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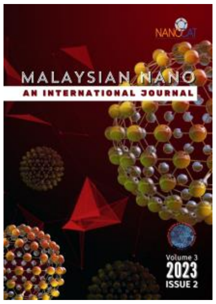

Research article

Investigation on impact properties of basalt and glass fiber reinforced polyester composites filled with nano silica

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Abstract

The relevance of granite waste is growing alongside the global demand for granite. This waste comprises various forms, including large granite pieces, tiny fragments, dust, and other debris. This research aimed to create a novel composite by incorporating nano silica from granite powder as a filler, combining it with basalt and glass fibres as the matrix, and using polyester as the resin. The fabrication involved Fiber Reinforced Composite (FRP) production through hand lay-up and vacuum silicon moulding to eliminate trapped air during lamination. After fabrication, tests were conducted for hardness, density, and Low-Velocity Impact under dropping weight. The results indicated that introducing nano silica as a filler in polyester resin positively impacted Basalt Fiber Reinforced Polyester Composite (BFRPC) and Glass Fiber Reinforced Polyester Composite (GFRPC). Analysis showed that as the nano-silica content increased, so did energy absorbed, impact strength and ductility index, up to a 1wt% nano-silica concentration. Beyond this point, agglomeration occurred, causing a decrease in these values. The 1 Nano silica Basalt Fiber Reinforced Polyester Composite (1NSBFRPC) material exhibited the highest energy absorption at 103.21J, indicating strong impact strength at 21.27kJ/m^2. Conversely, the 1NSGFRPC material demonstrated the highest ductility index at 4.13. In comparison, Carbon Tech Global's (CTG) energy absorption, initially 25.56J, experienced a significant increase of 303.79%, reaching 103.21J. The impact strength also showed a notable shift, escalating by 396.96% from 4.28 KJ/m^2 to an impressive 21.27kJ/m^2. This shift in impact strength represented a remarkable 128.2% surge, highlighting the significant influence of integrating nano-silica. This new composite suits truck body carriers and offers environmental benefits. Furthermore, utilising nano silica in this context not only aids in waste reduction within the granite sector but also contributes to sustainable resources.

Keywords: nano silica, basalt fibre, glass fibre, polyester, vacuum silicon mould

1. Introduction

Truck bodies are subject to various impacts and stresses during transportation and daily usage. Traditional materials used for truck bodies, such as metals, often face weight, corrosion, and maintenance issues. Researchers have been exploring innovative solutions by incorporating composite materials into truck body construction to address these challenges [1], [2]. These composites offer the potential for improved strength-to-weight ratios, corrosion resistance, and impact performance.

As the global demand for granite continues to rise, so does the accumulation of granite waste, which includes various forms such as large granite pieces, tiny fragments, dust, and other debris. The effective management and utilisation of granite waste have become critical due to environmental concerns and the need for sustainable resources [3], [4]. This review examines various strategies and applications for reusing and repurposing granite waste. The extraction of nano silica from granite waste exemplifies a circular economy approach, where waste materials are repurposed into valuable resources. This approach aligns with sustainability goals and fosters innovation in industries that benefit from nano-sized materials. Proper research, development, and collaboration between researchers, industry stakeholders, and policymakers are crucial to fully realising the potential of nano silica from granite waste [5], [6].

Composite materials, formed by combining different materials to achieve specific properties, have revolutionised industries due to their tailored mechanical, thermal, and electrical characteristics. Incorporating nano silica as a filler in composite matrices offers a novel and effective strategy to enhance these properties further while also contributing to sustainability efforts by repurposing waste materials [7], [8]. Nano silica, with its nanoscale dimensions and high surface area, can significantly influence the behaviour of composite materials when used as a filler [9], [10]. Its incorporation can improve mechanical strength, thermal stability, flame resistance, and barrier properties, among other benefits. The small size and large surface area of nano-silica particles enable them to interact effectively with the matrix material, promoting load transfer and reinforcing effects [11], [12].

Nano silica's strong interaction with the matrix enhances the composite's stiffness, strength, and toughness. This results in better resistance to deformation, cracking, and impact. The addition of nano-silica can enhance the thermal stability of the composite, making it suitable for applications with elevated temperatures. Achieving uniform dispersion of nano silica throughout the composite matrix is crucial to ensure optimal properties [13], [14]. Agglomeration of nanoparticles can lead to localised weak points in the material. Determining the appropriate amount of nano silica filler is essential. Excessive loading may lead to increased viscosity, difficulty in processing, and decreased mechanical properties due to particle agglomeration [15]. Nano silica-enhanced composites can be used in aircraft components, car parts, and structural elements to reduce weight while maintaining high strength.

