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EXPERIMENTAL INVESTIGATIONS ON FIBER REINFORCED CONCRETE WITH COCONUT FIBERS

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Abstract: The challenge of replacing fibre made from synthetic materials with natural, ecologically benign, and inexpensively manufactured renewable resources and agricultural waste must be resolved, claims the sustainable development idea. The main substance for which fibres are intended is concrete. Therefore, it is crucial and important to employ vegetable waste in concrete. This issue has drawn attention to coconut fibre, a by-product of the production of coconuts, making it pertinent. In this study, the experimental basis for the strength characteristics of dispersed fiber-reinforced concrete using coconut fibres is examined, as well as the impact of the fibre % on the mechanical, physical, and deformation properties. Concrete was used to create the samples, and its compressive strength ranged from 40 to 50 MPa after 28 days. We looked at the primary mechanical properties of the material, such as its strength in compression (cubic and prismatic) and tension (axial and bending), as well as its compressive and tensile stresses. The range for the proportion of reinforcement using coconut fibres was 0% to 2.5%, with 0.25 wt% increments. Testing was done 28 days following the product's production. The electron microscopy approach was used to examine the microstructure of the final compositions. The fraction of coconut fibres that made the most sense was 1.75%. For compression and axial compression, the rise in mechanical indicators was 24% and 26%, respectively, and for tensile bending and axial compression, it was 42% and 43%.

Keywords: concrete; fiber-reinforced concrete; sustainable concrete; natural fibers; coconut fiber.

INTRODUCTION

The international economy is now increasing quickly, but at the same time, current construction poses a number of challenges for engineers and scientists to address. The environmental degradation that the globe experiences as a result of the construction process and construction industry is one of these issues. The low tensile strength in comparison to its

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great compressive strength is one of the characteristics of concrete as well as one of its key drawbacks. Building constructions are equipped with bar reinforcement to make up for this deficiency. This reinforcement senses the primary tensile stresses and keeps the reinforced concrete structure from collapsing. However, the microstructure of the concrete matrix, in which many microcracks are generated already at the stage of hardening and shrinkage and which unavoidably start to grow during load application, is not substantially influenced by bar reinforcing. The strength characteristics (SC) of concrete as a material are greatly improved by restricting the growth of microcracks [1,2].

The basic ingredients for these fibres are acquired by the mechanical processing, washing, and drying of plant components. The use of plant fibres as an FDRC is one method to achieve largely trash-free agricultural operations, which is consistent with the idea of sustainable development [15–24]. Plant fibres are frequently a by-product or waste of agriculture. The benefits of such fibres for dispersed fibre reinforcement of concrete include high tensile strength that satisfies the standards of contemporary construction, low cost, no requirement for energy-intensive production with high CO2 emissions into the atmosphere, renewable nature, minimal waste production, and a comparatively safe environment for people and animals. Several experiments [18,22] were conducted, and it was discovered that adding different plant fibres to concrete enhanced its strength and deformation characteristics, making the destruction "smooth" rather than brittle like conventional concrete. When the amount of plant fibres added to concrete was up to 2% vol., it was discovered that the SC grew directly in proportion to the amount of fibre reinforcement, and that when this value was surpassed, an inverse connection was seen [18,22].

In this context, coconut fiber—a byproduct of the production of coconuts—has received particular interest. Figure 1 depicts the coconut palm fruit's structure.

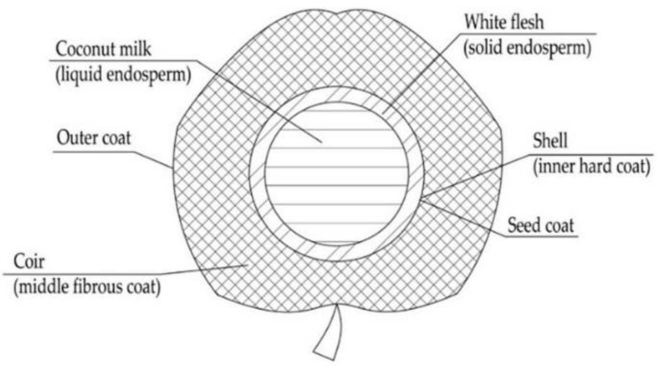

Figure 1. Schematic of the fruit of the coconut palm.

