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The Performance of Bamboo Fibre as Reinforcement Concrete in Substitude Cement with Nano Silica in Terms of Workability, Compressive Strength and Tensile Strength

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Abstract

In construction, concrete is a crucial material valued for its affordability, robustness, heat and fire resistance, wide availability, endurance, and versatility. However, its limited tensile strength restricts its use in areas dominated by tensile forces. Bamboo offers a compelling alternative: it is abundant in fibres, naturally sourced, cost-effective, easily procurable, and notably strong in both tension and compression. To explore the mechanical properties of bamboo fibre as reinforcement in concrete with nano silica as a cement substitute, laboratory investigations were conducted on workability, compressive strength, and split tensile strength. Based on these observations, conclusions were drawn about the impact of adding bamboo fibre and nano-silica to concrete. In summary, bamboo fibres and nano-silica are promising materials that can enhance concrete's strength, ductility, and post-cracking load-carrying capacity. Furthermore, a comparison of compressive strength test results for cube samples at 7 days and 28 days was made, as well as a split tensile strength test for a cylinder sample at 28 days. For both the 7 days and 28 days compressive strength tests, sample 4 (fibre 0.20%, nano-silica 2.0%) showed the highest strength, and for the split tensile strength test, sample 4 was also the highest. Additionally, the fibres allowed the concrete to sustain higher loads than ordinary concrete while reducing fracture width and deflection. Consequently, specimens with varying fibre contents showed considerable improvement in tensile strength as the fibre volume percentage increased.

1. Introduction

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Bamboo has emerged as a cost-effective and versatile resource for global housing construction, particularly in Malaysia where it is widely cultivated. Bamboo fibers, when integrated into concrete, enhance structural integrity by reducing cracks, aligning with Sustainable Development Goal 12 for sustainable consumption and production. Traditional carbon fibres were preferred for their strength, but natural plant fibres like bamboo faced limitations in stiffness [1]. Ongoing research in Bamboo Fibre Reinforced Concrete (BFRC) aims to mitigate cracking by combining bamboo fibres with nano silica, which improves concrete's strength and durability [2]. Despite cement's environmental impact, nano silica's small size and pozzolanic properties enhance concrete's microstructure and performance [2]. Bamboo's renewable nature and biodegradability offer positive environmental outcomes, contrasting with cement's greenhouse gas emissions and long-term degradation issues [3]. Integrating bamboo fibres into concrete improves resilience against tension-related cracks and enhances compressive strength, making it a sustainable alternative in construction practices [4]. Nano silica complements these efforts by compacting concrete microstructures and accelerating cement hydration, ensuring durability without completely replacing traditional materials [5]. Together, bamboo fibre and nano silica represent a promising solution to enhance concrete's strength, reduce cracks, and improve overall sustainability in construction.

2. Methodology

Concrete is an essential construction material comprising a blend of cement, water, aggregates like sand, gravel, or crushed stone, and occasionally admixtures. Renowned for its robustness, durability, and versatility, concrete is widely employed worldwide for its capacity to be shaped into diverse forms. The hydration process, initiated when cement mixes with water, triggers a chemical reaction that transforms the mixture into a solid, resilient substance known as concrete. Aggregates are integrated to enhance strength and volume, while admixtures, added in small quantities, improve specific properties such as workability and strength. This combination of materials ensures concrete's suitability for a broad array of construction applications.

2.1 Preparation of Design Mix Concrete

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Concrete mix proportioning aims to identify the most cost-effective and practical combination of readily available materials that meet specific performance criteria under defined conditions. Typically, cement mix proportions are expressed as the mass of each constituent per unit volume. The absolute volume method for concrete proportioning involves determining the volume of each component and its contribution to the final product, which is then converted into design weights. This conversion process includes multiplying the known volumes of components by their specific gravities and subsequently by the density of water [6].