2. Materials and Methods

2.1 Materials

Various combinations of materials were employed to fabricate the basalt and glass composites, with different loadings of nano-silica, twill weave glass fibre (TWGF), twill weave basalt fibre (TWBF), and polyester resin (PE) as the matrix. The polyester resin used in this study was CRYSTIC® 272E Isophthalic Polyester Resin, a low-viscosity organic-mineral resin provided by Carbon Tech Global Sdn Bhd, in Rawang Selangor. The resin was complemented with Butanox M60 hardener in a 2:1 ratio (resin: hardener). For reinforcement, twill weave basalt fibres were sourced from Zhejiang GBF Basalt Fibre Co. Ltd. in Dongyang, China. Meanwhile, Vistec Technology, based in Puchong, Malaysia, supplied twill weave glass fibres. These fibres served as the structural components within the composite materials, contributing to their strength and performance characteristics. The crucial component, nano silica, was derived from granite dust through a meticulous extraction process conducted within the facilities of UiTM. The source of the granite dust was the Kelantan Branch of Jabatan Kerja Raya (JKR) in Malaysia. This nano silica extraction process involved carefully isolating the nanometer-sized particles from the granite waste. The resulting nano-silica was then used as a filler to enhance the properties of the composite materials [16]. By bringing together these diverse materials and resources, the study aimed to explore the effects of different material loadings and combinations on the final properties of basalt and glass composites. This comprehensive approach, combining advanced materials, cutting-edge extraction processes, and collaboration with industry partners, underscores the multidisciplinary nature of composite material research and development.

Figure 1: Material used, glass fibre, basalt fibre, nano silica, polyester, granite dust, hardener and accelerator

2.2 Method

Fibre Reinforced Polymer (FRP) fabrication involves well-established techniques, namely hand lay-up and vacuum silicon moulding, known for their widespread popularity and effectiveness. To ensure the dispersion of nano-silica, the polyester resin was combined with the filler through a weight-based approach and stirred comprehensively using a mechanical stirrer at a rotation rate of 400 rotations per minute (rpm) for 120 minutes. This meticulous process was essential to achieve optimal filler dispersion within the resin. To achieve a complete cure, the polyester resin was combined with a hardener, following a prescribed weight ratio of 2:1 as recommended by the supplier. This careful proportioning ensured the thorough curing of the composite material. The fabrication procedure for the FRP commenced with the precision cutting and measurement of the fibre, aligned to the required thickness specifications. Subsequently, the resin-filler mixture, blended with the hardener, was meticulously and systematically layered over the fibre, each layer building upon the previous one. Ensuring an airtight seal, a silicon mould was employed to encapsulate the composite, and through the implementation of vacuum technology, trapped air within the specimen was effectively removed. Following this process, the FRP underwent extraction from the mould and was allowed to cure naturally at room temperature for 8 hours. Once fully cured, the composite specimens were meticulously cut into standardised 50mm × 50mm squares and prepared with precision using a circular saw machine. The composite was produced following the system designation as in Table 1. This comprehensive fabrication process, comprising intricate steps from mixing to curing and involving the integration of both traditional and advanced techniques, was crucial to ensure the production of consistent and well-prepared composite specimens for subsequent impact testing. The precision and attention to detail underscored the commitment to obtaining accurate and reliable experimental results, which are instrumental in evaluating the impact properties of the developed composites.

Table 1: System composite with different fibre and loading of nano-silica

System	**Description**
UMBFRPC	Un-Modified PE resin with Basalt Fibre Reinforced Polyester Composites
1NSBFRPC	Modified PE resin by 1wt% of NS with BFRPC
3NSBFRPC	Modified PE resin by 3wt% of NS with BFRPC
5NSBFRPC	Modified PE resin by 5wt% of NS with BFRPC
UMGFRPC	Un-Modified PE resin with Glass Fibre Reinforced Polyester Composite
1NSGFRPC	Modified PE resin by 1wt% of NS with GFRPC
3NSGFRPC	Modified PE resin by 3wt% of NS with GFRPC
5NSGFRPC	Modified PE resin by 5wt% of NS with GFRPC

2.3 Low-velocity impact test

The low-velocity impact properties were assessed using precise methodologies using the Instron Dynatup 8250 Impact Tester, adhering closely to the guidelines specified within the ASTM D7136 standard. A purposeful test arrangement was established, involving a drop tower outfitted with a hemispherical tip impactor, distinguished by its 13 mm diameter hemispherical tip indentor weighing 13.24kg. In alignment with rigorous experimental procedures, each composite specimen system was represented by five samples to ensure statistically robust results. The imparted energy throughout the tests was consistent at 101.3 J, maintaining controlled conditions at ambient room temperature. By methodically executing these tests, the focal point was to glean insights into the impact properties of the composite specimens. This comprehensive evaluation encompassed parameters such as the energy absorbed upon impact and the consequential impact strength of the composites. These pivotal metrics are key to comprehending the materials' inherent ability to counteract impact forces, exhibiting energy absorption prowess without succumbing to failure or substantial deterioration.

