to check a material's resistance to causing harm to a specimen for further damage tolerance testing. The results of these trials will be compared to gain a greater understanding and conclusions. The LVI uses a free-falling load system on the FRP, but QSI uses a targeted indentation force to create the effects. This is the distinction between QSI and LVI.

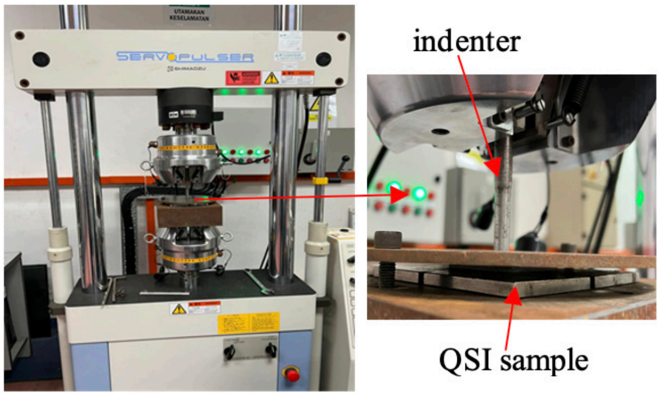

FIGURE 4. Quasi-static indentation

RESULTS AND DISCUSSION

This investigation examined the properties of various composite laminates, including basalt fibre-reinforced polymer composite (BFRPC), glass fibre-reinforced polymer composite (GFRPC), and an industrial sample from Carbon Tech Global (CTG). The results are based on average values obtained from five samples for each composite laminate category. The key parameters analyzed in this study were energy absorption, impact strength, and quasi-static indentation properties. The primary variable among the samples was the weight percentage of nano silica incorporated into the resin before the hand lay-up manufacturing process.

The research findings provide a comprehensive analysis of how different characteristics affect the performance of these composite laminates. By examining the energy absorption, impact strength, and quasi-static indentation properties, the study offers valuable insights into the behaviour of these materials under various conditions. Including an industrial sample (CTG) allows for a practical comparison between the experimental composites and commercially available alternatives, providing context for the potential applications and improvements offered by the nano silica-enhanced laminates.

EFFECT OF NANO SILICA ON ENERGY ABSORBED AND IMPACT STRENGTH OF BFRPC AND GFRPC

Examining the provided Figure 5, a noticeable trend emerges, revealing a notable elevation in energy absorption. Incorporating nano-silica into the Basalt Fiber Reinforced Polymer Composite (BFRPC) and Glass Fiber Reinforced Polymer Composite (GFRPC) significantly impacts their energy absorption properties. BFRPC's energy absorption increases by 6.4% when 1% nano-silica is added, rising from 96.76J to 103.21J. This substantial improvement showcases the potential of nano-silica to enhance the composite's ability to absorb impact energy. However, as the nano-silica content increases beyond 1wt%, a slight decline in energy absorption is observed, with values of 101.02J at 3wt% and 96.25J at 5wt% nano-silica.

A similar trend is observed in GFRPC, where the energy absorption progressively increases from 0wt% to 1wt% nano-silica content. The enhancement in GFRPC is even more pronounced, with a remarkable growth percentage of 8.02%. This indicates that GFRPC may be more responsive to nano-silica addition than BFRPC in terms of energy absorption improvement. However, mirroring the BFRPC results, the energy absorption values for GFRPC also experience a slight decrease after the 1wt% nano-silica point, reaching 102.50J and 100.79J at higher nano-silica concentrations.

The observed pattern, particularly the peak performance at 1wt% nano-silica, can be attributed to the aggregation tendency of nano-silica particles (Muslim et al. 2023). At this concentration, the nano-silica appears to reach an optimal dispersion within the polymer matrix, effectively enhancing the composite's energy absorption capabilities. This saturation point at 1wt% suggests a critical concentration beyond which the benefits of nano-silica addition begin to diminish.

