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# Investigating the Mechanical Properties of Natural Fiber-Reinforced Concrete with Kenaf, Jute, and Coconut Fibers

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**ABSTRACT**

This study investigates the mechanical properties of natural fiber-reinforced concrete (FRC) through the addition of natural fibers such as kenaf (KFRC), jute (JFRC), and coconut (CFRC). The evaluation focused on key properties including compressive strength, split tensile strength, and flexural strength. Fiber combinations were introduced in a fiber volume fraction of 0.5%, with fiber lengths standardized at 20 mm. A water-to-binder ratio of 0.44 was maintained for all mixes. Six specimens were tested for each parameter after a curing period of 28 days. The objective of this research was to assess the potential of natural fibers like kenaf, jute, and coconut for developing sustainable FRC while maintaining or improving its mechanical properties. Results demonstrated that the inclusion of natural fibers at the specified length and concentration positively influenced post-cracking flexural performance and splitting tensile strength. Among the tested combinations, FRC reinforced with jute fibers (JFRC) exhibited superior performance compared to other fiber combinations.



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## 1. Introduction

Natural fibers have been integral to construction materials for centuries, dating back to ancient civilizations where fibers like straw and horsehair were mixed with mud to reinforce walls and roofs [1, 2]. Today, with growing environmental concerns and the need for sustainable building practices, fiber-reinforced concrete (FRC) has gained renewed attention [3, 4]. The construction industry is a major contributor to global carbon dioxide emissions, and traditional FRC like steel FRC not only consume vast amounts of energy but also release significant greenhouse gases during production [5]. In response to these issues, researchers are increasingly focused on developing eco-friendly FRCs that reduce environmental impact while maintaining or even improving the mechanical properties of conventional construction materials [6, 7].

Natural fiber-reinforced concrete (NFRC) has been increasingly explored as a sustainable alternative to traditional synthetic fibers [8-10]. These fibers are not only renewable and biodegradable, but also exhibit several other advantages, including high tensile strength, lower

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processing costs and densities compared to synthetic fibers, making them ideal for environmentally friendly building materials [11–13]. The incorporation of natural fibers such as kenaf, jute, coconut, and sisal has been shown to enhance the tensile strength, flexural strength, and overall durability of concrete by preventing the propagation of microcracks [14-16]. Natural fibers help reduce the shrinkage-related cracks that typically occur in concrete during the drying process, providing enhanced resistance to mechanical stresses and improving the post-cracking behavior of concrete [1,12,17].

Advanced materials are essential in seismic regions where reinforced concrete (RC) structures endure repeated loads. Hassanshahi et al. [18] demonstrated that repeated earthquakes significantly damage RC joints by increasing inelastic displacements. This highlights the importance of materials like NFRC, which enhance toughness, ductility, and post-cracking strength, key properties for improving the performance of earthquake-resistant structures.

Despite their potential benefits, the optimization of NFRC remains a challenge. Factors such as fiber volume fraction, fiber length, and distribution within the concrete matrix significantly impact the mechanical properties of NFRC [19]. Excessive fiber content, for example, can result in clumping and reduced workability of the concrete mix, undermining its effectiveness [20, 21]. Moreover, each natural fiber type possesses unique characteristics, necessitating tailored approaches to maximize their reinforcement potential in concrete [16, 22].

This study provides insights into the individual contributions of each natural fiber type such as kenaf, jute, and coconut and their effects on mechanical properties of FRC performance. The research evaluates compressive strength, split tensile strength, and flexural strength, focusing on the feasibility of using natural fibers as a sustainable alternative to synthetic reinforcement in FRC, potentially reducing the carbon footprint of construction projects and enhancing FRC performance. The outcomes will not only advance the understanding of natural fiber applications in concrete but will also serve as a valuable reference for engineers and practitioners seeking to incorporate innovative materials into sustainable construction practices.

## 2. Materials and Mixture Proportions

The cement used in this study was CEM II/A-L 42.5 R, with a specific gravity of 2.95 g/cm³. Fine aggregates with a specific gravity of 2.63 and a fineness modulus of 2.77 were utilized, while coarse aggregates had a specific gravity of 2.68 and a fineness modulus of 2.62. The grading curves for both fine and coarse aggregates were determined using sieve analysis, as per ASTM C136 standards [23, 24], and complied with the relevant ASTM specifications. Figure 1 illustrates the aggregate combination used.