Following the DOE mix design methodology, a specific mix design was developed for bamboo fiber-reinforced concrete with nano-silica, targeting C30 concrete grade. This mix design specifies proportions of cement, water, sand, coarse aggregate, bamboo fiber, and nano-silica. Compressive strength and split tensile strength tests will be conducted at both 7 days and 28 days to evaluate the concrete's performance.

Table 1 *Concrete Mixture Proportion Based on DOE Method*

Control Sample	Cement (kg/m3)	Water (kg/m3)	Fine Aggregate (kg/m3)	Coarse Aggregate (kg/m3)	Total Mixture for6 Cube (kg/m3)
Cube	2.51	1.23	4.29	6.43	14.46
Cyclinder	2.51	1.23	4.29	6.43	14.46

2.2 Mixing and Casting

Concrete is mixed in a laboratory using a manual or machine mixer that meets British standards. Under regulated room temperature and humidity, freshly mixed concrete may take around 8 minutes and half seconds to mix. In this study, concrete materials are assessed, delivered individually, and combined using a mechanical mixer. Based on table 2 below shown that bamboo fibre and nano silica that will be use in this experiment [7].

Table 2 30mm Bamboo Fibre will be use

	Fiber 0.15%	Fiber 0.20%	Nano Silica 1.5%	Nano Silica 2.0%	Cube Sample	Cylinder Sample
Control Sample	x	x	x	x	6	3
Sample 1	√	x	√	x	6	3
Sample 2	√	x	x	√	6	3
Sample 3	x	√	√	x	6	3
Sample 4	x	√	x	√	6	3
				Total Sample	30	15

3. Result and Discussion

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This chapter synthesizes the results of tests conducted to assess the influence of bamboo fiber and nano silica on workability, compressive strength, and split tensile strength of concrete. The experimental findings are critically analyzed to determine if they align with the study's objectives. Bamboo Fiber Nano Silica Reinforced Concrete (BFNSRC) represents a novel approach in reinforced concrete technology. The study includes cube compressive strength testing and a slump test to evaluate the workability of the concrete mix. Previous research has highlighted the positive impact of bamboo fiber on the physical properties of high-quality concrete, reinforcing its potential as a viable construction material. The evaluation of the optimum ratio of bamboo fiber and nano silica aims to optimize the mechanical properties and durability of the concrete mix.

3.1 Workability of CRBFNS

The workability test assessed how easily freshly mixed concrete could be blended, spread, compacted, and finished. High workability indicates that the concrete is freshly mixed and easy to handle. Each concrete mix underwent a slump test, and the results are detailed in Table 3. The expected slump range was between 83 mm and 102 mm. Figure 1 illustrates that as the amount of bamboo fiber in the concrete increased, the slump decreased. Concrete reinforced with Bamboo Fiber and Nano Silica exhibited less slump compared to regular concrete, correlating with higher fiber content. This was attributed to the fibers absorbing water from the concrete mixture, causing it to stiffen and reduce workability. To mitigate this, fibers were pre-soaked in tap water for a full day before incorporation into the concrete mix, addressing water absorption issues and optimizing workability.

Table 3 Slump Test Result for Each Concrete Mix

Percentage of Bamboo Fibre and Nano-Silica	Slump Height (mm)	Type of Slump	Degree of Workability
Control Sample (0%)	102	True Slump	Medium
Sample 1 (F0.15%, NS1.5%)	83	True Slump	Medium
Sample 2 (F0.15%, NS2.0%)	95	True Slump	Medium
Sample 3 (F0.20%, NS1.5%)	87	True Slump	Medium
Sample 4 (F0.20%, NS2.0%)	91	True Slump	Medium