These findings have significant implications for the development of high-performance composite materials. Adding 1wt% nano-silica emerges as the optimal concentration for both BFRPC and GFRPC, which balances enhanced energy absorption and material properties. This optimization could improve impact resistance in applications such as automotive components, protective gear, or structural elements subject to dynamic loading (El-Salakawy, 2021; Quadflieg et al. 2023). This outcome indicates that the optimal impact performance enhancement is achieved at this specific concentration.

Similarly, GFRPC showcases a parallel pattern, with energy absorption rising progressively from 0wt% nano-silica to 1wt% nano-silica. This enhancement yields a considerable growth percentage of 8.02%. However, post the 1wt% nano silica inclusion, the energy absorption

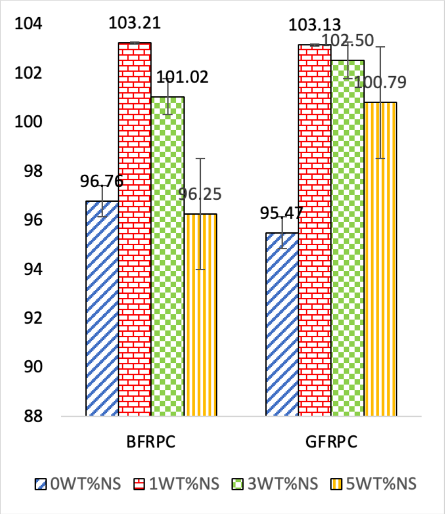

FIGURE 5. Energy absorbed vs composite with different wt% of nano-silica

The incorporation of nano-silica into Basalt Fiber Reinforced Polymer Composite (BFRPC) demonstrates a remarkable enhancement in impact strength, as evidenced by the data presented in Figure 6. A substantial surge of 61.14% in impact strength is observed when transitioning from the unmodified BFRPC to the 1wt% Nano Silica BFRPC (1NSBFRPC). This significant improvement is quantified by an increase from 13.20 kJ/m² to an impressive 21.27 kJ/m². However, it's noteworthy that beyond the 1wt% nano-silica concentration, a modest decline in impact strength occurs, with values dropping to 16.22 kJ/m² for 3wt% and 15.12 kJ/m² for 5wt% nano-silica concentrations.

A similar trend is observed in the Glass Fiber Reinforced Polymer Composite (GFRPC), albeit with a less pronounced improvement. The GFRPC exhibits a progressive increase in impact strength from 0wt% to 1wt% nano-silica content, resulting in a notable 15.22% enhancement. However, paralleling the BFRPC results, the impact strength of GFRPC also decreases beyond the 1wt% nano-silica threshold, reaching 11.57 kJ/m² at 3wt% and further declining to 9.41 kJ/m² at 5wt% nano-silica concentration.

The observed trend highlights a concentration-dependent impact performance enhancement, with optimal results achieved at the 1wt% nano-silica incorporation level for both BFRPC and GFRPC. This phenomenon can be attributed to the aggregation tendency of nano-silica particles, which appears to reach a saturation point at 1wt% in this experimental setup. At this optimal concentration, the nano-silica particles likely achieve an ideal dispersion within the polymer matrix, effectively enhancing the composite's ability to resist impact forces.

These findings have significant implications for the development of high-performance composite materials, particularly in applications requiring enhanced impact resistance. The substantial improvement in impact strength at 1wt% nano-silica concentration suggests a promising avenue for enhancing the durability and safety of components in industries such as automotive, aerospace, and protective equipment manufacturing (Zhang et al. 2023; Hao et al. 2021). However, the observed decline in performance at higher nano-silica concentrations underscores the importance of precise control over additive content in composite formulations.