The study took into account the effects of coconut fibre length and concrete material % on high-strength concrete qualities. In comparison to a comparable composition lacking coconut fibres, high-strength concrete performed better in terms of flexural strength, compression and tension strength, and deformability. The ideal length of coconut fibres and the proportion of fibre reinforcement for high-strength concretes have been determined to be 50 mm and 1.5% by weight of cement, respectively. The potential for recycling industrial and agricultural wastes as additives in bitumen and asphalt concrete were investigated. The elasticity modulus of asphalt concrete was raised and the mechanical characteristics of additives in the form of coconut and sisal fibres were significantly improved. The study adds to the body of

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knowledge about the effective use of waste and coir-type natural fibres in building. The mortar's flexural strength and durability were improved with the addition of 1%, 1.5, and 1.5% coconut fibre as well as 1.5% mineral wool. A high fibre dosage can negatively affect compressive strength, which can also change the microstructure, increase pore volume, or cause non-significant increases or decreases in bulk density, according to research in the field of fiber-reinforced concrete with experiments, numerical modelling, and microstructure study.

The following drawbacks of using coconut fibres in concrete can generally be identified based on the reviewed literature and susceptibility to shrinkage during drying or volume changes due to alternating wetting and drying of concrete, deterioration in the workability of concretes of normal strength, a decrease in density, and an increase in water absorption. The following are some benefits of employing coir: raising the normal strength of concrete at a fibre dosage of 0.5-1.5% and a length of 50 mm; boosting tensile and bending strength at a dosage of up to 2%; and enhancing the impact strength of concrete. Additionally, adding coconut chips to concrete improves its permeability, carbonization, and permeability to chloride.

The following are the scientific uniqueness goals of this study: First, a sensible amount of fibrous coconut fibre was chosen as a component of a novel material—FRC with enhanced properties. The parameters of the technological procedures for adding and combining the components of mixes of fiber-reinforced concrete for enhanced concretes were first established. The essential mechanisms of its production, both regulated and uncontrolled, happening during physical and chemical interactions, were first made clear during the microstructure examination.

The efficient collaboration of cement matrix and coconut fibre as a composite system with better structure and qualities for building elements was first shown. This article's major objective was to conduct experimental study on the strength characteristics of FRC reinforced with coconut fibres as well as the effects of fibre reinforcement fraction on the SC and deformation properties of concrete. The major goal was to find materials that had better SC, were more affordable, safer for people and animals to use, and were also better for the environment. New dependencies for FRC with coconut fibres were discovered as a consequence of the scientific study. The investigation was done, and the explanation for the microscale processes at phase boundaries was provided.

2. Materials and Methods

2.1. Materials

A careful selection of the beginning components was made in order to maintain the integrity of the experimental investigation. Portland cement grade CEM I 42.5N (CEM 42.5N - Portland cement type CEM I, strength class 42.5, normally hardening was used as a binder in the production of samples with the main physical and mechanical characteristics listed below (without additives), in order to determine the effect of the addition of coconut fibres most accurately: 335 m2/kg, a grinding fineness of 25% (passed through filter No. 008), a setting time of 165 minutes, a setting time of 230 minutes, a tensile strength in bending at 28 days, 7.6 MPa, and a compressive strength at 28 days, 55.7 MPa.

The bulk density of the applied quartz sand was 1478 kg/m3, the actual density was 2675 kg/m3, the percentage of dust and clay particles was 1.1%, the percentage of clay in the form of lumps was 0.11%, and there were no organic contaminants. The dimensions of coarse aggregate in the form of crushed granite were 5-10 mm, the bulk density was 1487 kg/m3, the actual density was 2650 kg/m3, the crushability was 11.6% wt, and the percentage of lamellar and acicular grains was 9.1%. It was reinforced with fiber-dispersed coconut fibre.