Natural fibers, including kenaf, jute, and coconut, as illustrated in Figure 2, were incorporated into the concrete mix. Kenaf fibers had an average diameter of 0.2 mm, tensile strength of 500 MPa, and a density of 1.4 g/cm³. Jute fibers had a smaller average diameter of 0.008 mm, with a tensile strength of 700 MPa and a density of 1.5 g/cm³. Coconut fibers were larger, with an average diameter of 0.25 mm, a tensile strength of 220 MPa, and a density of 1.25 g/cm³. All fibers were cut to a length of 20 mm to ensure consistency. However, natural fibers often contain compounds like lignin and hemicellulose, which hinder the cement hydration process, making pre-treatment necessary.

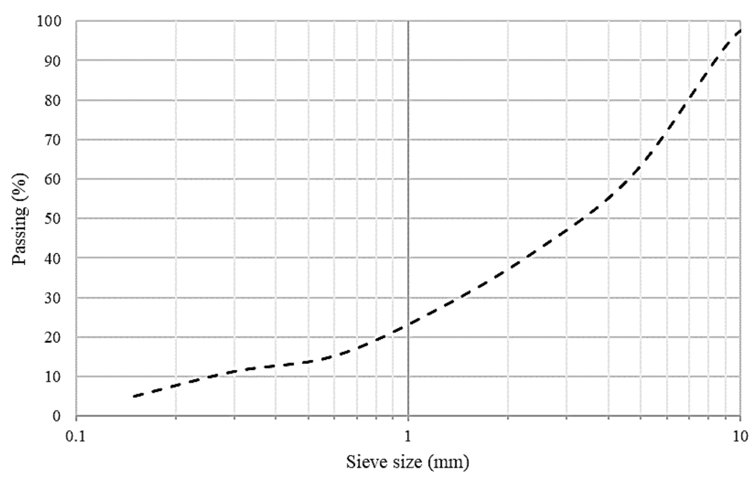


Figure 1. Distribution curve illustrating the particle sizes of the combined aggregates.


Figure 2. Natural fibers used in the study: a) Kenaf, b) Jute, and c) Coconut.

Table 1.
Proportions of the composite mixtures.

| Components | Quantity (kg/m3) | | | |
|---|---|---|---|---|
| | PC | KFRC | JFRC | CFRC |
| Cement | 420 | 420 | 420 | 420 |
| Water | 185 | 185 | 185 | 185 |
| Superplasticizer | 5.0 | 5.0 | 5.0 | 5.0 |
| Crushed granite | 700 | 700 | 700 | 700 |
| Coarse river sand | 900 | 900 | 900 | 900 |
| Fiber content | 0.0 | 7.0 | 7.5 | 6.25 |
| Water / cement | 0.44 | 0.44 | 0.44 | 0.44 |
| Dry density | 2296 | 1985 | 1910 | 2103 |

The fibers were subjected to an alkaline treatment by soaking them in a 5% sodium hydroxide (NaOH) solution for one hour. After the treatment, the fibers were air-dried for 24 hours, followed by oven-drying at 85°C for four hours to improve their mechanical properties. Each gram of dry fiber was then processed using a 200 W electric grinder for five seconds to ensure uniform dispersion within the concrete matrix. This process effectively broke down any fiber agglomerates, optimizing their integration into the concrete mix [25- 27].

The concrete mix was prepared using fresh, potable water that was free from organic and acidic contaminants. A superplasticizer (BASF Glenium 313C), with a specific gravity of 1.22 at 25°C, was uniformly added at 8 kg/m³ to all mixtures to enhance the workability of the concrete mix.

To investigate the behavior of NFRC, three distinct mixes were prepared in the laboratory: kenaf fiber-reinforced concrete (KFRC), jute fiber-reinforced concrete (JFRC), and coconut fiber-reinforced concrete (CFRC). Each mix maintained a consistent water-to-binder ratio of 0.44. These fiber-reinforced mixes were compared to a control mix of plain concrete (PC), following the ACI 211.1–91 standard [28] with the goal of achieving a target 28-day compressive strength. The fiber volume fractions for the NFRC mixes were set at 0.5% by volume of concrete. Specimens were labeled based on the type of fiber used in each mix. Cement was used consistently across all four mixtures at a dosage of 420 kg/m³. The quantities of crushed granite and coarse river sand aggregates remained constant in all mixes, at 700 kg/m³ and 900 kg/m³, respectively. The detailed proportions of these composite mixes are detailed in Table 1.