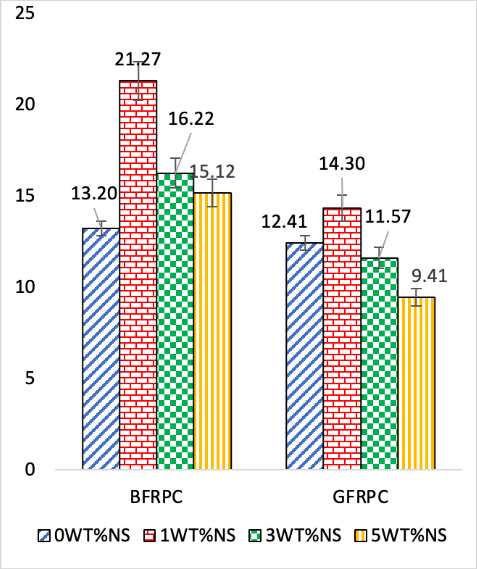

FIGURE 6. Impact strength vs composite with different wt% of nano-silica

EFFECT OF NANO-SILICA ON QSI PROPERTIES OF BFRPC AND GFRPC

Analyzing Figure 7, a distinct pattern emerges where the BFRPC consistently exhibits higher QSI values than the GFRPC. The peak performance achieved at the 1wt% nano silica concentration for both composites is particularly noteworthy, attaining impressive values of 53.68 J for 3wt% nano silica and 42.78 J for 5wt% nano-silica, respectively.

Within the realm of BFRPC, a remarkable journey unfolds as the QSI value escalates from unmodified with 0wt% nano-silica, 32.33 J, to a remarkable 53.68 J for 1wt% nano-silica, indicating a significant growth percentage of 66.03% with 1wt% because of its fibre and filler properties. This progression, however, experiences a subsequent decline, falling to 46.40 J for 3wt% nano-silica and further plummeting to 24.50 J at 5wt% nano-silica.

Meanwhile, for GFRPC, an analogous trend transpires, with the QSI value rising from 0wt% nano-silica, 23.71 J, to 1wt% nano-silica, 42.78 J, marking an impressive increment of 80.43%. Post the ascent, a dip is observed at 3wt% nano-silica, settling at 31.96 J and further declining to 29.49 J for 5wt% nano-silica.

This noteworthy trend underscores the enhancement in impact performance linked to the nano-silica concentration, prominently evident at the 1wt% nano-silica threshold (Mahović Poljaček et al. 2022; Raja Othman et al. 2022; Abdel-Rahim et al. 2022). This phenomenon can be attributed to the propensity of nano silica for both BFRPC and GFRPC to aggregate, reaching a saturation point, as distinctly observed within this experiment at the 1wt% incorporation of nano-silica (Quadflieg et al. 2023).

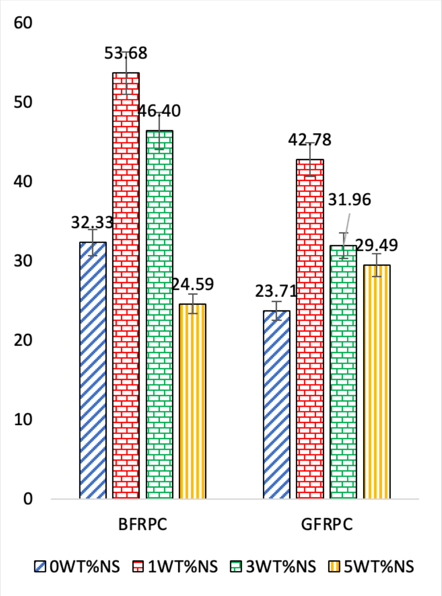

FIGURE 7. Quasi-static indentation vs composite with different wt% nano-silica

EFFECT OF NANO SILICA COMPARED TO INDUSTRIAL SAMPLE.

The analysis aimed to evaluate the impact of nano-silica compared to an industrial benchmark, Carbon Tech Global (CTG), specifically focusing on determining the optimal nano-silica content. Notably, the study identified that the ideal concentration of nano-silica was 1wt% in both the BFRPC and the GFRPC.