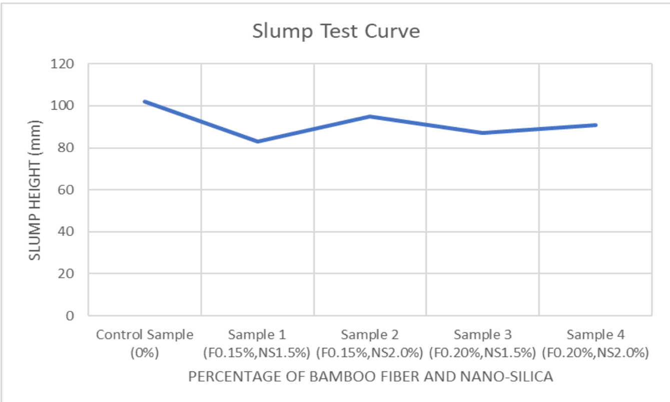

Figure 1 The Relationship between the Slump and Percentage of Bamboo Fibre and Nano Silica

The results aligned with the expected slump ranges specified in the mix design, as illustrated in the graph above. It was observed that the workability of bamboo fiber was consistent across different quantities used in the experiment. This consistency was due to the inverse relationship observed: as the amount of fiber increased, the concrete exhibited less slump. The influence on workability was primarily governed by the fiber's volume percentage, aspect ratio, size, and the quantity of coarse aggregates, affecting the risk of fiber clumping. Despite variations, the slump test confirmed that all combinations were feasible. The interaction between fibers and aggregates played a crucial role in regulating fiber orientation within the concrete mix.

3.2 Compressive strength of CRBFNS

One of the goals of this research was to determine the compressive strength of a concrete cube. It was possible to identify the link between the concrete strength of bamboo fibre and nano silica. The test cubes were cured in a wet curing environment. The compressive strength of the concrete cubes was measured after 7 days and 28 days. Figure 2 and Figure 3 show the results of the 7 days and 28 days compressive strength tests on a cube sample. Furthermore, Figure 4 compares the compressive strength test results of a cube sample between 7 days and 28 days.