2.2. Methods

Utilising the technological and regulatory framework that include testing and research methodologies was essential while performing scientific study. Concrete from the Russian class B30, which corresponds to SC between 40 and 50 MPa, was selected as the concrete sample. GOST 10181 "Concrete mixtures. Methods of testing" was used to establish the workability grade, which was P1 (cone draught 1-4 cm). A metal cone was "filled with a concrete mixture through a funnel in three layers of the same height on a smooth sheet" to test the flowability of concrete. The cone was firmly pressed to the sheet by 25 roddings of the concrete mixture. The surface was then levelled, the loading funnel was removed, and any extra mixture was cut off.

The GOST 27006 "Concrete. Rules for mix proposing" served as the foundation for the computations of the concrete composition parameter. The following stages were followed for choosing the concrete composition. Concrete's initial basic composition, initial extra compositions, and production of experimental batches from the initial and additional compositions are all calculated. Raw materials for concrete are chosen and characterised. Concrete testing to establish standardised quality parameters; processing of the results with the establishment of dependencies reflecting the influence of the parameters of the concrete composition on the standardised quality indicators; designation of the nominal composition of concrete, ensuring the receipt of a concrete mixture and concrete; and (d) designating the nominal composition of concrete.

3. Results and Discussion

3.1. The Influence of Various Percentages of FDRC with Coconut Fibers on the Strength and Strain Characteristics

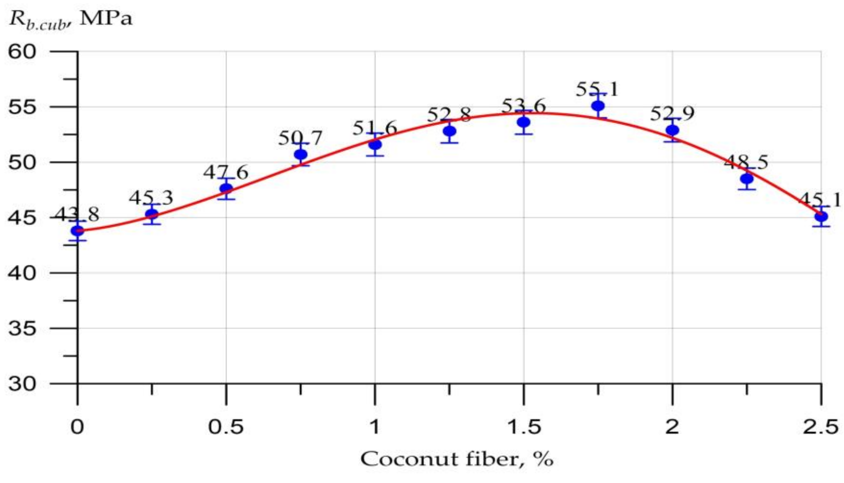

Figure 2 Dependence of the compressive strength ($R_{b.cub}$) of cube concrete samples with a face of 100 mm on the percentage of dispersed reinforcement with coconut fibers.

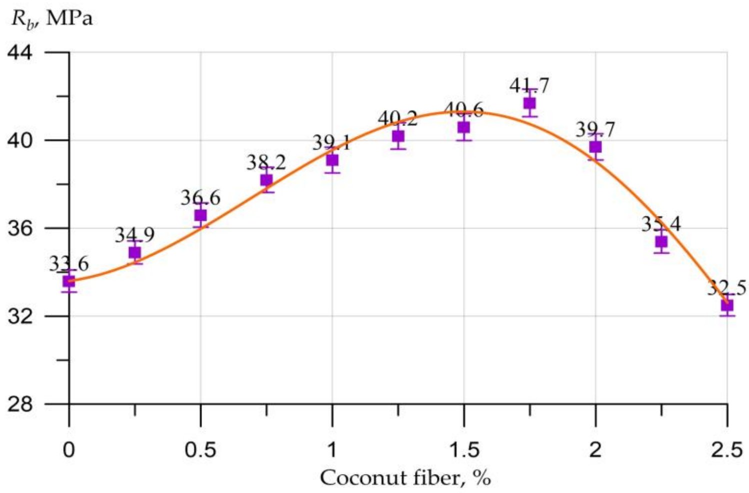

Figure 3. Dependence of the axial compressive strength (R_b) of prism concrete samples with dimensions of 100 × 100 × 400 (mm) on the percentage of coconut fibers.