Figure 8 illustrates that the industrial standard, CTG, demonstrated a total energy absorption value of 25.56J. When contrasting this against the baseline 0wt% nano silica BFRPC and CTG, a substantial disparity of 278% emerged. Similarly, when comparing CTG to 0wt% nano silica GFRPC, the difference amounted to 273.51%. These significant gaps underscored the substantial enhancement achieved by the newly developed composite materials as opposed to the industrial benchmark.

A more intricate comparison analysis between CTG and 1wt% nano silica BFRPC revealed a striking variation of 303.79%. Likewise, the contrast between CTG and 1wt% nano silica GFRPC demonstrated a differential value of 303.48%. This vividly illustrates that integrating nano silica into the composites led to an increase of up to 300% compared to the industrial sample.

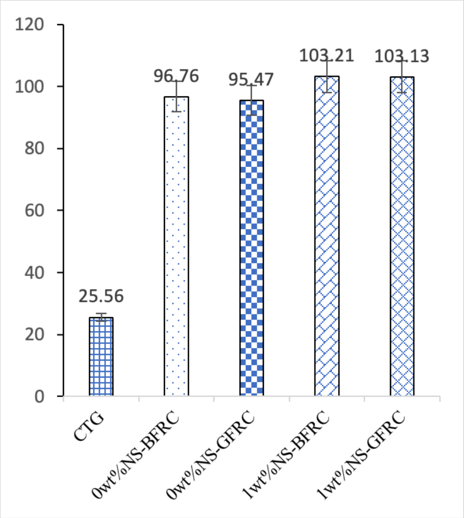

FIGURE 8. Energy absorbed *vs* CTG, Unmodified and max composite value at 1wt% nano-silica

Figure 9 shows that the industrial reference, CTG, registered an impact strength of 8.28 kJ/m². Contrasting this against the baseline 0wt% nano silica BFRPC and CTG, a notable divergence of 208% emerged. Similarly, comparing CTG with 0wt% GFRPC unveiled a substantial variance of 189.95%. These discernible disparities accentuate the substantial surge achieved by the newly developed composite materials concerning industrial standards.

Delving deeper into the analysis, when comparing CTG with 1wt% nano silica BFRPC, an extraordinary variation of 396.96% materialized. Similarly, in the context of CTG and 1wt% nano silica GFRPC, an impressive difference of 234.11% was observed. This striking comparison highlights that incorporating nano-silica (Hwayyin et al. 2022) into the composites led to an increment of over 200%, decisively establishing the efficacy of nano-silica in boosting the performance of these materials.

These results have far-reaching implications for various industries, particularly automotive and aerospace applications. Dramatically improving impact strength by incorporating nano-silica particles opens up new possibilities for designing lighter, stronger, and more durable components. Furthermore, using basalt and glass fibres in combination with nano silica offers a potentially more sustainable alternative to traditional materials, aligning with the growing demand for eco-friendly and high-performance engineering solutions. These findings underpin the remarkable potential of integrating nano silica (Gopalakrishnamurthy & Sandur, 2022; Salman et al. 2022), highlighting the ability to achieve more than a 200% increase in performance levels compared to established industry benchmarks.

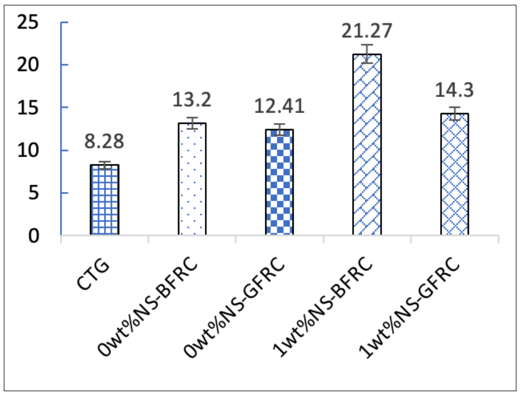

FIGURE 9.Impact strength *vs* CTG, Unmodified and max composite value at 1wt% nano-silica

The industrial reference sample, Carbon Tech Global (CTG), demonstrated a quasi-static indentation (QSI) value of 10.12J, serving as a baseline for comparison with the newly developed composite materials. When compared against the 0wt% nano silica Basalt Fibre Reinforced Polymer Composite (BFRPC) and Glass Fibre Reinforced Polymer Composite (GFRPC), striking disparities emerged. The BFRPC exhibited a 219.46% improvement over CTG, while the GFRPC showed a 134.29% enhancement. These substantial differences highlight the significant advancements achieved by the novel composite materials, surpassing the performance standards set by industrial samples (Muslim et al. 2022; Hwayyin et al. 2022).