## 3. Methodology

The specimen preparation began with manually blending cement and fine aggregates (coarse river sand) to create a homogeneous mix. Natural fibers were then added to this blend. At the final stage, coarse aggregates (crushed granite), water, and superplasticizer were introduced. Cylindrical specimens with a diameter of 150 mm and a height of 300 mm were cast for compressive and split tensile strength tests, while prismatic RILEM beam specimens (150 mm width, 150 mm depth, and 600 mm length) were cast for flexural strength testing. These specimens were prepared for all mixes, including PC, KFRP, JFRP, and CFRC. All specimens were stored in an environment with a minimum of 80% relative humidity and a temperature of 27 ± 2°C for 24 hours. They were then moved to a steam-curing room with automatic temperature control, set at 20 ± 2°C and 95% relative humidity. After 28 days of curing, a total of 72 specimens (six for each test type and mix) were tested, and the average results were recorded for evaluation.

### *3.1. Compressive Strength Tests*

The uniaxial compressive strength tests were conducted using a 2000 kN Electro-Hydraulic Pressure testing machine controlled by a computer, applying a steady load until failure. Before testing, all compressive specimens were capped with sulfur for uniform load distribution. The compressive tests followed NP EN 12,390–3:2011 [29] and NP EN 12,390–13:2014 [30] standards. The test control used axial displacement as the control variable, measured by an internal displacement transducer within the loading equipment. The experimental setup for the compressive tests is shown in Figure 3-a.

### *3.2. Splitting Tensile Strength Tests*

Cylindrical specimens were horizontally placed between two hard metal strips, following ASTM C496/C496M [31] guidelines (Figure 3-b). The same testing machine used for the compressive tests performed the splitting tests, with a jig ensuring specimen alignment. During testing, transversal deformation perpendicular to the load direction was recorded, providing detailed insights into the concrete's tensile response. The tensile strength was calculated from the first peak of the load-deformation curve, representing the material's elastic limit [32-34].

### *3.3. Flexural Strength Tests*

Prismatic beam specimens were prepared with precise dimensions and a standardized notch to ensure controlled crack propagation. The beams were placed in a three-point bending configuration with the notch aligned under the load application point. The load was applied centrally over a 500 mm span at a controlled rate to ensure consistent data collection. The three-point notched beam bending tests (3PNBBT) followed the fib Model Code 2010 [35] recommendations and were conducted using a 300 kN hydraulic jack under monotonic loading.

The tests aimed to assess residual flexural tensile strength parameters ($f_{R,1}$, $f_{R,2}$, $f_{R,3}$, $f_{R,4}$) at crack mouth opening displacements (CMOD) of 0.5, 1.5, 2.5, and 3.5 mm. The flexural tensile strength ($f_{ct,L}$) was measured at a CMOD of 0.05 mm, which is crucial for understanding post-cracking behavior. Figure 3-c shows the testing setup for the notched beams.

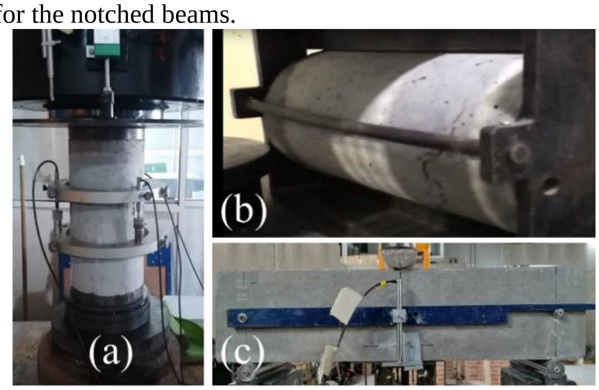


Figure 3. Experimental test setup employed in the study: a) Compressive strength tests, b) Splitting tensile strength tests, c) Flexural strength tests