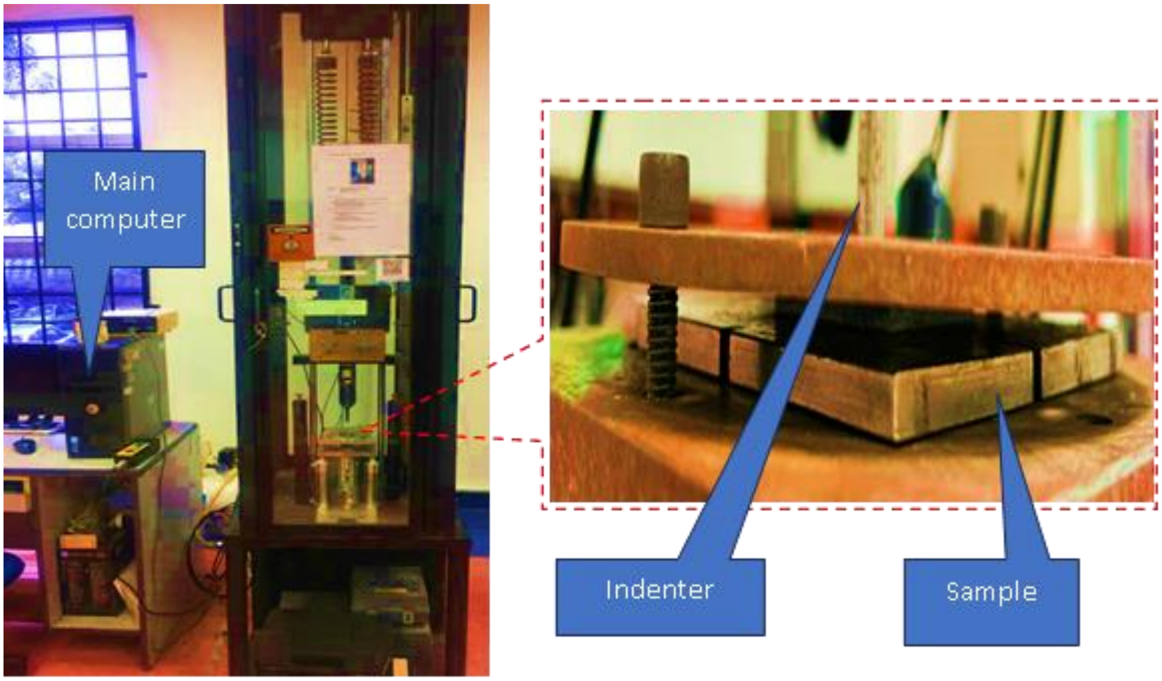

Figure 2: Low velocity impact machine instron 8250

3. Results and discussion

The investigation into the impact properties of composites enriched with the incorporation of nano silica as reinforcing agents constitutes a focal point of this study, undertaken across various configurations of Fiber Reinforced Polymer (FRP) compositions. The ensuing sections delve into a comprehensive discourse, unravelling these investigations' multifaceted outcomes and implications.

3.1 Effect of nano silica (NS) on energy absorbed by Glass Fibre Reinforced Polyester Composites (GFRPC) and Basalt Fibre Reinforced Polyester Composites (BFRPC)

Upon meticulous examination of Figure 5, an unmistakable trend manifests, characterised by a conspicuous augmentation in energy absorption. This augmentation, quantified at 6.4%, is discernible as the transition unfolds from the unmodified Basalt Fiber-Reinforced Polyester Composite (BFRPC) to the ingeniously modified counterpart, the 1wt% Nano Silica Basalt Fiber-Reinforced Polyester Composite (1NSBFRPC). The energy absorption metric escalates appreciably, progressing from its initial stance at 96.76J to a heightened plateau at 103.21J. As the investigation delves further, it becomes evident that upon crossing the threshold of 1wt% Nano Silica (NS) incorporation [17], a subtle yet noticeable attenuation occurs, resulting in a stabilised range of 101.02J and 96.25J. Similarly, the trajectory traced by the Glass Fiber-Reinforced

Polyester Composite (GFRPC) echoes the earlier pattern. Embarking from the foundation of 0wt% NS, the energy absorption capability exhibits a gradual and consistent rise, an upswing that culminates in a significant expansion by 8.02% as 1wt% NS incorporation is realised. It's worthy of note, however, that after the pivotal 1% NS infusion, the energy absorption profile experiences a marginal deviation, arriving at values of 102.50J and 100.79J.

This remarkable consistency and effect, mainly observed at the juncture of 1wt% NS inclusion, can be attributed to the intrinsic propensity of nano-silica particles to aggregate. This outcome, congruent with earlier research [18], points to the phenomenon of nano-silica reaching a saturation point at the 1wt% threshold [19]. Thus, the inflexion observed in the energy absorption trend underscores a concentration-specific enhancement in impact performance. This outcome underscores the pivotal role of this particular concentration in achieving optimal impact resilience. The nuanced dynamics unravelling from this analysis accentuate the intricate interplay between nano-silica incorporation and impact performance enhancement [20]. This insight contributes to a comprehensive understanding of the underlying mechanisms at work. It underpins the informed design and formulation of composite materials for attaining maximal impact resilience across various applications.