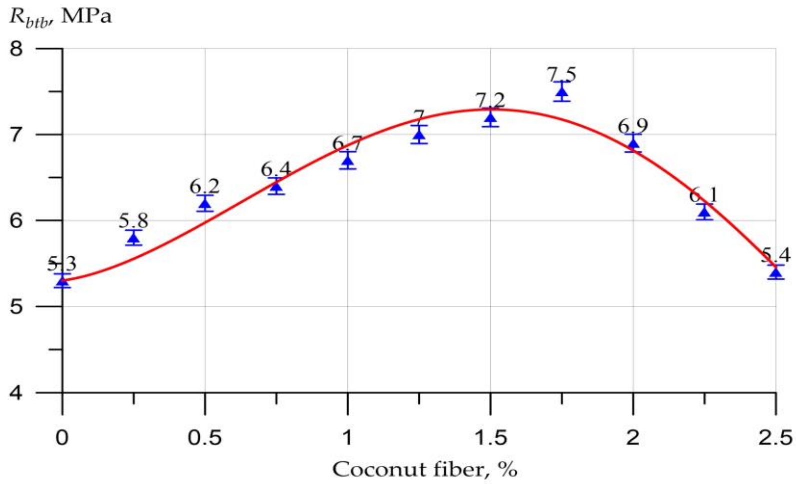

Figure 4. Dependence of tensile strength in bending (R_{btb}) of prism concrete samples with dimensions of 100 × 100 × 400 (mm) on the percentage of coconut fibers.

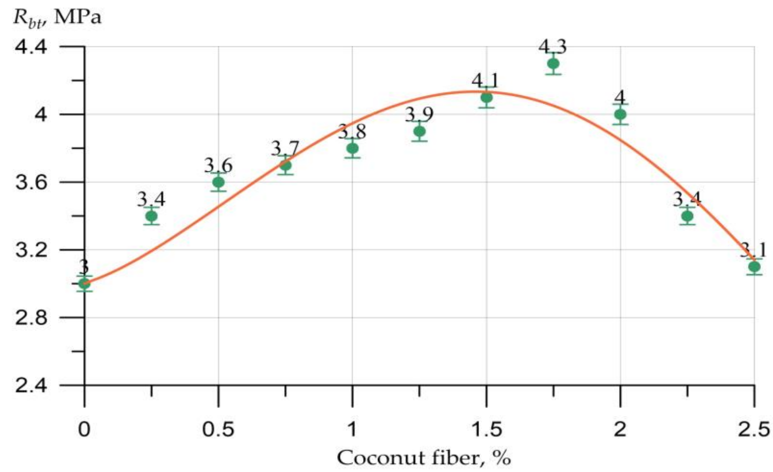

Figure 5. Dependence of the axial tensile strength (R_{bt}) of prism concrete samples with dimensions of 100 × 100 × 400 (mm) on the percentage of dispersed reinforcement with coconut fibers.

In the range of 1% to 1.5%, Figure 2 demonstrates a progressive rise in compressive strength from 43.8 MPa to 51.6 MPa at a dose of coconut fibres. The increase in compressive strength was already less pronounced, going from 51.5 MPa to 53.6 MPa. The greatest value of compressive strength, which is equal to 55.1 MPa, was recorded at a dosage of coconut fibres of 1.75 percent by weight of cement. However, the strength started to decline up to a value almost comparable to the strength of the control composition (without fibres) with a further rise in the amount of fibres from 2% to 2.5%.