## 4. Results and Discussion

### *4.1. Compressive Strength*

The compressive strength results at 28 days (Table 2) demonstrate a noticeable reduction in strength with the incorporation of natural fibers. Plain concrete (PC) exhibited the highest compressive strength of 41.21 MPa, serving as the baseline for comparison. Among the fiber-reinforced concrete mixes, CFRC demonstrated the best performance with a compressive strength of 37.42 MPa, followed by KFRC at 33.1 MPa, and JFRC at 30.53 MPa. The reductions in strength compared to PC were 9.17%, 19.67%, and 25.91% for CFRC, KFRC, and JFRC, respectively. These results highlight the fact that the inclusion of natural fibers reduces the compressive strength, likely due to the increased porosity and fiber-matrix interface discontinuities introduced during mixing.

Table 2.
Compressive strength of all mixes at 28 days: PC, KFRC, JFRC, and CFRC.

| Cylinder specimens | Compressive strength | |
|---|---|---|
| | $f'_c$ (MPa) | CoV (%) |
| PC | 41.21 | 2.2 |
| KFRC | 33.1 | 7.2 |
| JFRC | 30.53 | 6.9 |
| CFRC | 37.42 | 4.18 |

Figure 4 further illustrates the stress-strain behavior of all mixes, where it is evident that PC maintained the highest peak compressive stress, while the fiber-reinforced concrete mixes displayed enhanced ductility and post-peak behavior. Coconut fibers, in particular, contributed to CFRC retaining more of its compressive strength due to better bonding with the cement matrix. The lower compressive strengths of KFRC and JFRC can be attributed to the higher water absorption of kenaf and jute fibers, which likely led to the introduction of additional voids within the matrix. These voids act as stress concentrators, contributing to early failure under compressive loads. Overall, while natural fibers reduce compressive strength, they also improve ductility and toughness, which are crucial for applications requiring enhanced crack control and energy absorption.

### *4.2. Splitting Tensile Strength*

The splitting tensile strength results at 28 days (Figure 5) demonstrate that the addition of natural fibers significantly enhanced the tensile capacity of the concrete mixes compared to the PC. Among the mixes, JFRC achieved the highest splitting tensile strength of 4.1 MPa, followed closely by KFRC at 3.9 MPa, and CFRC at 3.7 MPa. PC exhibited the lowest splitting tensile strength of 2.8 MPa, which is consistent with the expectation that natural fibers improve the tensile capacity of concrete due to their ability to bridge cracks and delay crack propagation. However, it is important to note the relatively high coefficient of variation (CoV) observed for the fiber-reinforced mixes, particularly for JFRC and KFRC, which indicates variability in the test results. The CoV reflects the natural variability in fiber properties, such as fiber length, aspect ratio, and dispersion within the matrix, which can

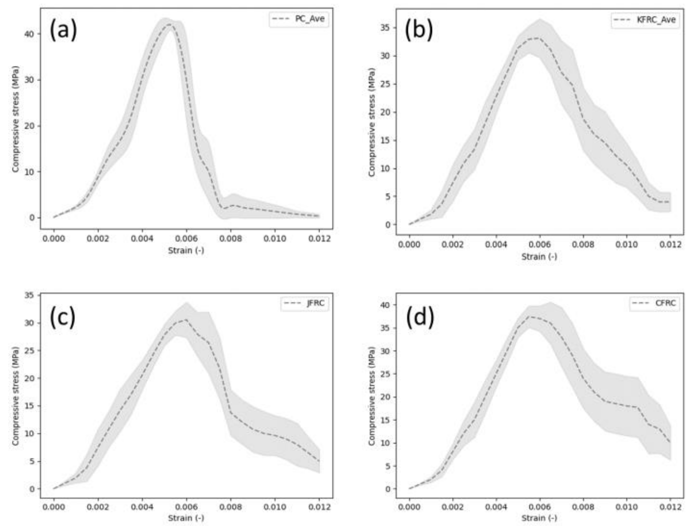


Figure 4. Stress-strain curves for all mixes at 28 days: a) PC, b) KFRC, c) JFRC, d) CFRC.