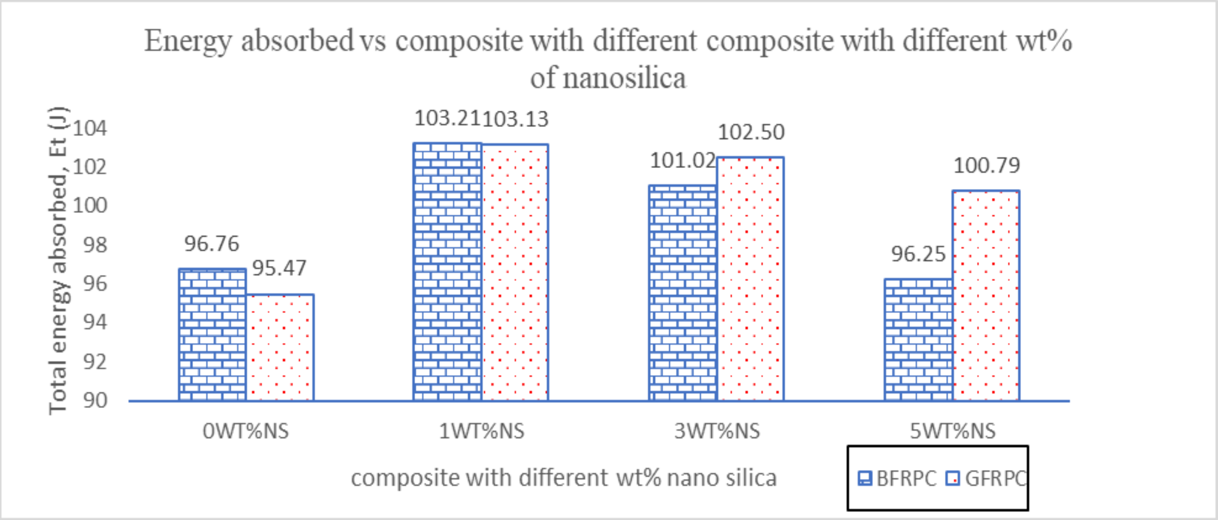

Figure 3: Energy absorbed vs composite with different wt% of nano-silica

3.2 Effect of nano silica (NS) on the impact strength of Glass Fibre Reinforced Polyester Composites (GFRPC) and Basalt Fibre Reinforced Polyester Composites (BFRPC)

Upon meticulous analysis of the insights derived from Figure 5, a distinctive pattern emerges, unveiling a remarkable surge of 61.14% in impact strength, a surge that traverses the spectrum from the foundational point of the unmodified Basalt Fiber-Reinforced Polyester Composite

(BFRPC) to the elevated configuration, the 1% Nano Silica Basalt Fiber-Reinforced Polyester Composite (1NSBFRPC). In this transition, the impact strength experiences a substantial elevation, soaring from its initial stance of 13.20 kJ/m² to an impressive zenith at 21.27 kJ/m². However, as the concentration of Nano Silica (NS) reaches the 1wt% threshold, a modest regression is observed, with this metric tapering to 16.22 kJ/m² and 15.12 kJ/m², respectively. Concurrently, a parallel narrative unfolds within the Glass Fiber-Reinforced Polyester Composite (GFRPC), wherein a comparable trajectory is traced. Impact strength ascends progressively as NS content increases from 0wt% to 1wt%, effectuating a commendable percentage upswing of 15.22%. Notwithstanding, after the incorporation of 1% NS, this ascending trajectory experiences a measured decrement, culminating at 11.57 kJ/m² and 9.41 kJ/m².

This compelling and consistent trend illuminates the impact performance enhancement, intricately woven with the concentration of nano-silica and notably prominent at the 1wt% NS juncture. This phenomenon, aligned with prior research [21], [22], can be attributed to the characteristic propensity of nano-silica to aggregate. This aggregative tendency reaches its pinnacle, distinctly observed at the 1wt% juncture in this specific experiment. Consequently, the discernible ascent and subsequent moderation in impact strength underscore a concentration-dependent relationship. This crucial revelation underscores the paramount importance of the 1wt% NS concentration in eliciting optimal impact resilience within the composite specimens.