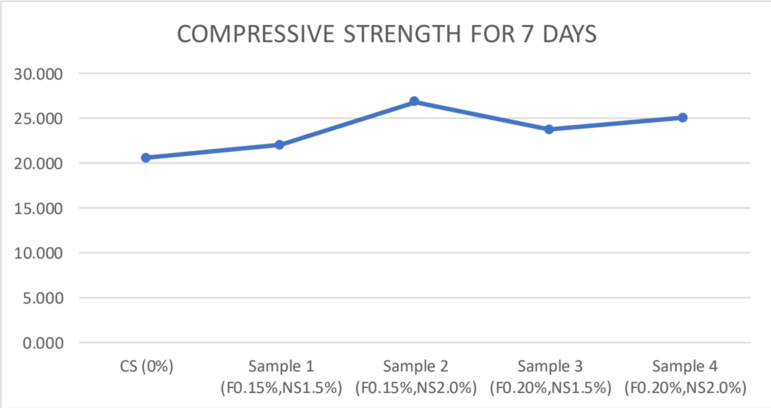

Figure 2 Compressive Strength Curve for 7 Days of the Concrete Cube

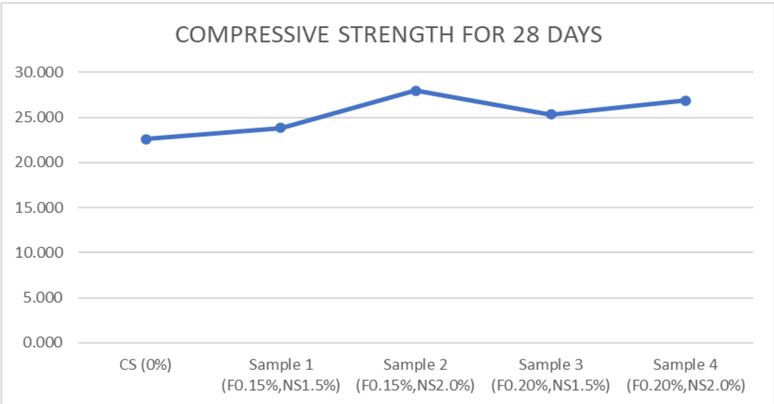

Figure 3 Compressive Strength Curve for 28 Days of the Concrete Cube

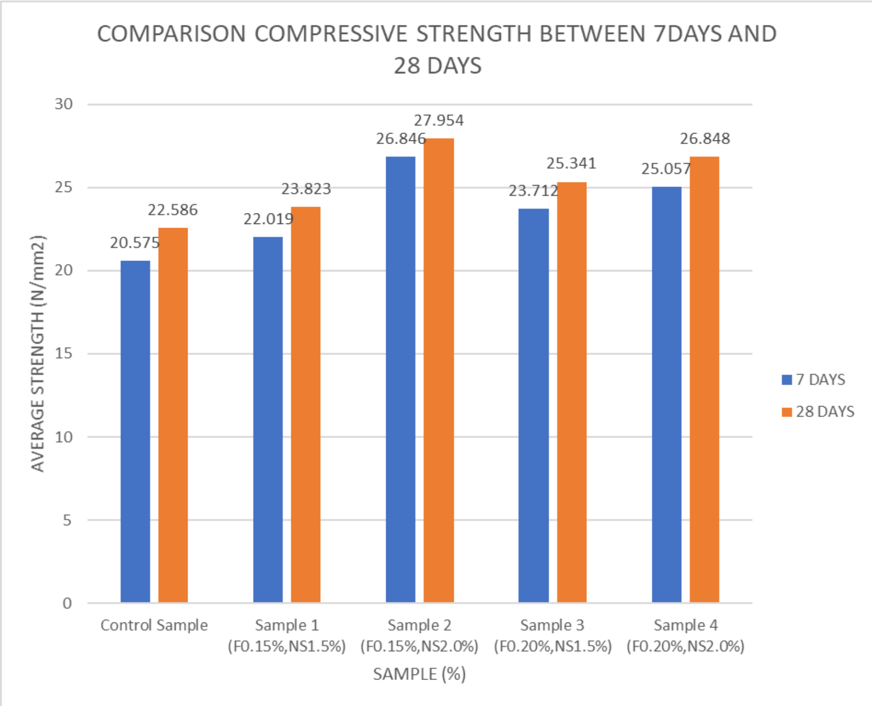

Figure 4 Comparison Compressive Strength Curve Between 7 days and 28 Days

The compressive strengths of all concrete mixes increased from 7 days to 28 days, as illustrated in Figure 4. This improvement reflects the ongoing hydration process within the concrete samples over time. By the 28th day, the concrete had fully dried through hydration, resulting in higher compressive strengths compared to the 7 days samples. Notably, concrete mixes containing 0.15% bamboo fibre and 2.0% nano silica (Samples 2 and 4) exhibited higher compressive strengths than mixes with lower nano silica content (Samples 1 and 3). This indicates that the addition of bamboo fibre and higher nano silica content effectively enhances the compressive strength of Bamboo Fiber Nano Silica Reinforced Concrete (BFNSRC). These findings align with the anticipated strength ranges in the mix design, highlighting that 0.15% and 0.20% bamboo fibre with 2.0% nano silica additions notably boost compressive strength.

3.3 Split tensile strength of CRBFNS

An indirect tension test for concrete was the split tensile strength test. It was conducted using a typical cylinder specimen that was examined under diametric compression while lying on its side. Four different percentage additions of bamboo fibre and nano silica were tested for split tensile strength. Three-cylinder samples were examined for each % of bamboo fibre and nano silica addition. The figure below shows the typical failure loads and tensile strength of the 28 days Concrete Reinforcement with Bamboo Fibre and Nano Silica when subjected to tensile loading. Figure 5 below shows the full test results for the split tensile strength of concrete reinforcement with bamboo fibre and nano silica at ages of 7 days and 28 days.