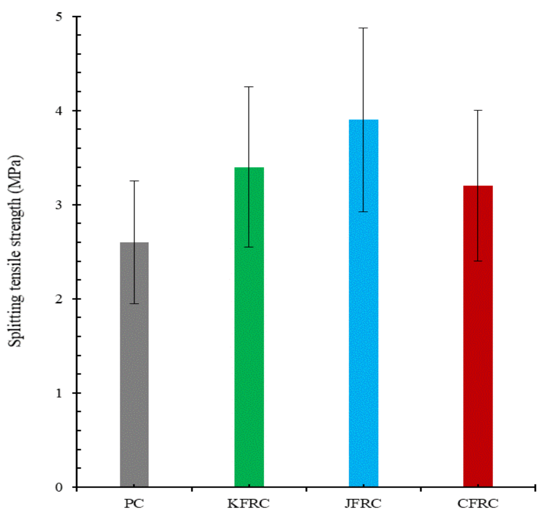


Figure 5. Split tensile strength of all mixes at 28 days: PC, KFRC, JFRC, and CFRC

affect the fiber-matrix bond and ultimately the tensile strength.

The superior performance of JFRC and KFRC can be attributed to the stronger bond between the jute and kenaf fibers and the cement matrix. Jute and kenaf fibers have a high tensile strength and good interaction with the cement matrix, which allows them to absorb and distribute tensile stresses effectively, delaying crack formation. The relatively lower splitting tensile strength of CFRC, although still higher than PC, may be related to the lower aspect ratio and strength of coconut fibers compared to jute and kenaf, leading to less effective crack bridging. Additionally, the variability in tensile strength among the mixes, as indicated by the error bars, suggests that fiber dispersion and the natural variability in fiber properties play a role in the results. Overall, the inclusion of natural fibers significantly enhances the tensile strength of concrete, with jute and kenaf fibers being the most effective.

### *4.3. Flexural Strength*

Figure 6 illustrates the load-CMOD and flexural tensile stress curves for all mixes in the three-point notched RILEM beams at 28 days, while Table 3 provides a detailed comparison of the residual flexural tensile strength parameters for each mix. The results demonstrate that the NFRC mixes exhibited significantly higher residual flexural tensile strengths at various crack mouth opening displacements (CMOD) compared to the PC. Specifically, at CMOD = 0.05 mm, JFRC achieved the highest flexural tensile strength ($f_{ct,L}$ = 5.17 MPa), followed by KFRC (4.57 MPa), and CFRC (4.41 MPa), while PC had the lowest value (4.33 MPa). This trend reflects the enhanced ability of the natural fibers to bridge cracks and distribute stresses, particularly at early stages of crack formation, which is reflected in the higher peak load (FL) for the fiber-reinforced mixes.

As the CMOD increases, the residual tensile strengths ($f_{R,1}$ to $f_{R,4}$) for the NFRC mixes decline, with JFRC consistently maintaining superior performance. At CMOD1 = 0.5 mm, JFRC shows a residual flexural tensile strength of 3.19 MPa, while KFRC and CFRC also exhibit considerable strength, at 2.16 MPa and 2.02 MPa, respectively, compared to PC's negligible value (0.21 MPa). This significant difference indicates the ability of the natural fibers, particularly jute and kenaf, to provide substantial post-cracking load-bearing capacity, mitigating the rapid degradation of structural integrity seen in PC. However, as crack widths increase, the contribution of fibers becomes less pronounced, which is evident in the declining residual strengths across all mixes at CMOD3 = 2.5 mm and CMOD4 = 3.5 mm.

Notably, the CoV values for residual flexural tensile strengths are higher at larger CMOD levels, particularly for KFRC and CFRC. This suggests that these natural fibers may exhibit inconsistent behavior during larger deformations, possibly due to variations in fiber orientation, and dispersion, leading to fluctuating crack-bridging efficacy. JFRC, with consistently lower CoV values, shows more stable performance across all CMOD levels, indicating better fiber-matrix interaction and more uniform fiber dispersion. This consistent performance explains JFRC's superior flexural strength and post-cracking load capacity throughout the entire range of crack development.