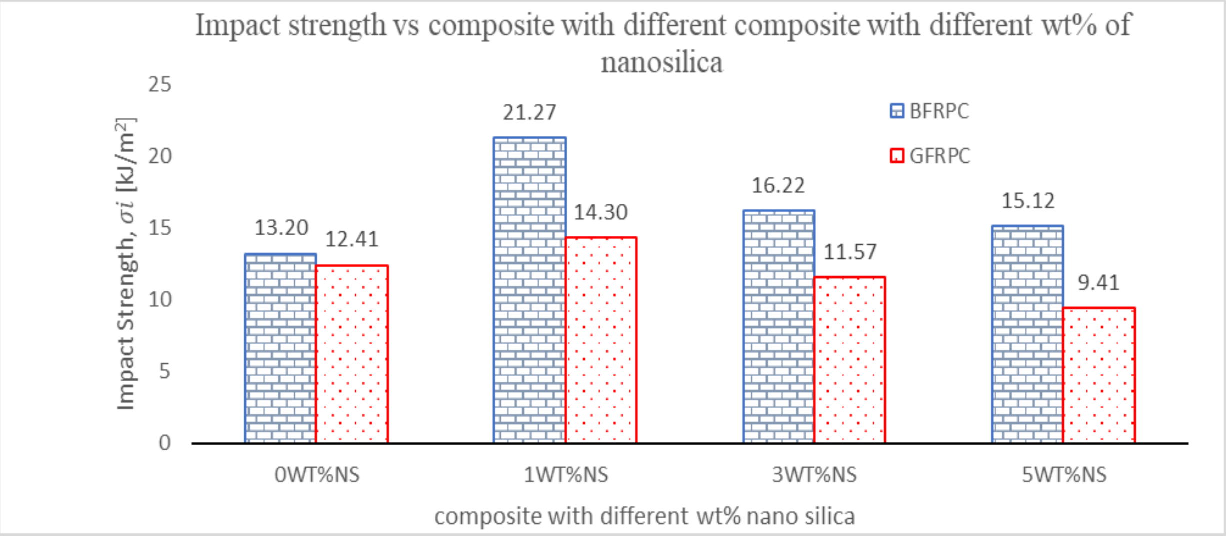

Figure 4: Impact strength vs composite with different wt% of nano-silica

3.3 Effect of nano silica (NS) on ductility index of Glass Fibre Reinforced Polyester Composites (GFRPC) and Basalt Fibre Reinforced Polyester Composites (BFRPC)

The ductility index is a significant parameter that provides insights into composite materials' flexibility and deformation behaviour under various loading conditions. It offers a quantitative measure of a material's ability to undergo plastic deformation and absorb energy before reaching the point of failure. The ductility index is crucial for applications where materials need to exhibit toughness, resistance to brittle fracture, and the capacity to deform without catastrophic failure. Analysing the trends depicted in Figure 4 provides valuable insights into the ductility index across various composite configurations. Initially, for UnModified Glass Fiber-Reinforced Polyester Composite (UMGFRC), the ductility index registers at 2.03. Upon the infusion of 1% Nano Silica (1NSGFRC), a discernible rise is noted, ascending to 2.15. However, subsequent alterations are observed, with the index experiencing a reduction to 1.79 and eventually settling at 1.28.

Remarkably, a parallel pattern emerges within the Basalt Fiber-Reinforced Polyester Composite (BFRPC), which embarks from a baseline of 2.62. As 1wt% Nano Silica incorporation is effected, a substantial increment is witnessed, elevating the index to 4.13. This elevated value subsequently undergoes a decrement, converging at 3.10 and 2.39. Notably, a distinct concentration-dependent behaviour unfolds across Glass Fiber-Reinforced Polyester Composite (GFRPC) and BFRPC. The ductility index accentuates its rise at 1wt% Nano Silica (NS) incorporation, dipping at 3wt% NS and 5wt% NS levels. Consequently, the most intriguing observation emerges – at 1wt% NS, both GFRPC and BFRPC attain their maximum ductility index. This implies that these composite systems can exhibit substantial deformation before fracture, indicative of enhanced toughness and resilience.

An intriguing facet contributing to this behaviour is the characteristic inclination of nano-silica to aggregate at specific concentrations. This tendency reaches its pinnacle at the 1wt% NS threshold, yielding a marked increase in the ductility index. This observation underscores the intricate interplay between nano-silica concentration and ductility, thereby imparting pivotal insights into the optimal formulation of composite materials for attaining maximal deformation capacity and resistance to catastrophic failure.

The ductility index trends unravel a nuanced concentration-driven narrative, elucidating the interrelation between nano-silica content, deformation capability, and overall composite performance. This revelation proves instrumental in refining composite material formulations for applications demanding superior toughness and resilience against deformative forces. The ductility index is a crucial parameter in assessing the overall mechanical behaviour of composite materials, especially in scenarios involving dynamic loading, impact, or structural resilience [23]. A high ductility index can signify improved toughness and resistance to sudden failure, making the material suitable for automotive, aerospace, construction, and sports equipment manufacturing applications.