At doses of 2% to 2.5%, axial compressive strength was similar to compressive strength declines. Figure 8 illustrates the most intense rise in axial compressive strength at a dosage of coconut fibres from 0% to 0.75%, followed by a somewhat less intense increase that peaks at about 1.75%. The maximum values, like in the case of axial compression, were fixed at a dosage of coconut fibres of 1.75 percent by weight of cement, as shown in Figures 9 and 10. These curves for flexible strength and axial tensile strength were identical. Above figures display the findings of a study on the effects of scattered coconut fibres on the features of concrete strain.

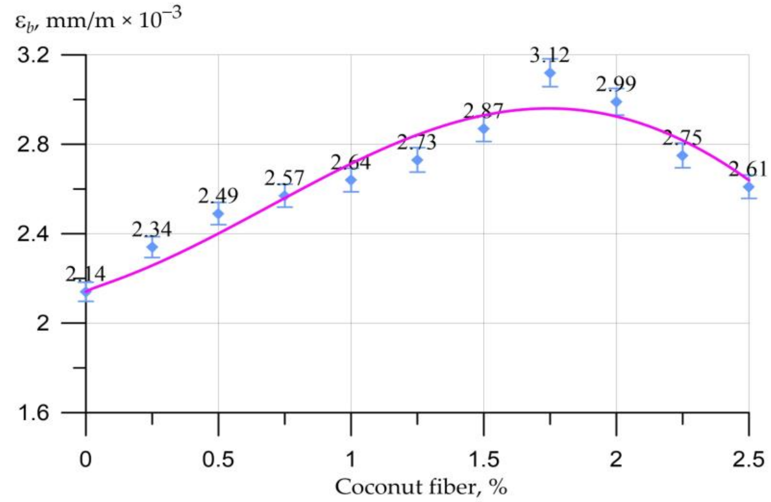

Figure 6. Dependence of the limiting deformations in axial compression (ε_b) of prism concrete samples with dimensions of 100 × 100 × 400 (mm) on the percentage of dispersed reinforcement with coconut fibers.

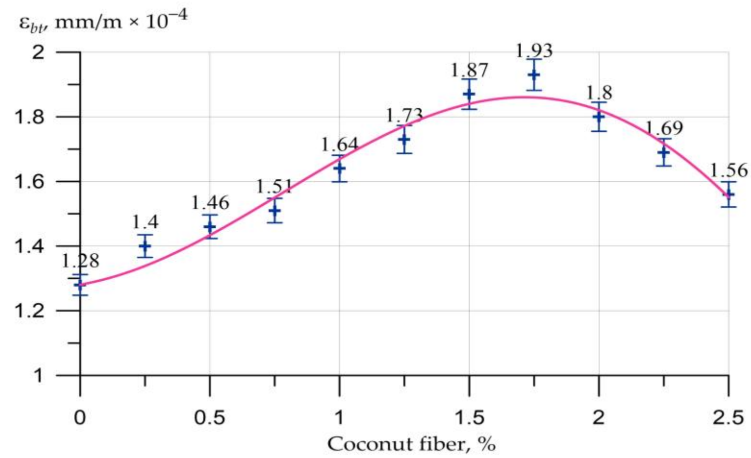

Figure 7. Dependence of the limiting deformations in axial tension (ε_{bt}) of prism concrete samples with dimensions of 100 × 100 × 400 (mm) on the percentage of dispersed reinforcement with coconut fibers.