## 5. Conclusion

This study successfully evaluated the mechanical properties of natural fiber-reinforced concrete (FRC) incorporating kenaf (KFRC), jute (JFRC), and coconut (CFRC) fibers, highlighting their potential to enhance the sustainability and performance of plain concrete (PC). The research demonstrated that the addition of natural fibers at a volume fraction of 0.5% and a standardized length of 20 mm significantly improved key mechanical properties, including compressive strength, splitting tensile strength, and flexural strength, compared to PC. The results indicated that while the addition of natural fibers reduced compressive strength compared to PC-with compressive strengths of 41.21 MPa for PC, 37.42 MPa for CFRC, 33.1 MPa for KFRC, and 30.53 MPa for JFRC-this reduction was offset by improved ductility and toughness.

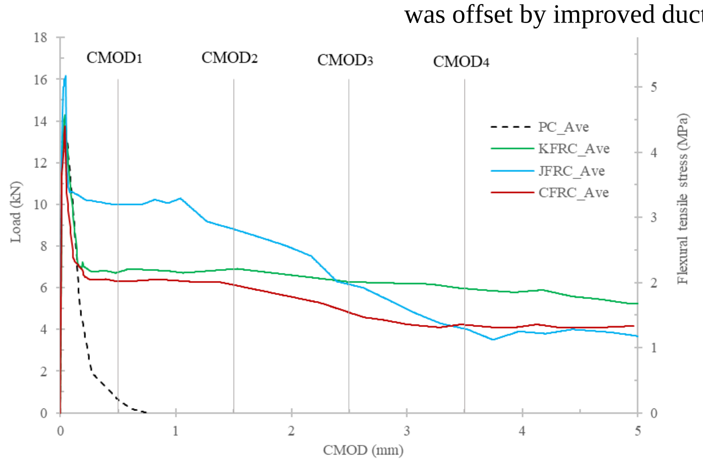


Figure 6. CMOD versus load and flexural stress curves for all mixes in three-point notched RILEM beams at 28 days.

Table 3.
Residual flexural tensile strength parameters for all mixes in three-point notched RILEM beams at 28 days

| Flexural tensile strength parameters | | RILEM Beams | | | |
|---|---|---|---|---|---|
| | | PC | KFRC | JFRC | CFRC |
| CMOD = 0.05 mm | fct,L (Mpa) | 4.33 | 4.57 | 5.17 | 4.41 |
| | FL (kN) | 13.52 | 14.29 | 16.16 | 13.77 |
| | CoV (%) | 6.38 | 5.21 | 3.09 | 7.4 |
| CMOD1 = 0.5 mm | fR,1 (Mpa) | 0.21 | 2.16 | 3.19 | 2.02 |
| | F1 (kN) | 0.65 | 6.74 | 9.98 | 6.31 |
| | CoV (%) | 7.67 | 7.52 | 5.81 | 8.13 |
| CMOD2 = 1.5 mm | fR,2 (Mpa) | - | 2.21 | 2.82 | 1.96 |
| | F2 (kN) | - | 6.89 | 8.81 | 6.13 |
| | CoV (%) | - | 12.62 | 8.79 | 11.99 |
| CMOD3 = 2.5 mm | fR,3 (Mpa) | - | 2.01 | 1.97 | 1.54 |
| | F3 (kN) | - | 6.28 | 6.16 | 4.81 |
| | CoV (%) | - | 27.62 | 20.75 | 30.19 |
| CMOD4 = 3.5 mm | fR,4 (Mpa) | - | 1.91 | 1.29 | 1.35 |
| | F4 (kN) | - | 5.96 | 4.03 | 4.22 |
| | CoV (%) | - | 32.71 | 29.25 | 32.83 |

The inclusion of natural fibers significantly enhanced splitting tensile strength, with JFRC achieving the highest value of 4.1 MPa, followed by KFRC at 3.9 MPa and CFRC at 3.7 MPa, compared to PC's 2.8 MPa. This improvement is attributed to the fibers' ability to bridge cracks and delay propagation. In terms of flexural strength, JFRC consistently outperformed PC, particularly at low crack mouth opening displacements (CMOD), achieving a flexural tensile strength of 5.17 MPa at CMOD = 0.05 mm. The ability of natural fibers to provide significant post-cracking load-bearing capacity demonstrates their effectiveness in enhancing concrete performance. Overall, this research underscores the potential of natural fibers to improve the mechanical properties of concrete while promoting sustainability. Future studies should focus on optimizing fiber combinations and examining long-term durability to validate these findings further.