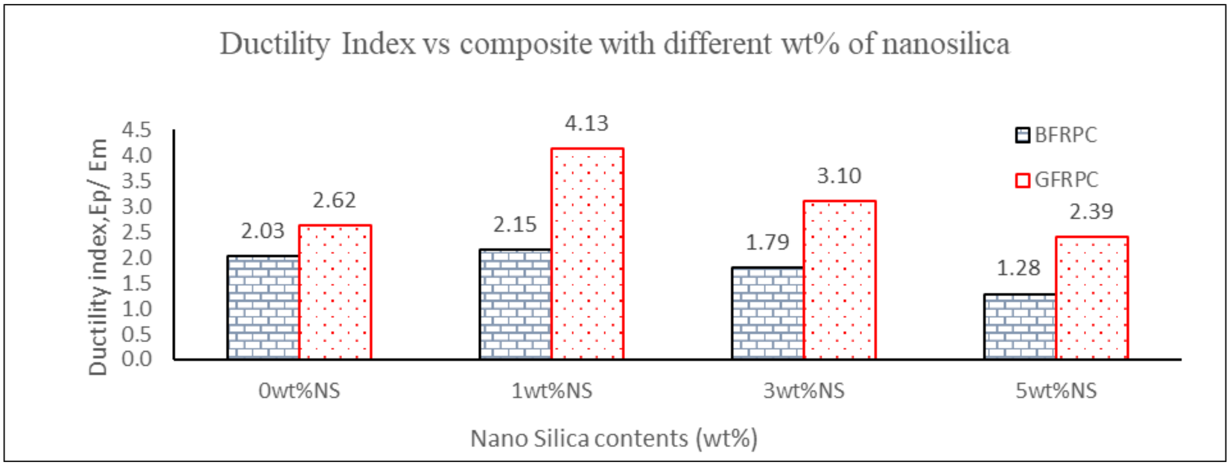

Figure 5: Ductility Index vs composite with different wt% of nano-silica

3.4 Effect of nano-silica compared to industrial sample, Carbon Tech Global (CTG)

The primary objective of this analysis was to discern the influence of nano-silica, juxtaposed against an established industrial benchmark—Carbon Tech Global (CTG). A central facet of this endeavour involved homing in on the precise threshold of nano-silica content that would yield optimal outcomes. Intriguingly, the research pinpointed the precise concentration at which nano-silica exerted its most pronounced impact: an ideal 1wt% composition. This concentration emerged as a common denominator, optimising the Basalt Fiber-Reinforced Polyester Composite (BFRPC) and the Glass Fiber-Reinforced Polyester Composite (GFRPC).

Referring to Figure 6, a remarkable distinction emerges between the energy values absorbed between composites. The contrast is particularly striking when comparing CTG and Unmodified Basalt Fiber-Reinforced Polyester Composite (UMBFRPC), exhibiting a substantial difference of 278%. The same pattern follows with Unmodified Glass Fiber-Reinforced Polyester Composite (UMGFRPC), with a remarkable divergence of 273.51%.

Energy absorption displays a noteworthy ascent from CTG to 1wt% Nano Silica Basalt Fiber-Reinforced Polyester Composite (NSBFRPC), portraying an impressive 303.79% increase, ascending from 25.56J to 103.21J. This parallel trend persists between CTG and 1wt% Nano Silica Glass Fiber-Reinforced Polyester Composite (NSGFRPC), where energy absorption surges from 25.56J to 103.13J, embodying a substantial 303.48% enhancement.

Delving into the comparison between Unmodified and 1wt% Nano Silica Basalt Fiber-Reinforced Polyester Composite (NSBFRPC), the energy absorption values stand at 96.76J and 103.21J, showcasing a noteworthy 6.66% difference. Similarly, Unmodified and 1wt% Nano

Silica-Modified Glass Fiber-Reinforced Polyester Composite (NSGFRPC) present energy absorption disparities of 95.47J and 103.13J, constituting an appreciable 8.02% distinction.

In summary, Figure 6 clearly shows substantial differences in energy absorption values across various composite configurations, underscoring the substantial impact of nano silica incorporation and its potential to revolutionise composite performance.