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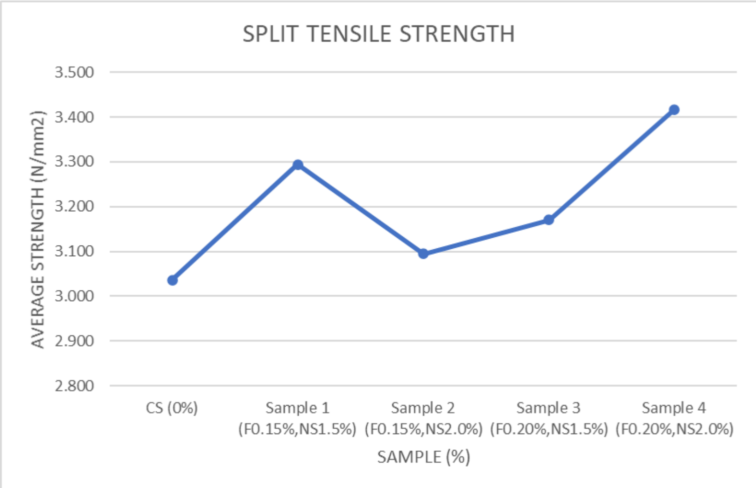

Figure 5: Split Tensile Strength Curve for 28 Days of the Concrete Cylinder

According to Figure 5, Sample 4 (F0.20%, NS2.0%) of Concrete Reinforcement with Bamboo Fibre and Nano Silica achieved the highest split tensile strength of 3.417 N/mm² after 28 days compared to other concrete mixes, which ranged from 3.036 N/mm² to 3.294 N/mm². Figure 5 further illustrates that the superior split tensile strength in Sample 4 can be attributed to the optimal combination of bamboo fibre and nano silica. This suggests that the most effective proportion of bamboo fibre and nano silica to enhance split tensile strength in concrete is found in Sample 4 (F0.20%, NS2.0%). Comparing these results to expected strength ranges from the mix design confirms that tensile strength increases with additions of 0.15% and 0.20% bamboo fibre and 1.5% and 2.0% nano silica. Notably, the addition of 0.20% bamboo fibre and 2.0% nano silica significantly enhances tensile strength

4. Conclusion

In conclusion, the integration of bamboo fibre and nano silica into concrete presents both challenges and opportunities in enhancing its mechanical properties. The workability tests revealed a significant reduction in slump as the proportions of bamboo fibre and nano silica increased, posing challenges in managing the concrete mixture. Meanwhile, the study on compressive strength under wet curing conditions demonstrated that higher concentrations of bamboo fibre generally reduced strength, but optimal performance was achieved with 0.15% bamboo fibre and 2.0% nano silica due to improved hydration processes. Similarly, the split tensile strength tests showed a consistent improvement across all samples with the highest performance recorded in sample 4, containing 0.20% bamboo fibre and 2.0% nano silica. These findings underscore the critical importance of carefully balancing the proportions of bamboo fibre and nano silica to achieve desired enhancements in concrete's mechanical properties while maintaining practical workability in construction applications

5. Recommendation

Based on the findings of this study, it is recommended to carefully consider the balance between bamboo fibre and nano silica content when incorporating them into concrete mixes. For optimizing workability, especially in scenarios requiring higher slump values, adjustments in the proportions of additives may be necessary to mitigate the observed reductions. In terms of enhancing compressive strength, using a moderate amount of bamboo fibre (around 0.15%) combined with 2.0% nano silica showed promising results during the hydration process, yielding improved mechanical performance. Additionally, for applications requiring superior tensile strength, formulations similar to sample 4, with 0.20% bamboo fibre and 2.0% nano silica, should be considered. Continuous monitoring and further research into the long-term durability and environmental impacts of these additives will also be crucial in refining their practical application in sustainable construction practices.

(a) **(b)**

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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Author Contribution

The authors confirm sole responsibility for the following: study concept and mix design, material and data collection, analysis and interpretation of results, and thesis preparation.

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