## References


[1] da Fonseca, Régis Pamponet, Janaíde Cavalcante Rocha, and Malik Cheriaf. "Mechanical properties of mortars reinforced with amazon rainforest natural fibers." Materials 14.1 (2020): 155. https://doi.org/10.3390/ma14010155

[2] Juarez, Cesar, et al. "Performance of "Agave lecheguilla" natural fiber in portland cement composites exposed to severe environment conditions." Building and environment 42.3 (2007): 1151-1157. https://doi.org/10.1016/j.buildenv.2005.12.005

[3] Salati, Maryam, Luis Bragança, and Ricardo Mateus. "Sustainability assessment on an urban scale: context, challenges, and most relevant indicators." Applied System Innovation 5.2 (2022): 41. https://doi.org/10.3390/asi5020041

[4] Salles, Adriana, Maryam Salati, and Luís Bragança. "Analyzing the feasibility of integrating urban sustainability assessment indicators with city information modelling (CIM)." Applied System Innovation 6.2 (2023): 45. https://doi.org/10.3390/asi6020045

[5] Pacheco-Torgal, F., and Said Jalali. "Earth construction: Lessons from the past for future eco-efficient construction." Construction and building materials 29 (2012): 512-519. https://doi.org/10.1016/j.conbuildmat.2011.10.054

[6] Mahboob, Amir, et al. "Experimental investigation of eco-friendly fiber-reinforced concrete using recycled and natural fibers, integrated with recycled aggregates." Advanced Composite Materials (2024): 1-30. https://doi.org/10.1080/09243046.2024.2322799

[7] Abedi, Mohammadmahdi, et al. "Three-dimensional braided composites as innovative smart structural reinforcements." Composite Structures 297 (2022): 115912. https://doi.org/10.1016/j.compstruct.2022.115912

[8] Yousefi, Ali, et al. "Experimental investigation on effect of multi-walled carbon nanotubes concentration on flexural properties and microstructure of cement mortar composite." AIP Conference Proceedings. Vol. 1892. No. 1. AIP Publishing, 2017. https://doi.org/10.1063/1.5005663

[9] Abedi, Mohammadmahdi, et al. "Investigation of Mechanical Behavior of a Sustainable Cementitious Composite Reinforced with Natural Fibre: An Experimental and Numerical Study." Available at SSRN 4247583. https://doi.org/10.1016/j.compstruct.2022.115912

[10] Mahboob, Amir, Omid Hassanshahi, and Ashkan Sarabi Tabrizi. "Three-dimensional simulation of granular materials by discrete element method (DEM) by considering the fracture effect of particles." Journal of Civil Engineering Researchers 5.2 (2023): 14-28. https://doi.org/10.61186/JCER.5.2.14

[11] Mahmud, Sakil, et al. "Comprehensive review on plant fiber-reinforced polymeric biocomposites." Journal of Materials Science 56 (2021): 7231-7264. https://doi.org/10.1007/s10853-021-05774-9

[12] Memon, Muhammad Jaffar, et al. "Production of eco-friendly concrete incorporating rice husk ash and polypropylene fibres." Environmental Science and Pollution Research 28 (2021): 39168-39184. https://doi.org/10.1007/s11356-021-13418-3

[13] Olivito, Renato Sante, O. A. Cevallos, and A. Carrozzini. "Development of durable cementitious composites using sisal and flax fabrics for reinforcement of masonry structures." Materials & Design 57 (2014): 258-268. https://doi.org/10.1016/j.matdes.2013.11.023

[14] Poorsaheli, Hadi Bolooki, Amir Behravan, and Seyed Taha Tabatabaei Aghda. "Durability performance of hybrid reinforced concretes (steel fiber+ polyolefin fiber) in a harsh marine tidal zone of Persian Gulf." Construction and Building Materials 266 (2021): 121176. https://doi.org/10.1016/j.conbuildmat.2020.121176

[15] Kumar, K. Senthil, et al. "Layering pattern effects on vibrational behavior of coconut sheath/banana fiber hybrid composites." Materials & Design 90 (2016): 795-803. https://doi.org/10.1016/j.matdes.2015.11.051

[16] Ahamed, M. Shadheer, P. Ravichandran, and A. R. Krishnaraja. "Natural fibers in concrete–A review." IOP Conference Series: Materials Science and Engineering. Vol. 1055. No. 1. IOP Publishing, 2021.