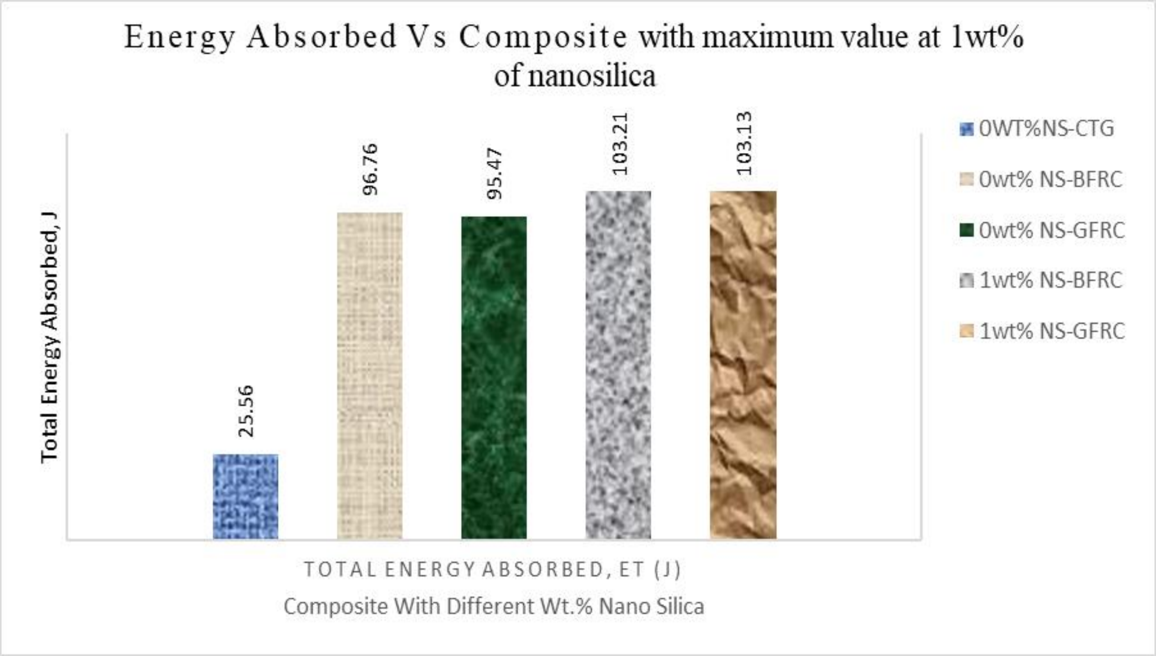

Figure 6: Energy Absorbed Vs Composite with Different Wt% of Nanosilica

Turning our attention to Figure 7, an undeniable contrast in impact strength values emerges, illustrating the significance of the observations. This divergence becomes particularly pronounced when we compare Carbon Tech Global (CTG) and the Unmodified Basalt Fiber-Reinforced Polyester Composite (UMBFRPC), revealing a considerable discrepancy of 208%. Similarly, this trend replicates itself with the Unmodified Glass Fiber-Reinforced Polyester Composite (UMGFRPC), where an impressive variance of 189.9% becomes evident.

The impact strength trajectory is impressive as we move from CTG to the 1wt% Nano Silica Basalt Fiber-Reinforced Polyester Composite (NSBFRPC). This journey exemplifies a staggering 396.96% surge, elevating the impact strength from 4.28 KJ/m^2 to an impressive $21.27kJ/m^2$. A similar narrative unfolds in the context of CTG and the 1wt% Nano Silica Glass Fiber-Reinforced Polyester Composite (NSGFRPC), where impact strength soars from $4.28kJ/m^2$ to $14.30kJ/m^2$, manifesting a notable enhancement of 234.11%.

Further exploration into the comparison between Unmodified and 1wt% Nano Silica Basalt

Fiber-Reinforced Polyester Composite (NSBFRPC) underscores the impact strength distinctions, with values at 13.20J and 21.27J. This differential of 8.07% is substantial and revealing. Similarly, when contrasting Unmodified and 1wt% Nano Silica Glass Fiber-Reinforced Polyester Composite (NSGFRPC), we witness impact strength discrepancies of 12.41kJ/m^2 and 14.30kJ/m^2, representing an appreciable distinction of 8.02%.

Figure 7 paints an unmistakable portrait of significant disparities in impact strength values across diverse composite configurations. This emphatically underscores the remarkable influence of nano-silica integration and its inherent potential to catalyse a paradigm shift in composite performance capabilities.

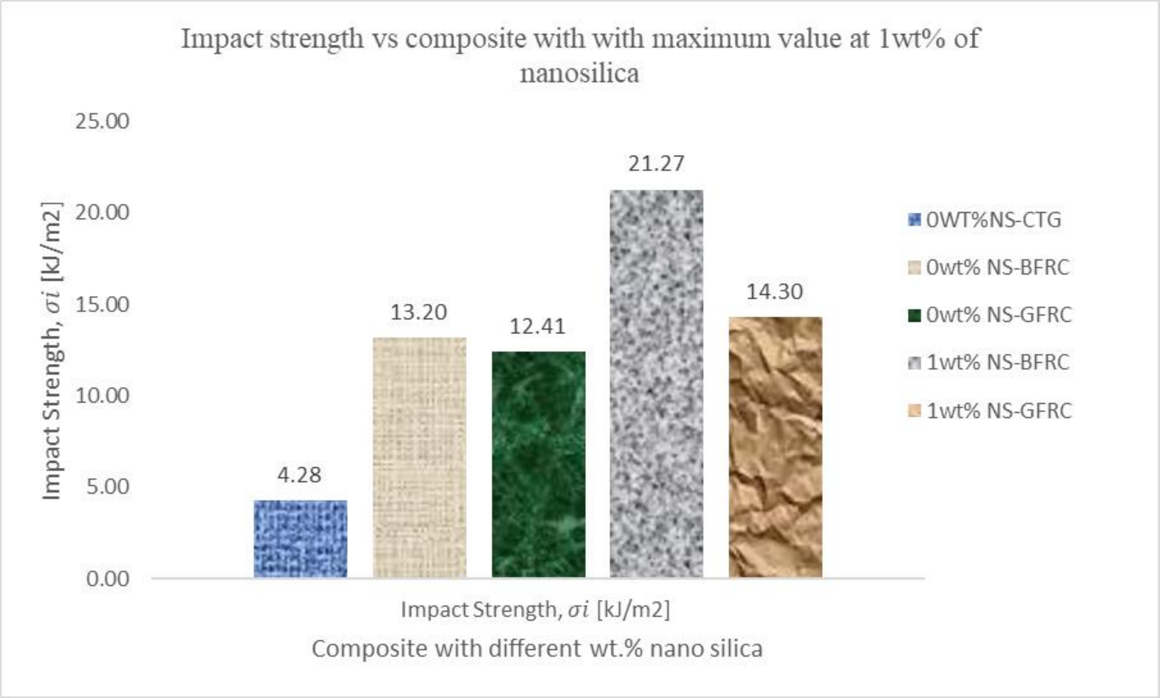

Figure 7: Impact strength vs composite with different wt% of nano-silica

Examining Figure 8, a distinct contrast materialises between Carbon Tech Global (CTG) and the Unmodified Basalt Fiber-Reinforced Polyester Composite (0wt%NSBFRPC), as their values diverge by 12%, shifting from 1.81 to an impressive 20.3. Similarly, in Unmodified Glass Fiber-Reinforced Polyester Composite (0wt%NSGFRPC), the values experience an ascent from 1.81 to 2.62, registering a substantial 44.75% increase.