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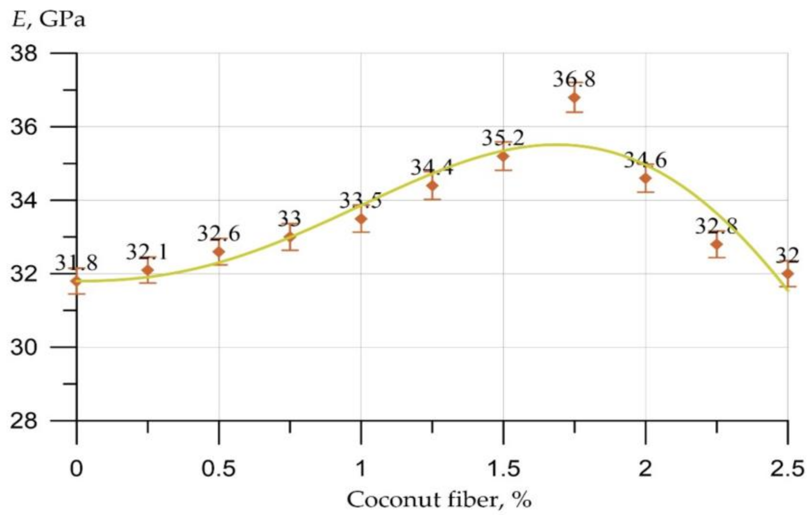


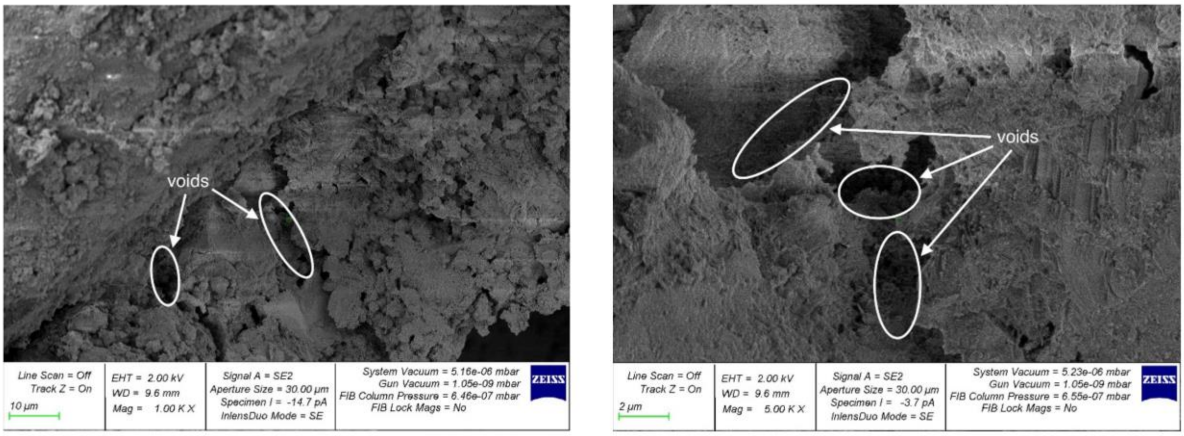
Figure 8. Dependence of the modulus of elasticity of concrete samples (*E*) on the percentage of dispersed reinforcement with coconut fibers.

The results were compared with those obtained on the control composition, which had a significant impact on the concrete SC, not only of the fibre reinforcement itself with coconut fibres, but also of its quantity in relation to the mass of cement. During the analysis of the concrete mechanical characteristics, dispersed reinforcement with coconut fibre constructed several dependencies on the impact of the amount of FDRC on its strength properties. It was discovered that, up to a fibre level of 1.75 percent, an increase in the SC of concrete was seen along with a larger percentage of fibre reinforcement. In order to achieve a greater density, it was found that distributed reinforcement using coconut fibres in an amount of 1.75 percent by weight of the binder was effective. Above Figures depict the "stress-strain" curves in compression "b-b" and in tension "bt-bt," which were created using the outcomes of evaluating the strength and deformation properties of the test concrete. The stress-strain curves of concrete that were produced by dispersing reinforcement with coconut fibres showed how the deformability was greatly impacted. The peak of the curve of concrete deformation with the amount of fibre 2.5% wt. almost coincides with the peak diagrams of concrete with the amount of fibre 0.25% and 0.5%, or slightly below and to the right. The maximum of the "stress-strain" curves of FDRC in the amount of 1.75% wt. of cement is above and to the right in the diagrams of concrete with other considered dosages of coconut fibre.