[17] Sathishkumar, T. P., et al. "Mechanical properties of randomly oriented snake grass fiber with banana and coir fiber-reinforced hybrid composites." Journal of composite materials 47.18 (2013): 2181-2191. https://doi.org/10.1177/0021998312454903

[18] Hassanshahi, Omid, et al. "Seismic performance of the typical RC beam–column joint subjected to repeated earthquakes." AIP Conference Proceedings. Vol. 1892. No. 1. AIP Publishing, 2017. https://doi.org/10.1063/1.5005755

[19] Callister Jr, William D., and David G. Rethwisch. Materials science and engineering: an introduction. John wiley & sons, 2007.

[20] Cevallos, O. A., and Renato Sante Olivito. "Effects of fabric parameters on the tensile behaviour of sustainable cementitious composites." Composites Part B: Engineering 69 (2015): 256-266. https://doi.org/10.1016/j.compositesb.2014.10.004

[21] Haseena, A. P., et al. "Mechanical properties of sisal/coir hybrid fibre reinforced natural rubber." Progress in Rubber Plastics and Recycling Technology 21.3 (2005): 155-181. https://doi.org/10.1177/147776060502100301

[22] Izquierdo, Indara Soto, et al. "Sisal fiber reinforced hollow concrete blocks for structural applications: Testing and modeling." Construction and Building Materials 151 (2017): 98-112. https://doi.org/10.1016/j.conbuildmat.2017.06.072

[23] C. Astm, 'Standard test method for sieve analysis of fine and coarse aggregates', ASTM C136-06, (2006).

[24] Oh, Chai Lian, et al. "Shape change analysis of tensegrity models." Latin American Journal of Solids and Structures 16 (2019): e221. https://doi.org/10.1016/j.compstruct.2022.115912

[25] Abedi, Mohammadmahdi, et al. "A sustainable cementitious composite reinforced with natural fibers: An experimental and numerical study." Construction and Building Materials 378 (2023): 131093. https://doi.org/10.1016/j.conbuildmat.2023.131093

[26] Abedi, Mohammadmahdi, et al. "A self-sensing and self-heating planar braided composite for smart civil infrastructures reinforcement." Construction and Building Materials 387 (2023): 131617. https://doi.org/10.1016/j.conbuildmat.2023.131617

[27] Mahboob, Amir, et al. "Evaluating the performance of hollow core slabs (HCS)-concrete and simplifying their implementation." Recent Progress in Materials 5.2 (2023): 1-15. http://dx.doi.org/10.21926/rpm.2302016

[28] D. E. Dixon et al., 'Standard practice for selecting proportions for normal, heavyweight, and mass concrete (ACI 211.1-91)', Farmington Hills: ACI, 1991

[29] Standard B. Testing hardened concrete. Compressive Strength Of Test Specimens, BS EN.2009;12390–12393.
[30] CEN (European Committee for Standardization). "Testing hardened concrete—Part 13: Determination of secant modulus of elasticity in compression." (2013).
[31] ASTM International Committee C09 on Concrete and Concrete Aggregates. Standard test method for splitting tensile strength of cylindrical concrete specimens1. ASTM international, 2017.
[32] Denneman, Erik, Elsabe P. Kearsley, and Alex T. Visser. "Splitting tensile test for fibre reinforced concrete." Materials and structures 44 (2011): 1441-1449. https://doi.org/10.1617/s11527-011-9709-x
[33] Standard A. Standard test method for slump of hydraulic-cement concrete. ASTM Annual Book of ASTM Standards; 2015.
[34] Peen, Woo Yian, Choong Kok Keong, and Omid Hassanshahi. "Behaviour of hollow circular section with multiple perforations under compression, flexure and torsion." Latin American Journal of Solids and Structures 16.02 (2019): e169. https://doi.org/10.1016/j.compstruct.2022.115912
[35] Taerwe L, Matthys S. Fib model code for concrete structures 2010. Berlin, Germany: Ernst & Sohn, Wiley; (2013).