Further analysis revealed even more remarkable results when comparing CTG with the 1wt% nano-silica reinforced composites. The 1wt% nano silica BFRPC demonstrated an exceptional 430% improvement over CTG, while the 1wt% nano silica GFRPC showed a 322.72% enhancement. These compelling comparisons underscore the potent impact of incorporating nano silica into the composites, consistently yielding improvements exceeding 300% across both BFRPC and GFRPC formulations (Raja et al. 2022)

Integrating nano-silica particles into composite materials has proven to be a game-changing strategy for enhancing mechanical properties. The dramatic improvements observed, particularly in quasi-static indentation resistance, can be attributed to several factors. Nano-silica particles reinforce at the molecular level, enhancing the overall strength and toughness of the composite. Additionally, they improve interfacial bonding between the matrix and fibres and act as obstacles to crack propagation, increasing the energy required for failure (Mahović Poljaček et al. 2022).

These findings significantly affect the development of high-performance materials in various industries, particularly automotive and aerospace applications. Achieving such substantial improvements in mechanical properties by incorporating nano-silica particles opens up new possibilities for designing lighter, stronger, and more durable components. Furthermore, the use of basalt and glass fibres in combination with nano-silica offers a potentially more sustainable alternative to traditional materials, aligning with the growing demand for eco-friendly and high-performance engineering solutions

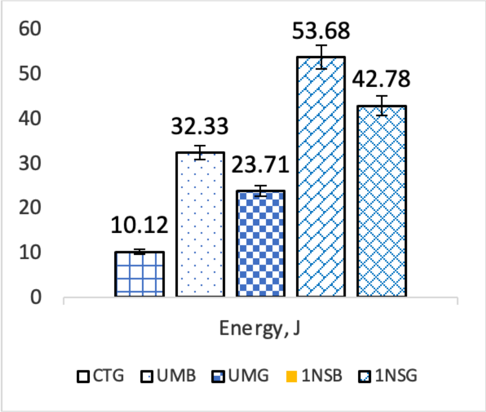

FIGURE 10. Quasi-static Indentation vs CTG, Unmodified and max composite value at 1wt% nano-silica

CONCLUSION

In summary, the findings from the analysis unequivocally demonstrate that integrating nano-silica into the composite material yields substantial improvements in impact strength, energy absorption, and QSI, particularly up to a concentration of 1wt% nano-silica. Beyond this threshold, the properties exhibit a diminishing trend, attributed to achieving the maximum achievable enhancement limit. This phenomenon can be attributed to the agglomeration of nano silica beyond the 1wt%. Notably, the developed composite material surpassed the performance of the industrial sample CTG by a significant margin for the energy absorbed, a value of 25.56 J with more than 300% value of 103.21 J for BFRPC and GFRPC, of 103.13 J. Impact strength value more than 180% from 8.28 kJ/m² CTG to 21.27 kJ/m² for BFRPC and 14.3 kJ/m² for GFRPC. Meanwhile, for QSI, the value increased by more than 300% with a value of CTG, 10.12 J to 53.68 J for BFRPC and 42.78 J for GFRPC. Moreover, nano silica proved superior to natural fibres, favouring the former over synthetic fibres. This approach not only yields superior products but also contributes to environmental preservation. These findings underscore the potential of nano silica as a catalyst for enhancing composite properties, serving as a pathway toward achieving optimal performance while fostering sustainability.

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DECLARATION OF COMPETING INTEREST

None.

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