3.2. Study of the Microstructure of Hardened Cement Paste, Dispersion-Reinforced with

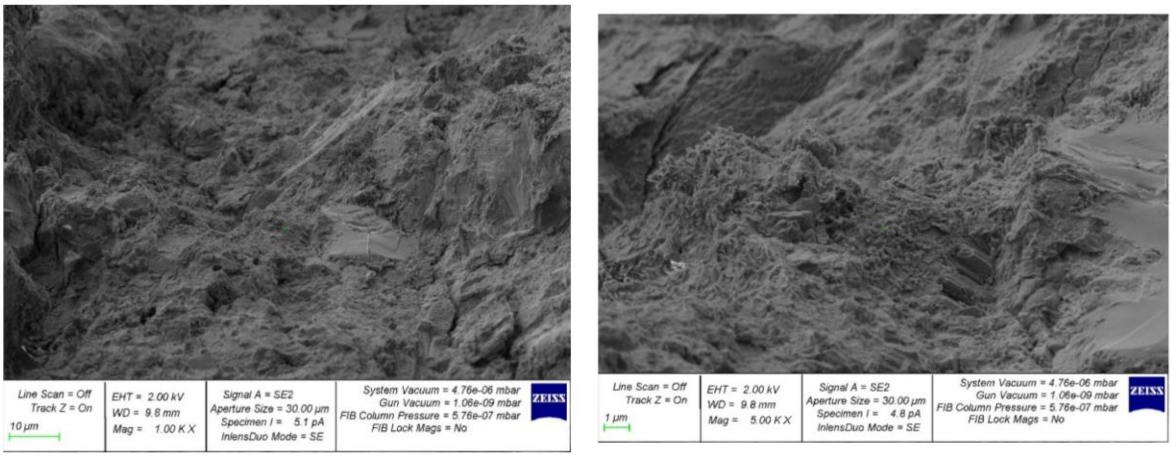
Coconut Fibers

In order to determine the connection between the concrete structure and its SC, microstructural alterations in cement paste that was dispersion-reinforced with coconut fibres were examined. The hardened cement paste of the control composition and with coconut fibres in quantities of 1.75% wt. and 2% wt. are shown in microstructure pictures in Figures 9 to 11.



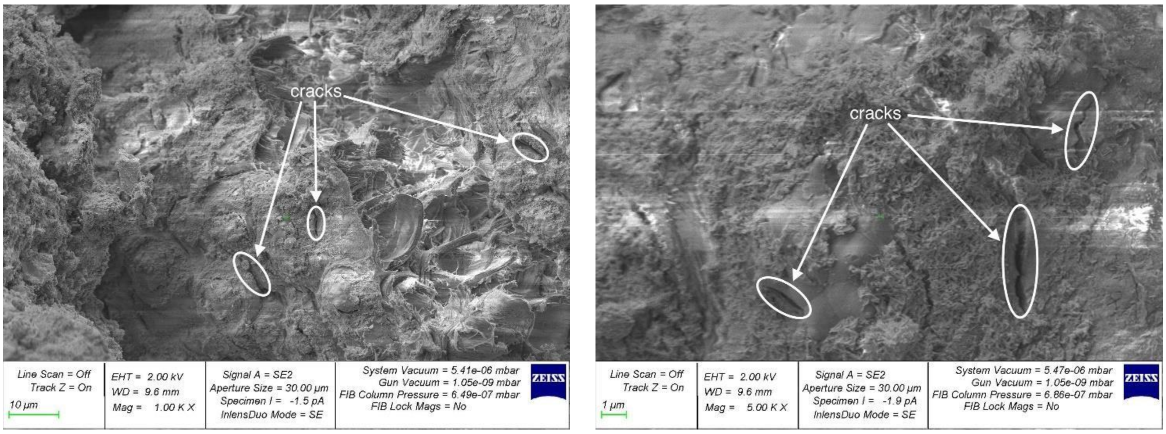
(a) (b)

Figure 9. Photographs of the microstructure of a sample of the hardened cement paste of the control composition: (**a**) 1000×; (**b**) 5000×.