Diving into the realm of ductility index, a discernible pattern emerges by incorporating nano silica. The transition from 2.03 to 2.15 reflects a 5.9% enhancement in the ductility index. A remarkable surge is witnessed in the case of 1wt% nano-silica glass fibre-reinforced polyester composite (1wt%NSGFRPC), with the ductility index skyrocketing from 2.62 to an impressive

4.13. This leap signifies an astonishing 57.63% increment.

Highlighting a notable distinction, the contrast between CTG and 1wt% nano-silica glass fibre-reinforced polyester composite (1wt%NSGFRPC) showcases a remarkable shift from 1.81 to 4.13. This leap embodies an extraordinary 128.2% surge, underscoring the substantial impact of nano silica integration.

In summary, the data depicted in Figure 8 underscores a distinct pattern of ductility index variation across diverse composite configurations. Glass Fiber-Reinforced Polyester Composites (GFRC) demonstrate a notably higher ductility index than Basalt Fiber-Reinforced Polyester Composites (BFRPC) and CTG. This observation elucidates the potential advantages of incorporating glass fibres in enhancing ductility, thereby contributing to the broader understanding of composite material performance [24].

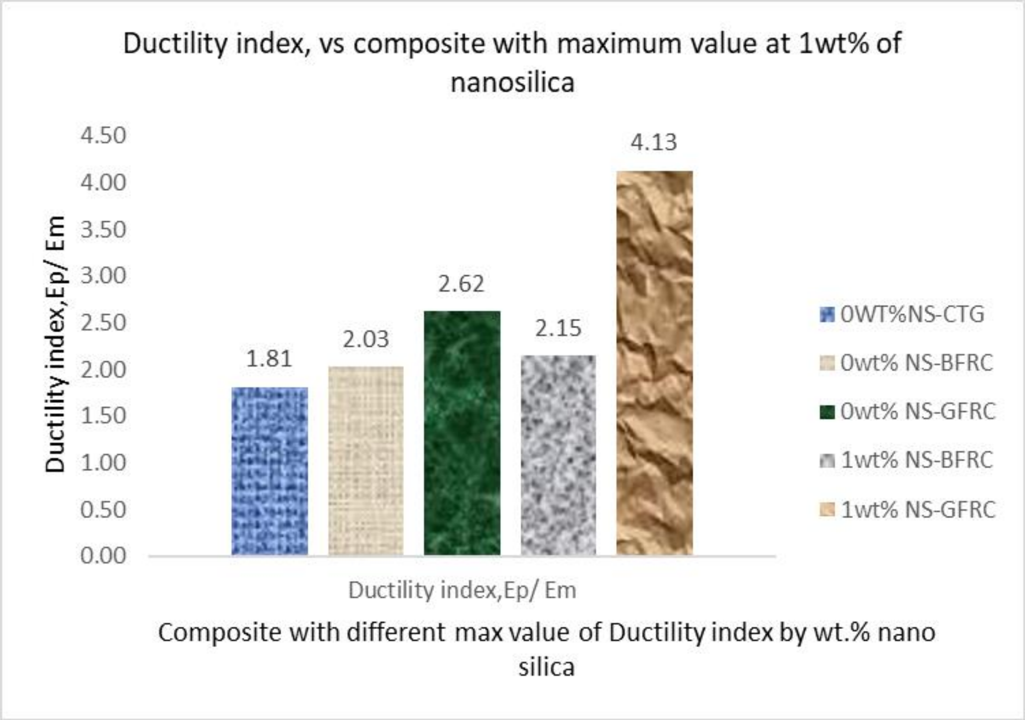

Figure 8: Ductility index vs composite with maximum value at 1wt% of nanosilica

4. Conclusions

The careful analysis highlights the significant impact of adding nano-silica to composite materials. The impact strength, energy absorption, and ductility improvements are evident, mainly when the nano-silica concentration stays below 1wt%. However, a decline is noticeable beyond this critical point, representing the peak of achievable enhancement. Enhancement. Interestingly, the composite material developed in this study surpasses the performance benchmarks of the industrial sample by a considerable margin.

A notable finding emerges that nano-silica is more appealing than natural fibres, surpassing their synthetic counterparts. Amidst these findings, a profound dual effect becomes apparent. The incorporation of nanosilica not only results in superior products but also paves the way for environmental responsibility. These revelations clarify the transformative potential of nano-silica in enhancing composite properties and outline a path to achieving optimal performance while promoting sustainability ideals.

Conflicts of interest

The authors declare no conflict of interest.

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