(a) (b)

Figure 10. Photographs of the microstructure of a sample of hardened cement paste with dispersed reinforcement with coconut fibers in an amount of 1.75% by weight of cement: (**a**) 1000×; (**b**) 5000×.



(a) (b)

Figure 11. Photographs of the microstructure of a sample of hardened cement paste with dispersed reinforcement with coconut fibers in an amount of 2%: (a) 1000×; (b) 5000×

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As a result, it was determined that, at the micro level, the proper quality of the structure was maintained, the degree of cracking at the interface was low, and the fibres were well compatible with cement paste and other concrete components. Studies on the microstructure of concrete further supported the efficiency of fiber-dispersed reinforcing.

A logical concentration of crystallisation centres occurred across the whole volume of the composite under the condition of uniform distribution of coconut fibres in the mixture, taking into account the creation of the concrete structure at the micro and macro levels. Coconut fibres' favourable chemical compatibility with hydration products and their substantial mechanical anchoring.

We obtained high SC values for concrete reinforced with coconut fibres when compared to the findings of other authors. Due to the FDRC with coconut fibres, the authors of [5] were able to raise the axial tensile strength of concrete by up to 30.63%. Our technological and composition suggestions resulted in a 43% improvement in the axial tensile strength of concrete. By using coconut fibres and recycled filler that ranged in percentage from 16% to 45%, the authors of were able to boost the tensile strength in bending by up to 45%. In our investigation, concrete's tensile strength in bending might be increased by as much as 42% by utilising simply coconut fibres, which roughly matched the gain attained. The increase in compressive strength up to 26% was more than the increases made in, which were 12%. The current study's effective dose of coconut fibres was in good accordance with the work that systematised several previous research. In addition to concrete's compressive strength, it was also able to maximise its tensile strength at the same time. Coconut fibre was utilised in a study to increase the compressive strength, flexural strength, and splitting tensile strength of foam concrete. Results of the tests revealed that the strengths of all three varieties of foam concrete under study rose as the volume percentage of coconut coir fibres in the concrete mixture went from 0% to 0.4%, with the highest performance being seen at a volume percentage of 0.4%.

Thus, this comparison analysis also attests to the study's efficacy, We figured out all the dependencies on the FRC mixture's components from an analytics perspective. Aspects of the topic were considered from the perspectives of chemistry, physics, and mathematics. As a result, the research project discussed in this article is a study designed to acquire new basics while also developing already held beliefs about FRC, dispersed-reinforced with coconut fibres. With all of this, the research enables us to resolve a serious challenge, not only for the building industry but also for the agricultural sector, which has a direct stake in the disposal of production waste, which establishes the work's practical relevance.

4. Conclusions

The main achievements of the study are as follows.

1. It was found that 1.75 percent of coconut fibres should be used to strengthen concrete.
2. An increase in the concrete's SC was used to express the improved characteristics brought about by the distributed reinforcing using coconut fibres. The compression strength, axial compressive strength, tensile strength in bending, and axial tensile strength of the resulting FRC samples all increased by 26%, 24%, 42%, and 43%, respectively.

3. The increase in strain characteristics was 46% for axial compression deformation, 51% for axial tension deformation, and 16% for elastic modulus.
4. The densest microstructure, virtually free of structural flaws like voids and fractures, was found in samples of cured cement paste that had 1.75% fibre reinforcement. Due to their high water-absorption, cracking was seen at the phase boundaries at a dose of 2% coconut fibre, which decreased the fiber's ability to bind to concrete.
5. With a general rise in its SC compared to regular concrete, it was highlighted that the proposed recipe process and the material produced had a considerable benefit for the economics and ecological.
6. Future research is advised to investigate the impact of coir fibre and other industrial and agricultural waste on the physical characteristics of composites as well as the impact of coconut fibre on the long-term strength of concrete.
7. The finished product should be utilised to build single-family homes and cottages. Because of the great mechanical properties of concrete, it is possible to make accurate forecasts about how long such structures will last.

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