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Tensile Strength Performance of a Sustainable Concrete Produced Using Coconut Fibre

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Abstract:- This research investigates the structural performance of micro-reinforced concrete utilizing coconut fiber as an eco-friendly reinforcement material. The objective was to understand how varying percentages of coconut fiber impact the workability, tensile strength, and compressive strength of concrete. The study involved a series of tests, including sieve analysis, slump tests, tensile strength tests, and compressive strength tests, to evaluate the mechanical properties of the fiber-reinforced concrete.The findings revealed that the addition of coconut fiber reduced workability, as shown by the slump test results. The control mix (0% fiber) recorded a slump value of 130 mm, while the mix containing 1.5% fiber had a significantly lower slump value of 20 mm. Tensile strength improved notably with the inclusion of fibers, with the 1.5% fiber mix achieving a peak tensile strength of 4.0 MPa at 28 days of curing. In contrast, compressive strength decreased as fiber content increased; the control mix had the highest compressive strength of 19.0 N/mm² at 28 days, while the 1.5% fiber mix recorded a lower value of 8.45 N/mm², primarily due to increased voids and fiber clumping.Despite the reduction in compressive strength, coconut fiber demonstrated potential as a sustainable reinforcement material, particularly for applications prioritizing tensile strength. The study suggests optimizing mix design to balance workability and performance, employing fiber treatment techniques to enhance bonding, and conducting further research on long-term durability.

Keywords:- *Coconut Fiber, Sustainable Concrete, Tensile Strength, Compressive Strength, Fiber-Reinforced Concrete.*

I. INTRODUCTION

Landfill dumping, open burning, and open dumping are common methods used in underdeveloped nations to dispose of solid waste. The devastation of aquatic and plant life, air pollution, greenhouse gas emissions, and other major environmental effects of these operations have an effect on human health and quality of life (Onanuga and Odunsi, 2018). A lot of work has gone into recycling different kinds of solid waste so that they can be used to make different kinds of building materials and help the environment (Ogunjiofor, et al, 2023a), (Ogunjiofor, et al, 2023b) . Because of our overreliance on natural resources, traditional construction material manufacturing techniques deplete them. Construction materials are scarce and expensive as a result, and there is an ecological imbalance (Zavadskas et al., 2018).

Since the production of concrete raises global carbon emissions, which fuel global warming, the increasing use of concrete in buildings is regrettably presenting a significant issue (Cazacliu and Ventura, 2010; Şanal, 2018). According to Favier et al. (2018), every tonne of cement generates 600–900 kg of CO_2 due to the grinding, processing, energy use, and conversion of calcium carbonate to calcium oxide. The production of cement is therefore responsible for 5–8% of global anthropogenic carbon dioxide emissions (Andrew, 2019; Friedlingstein et al., 2019).

Despite continuous improvements in cement mill processing methods, calcination carbon emissions cannot be prevented until the whole clinker concentration which is normally burnt at temperatures as high as 1450 °C—is reduced (Kartini, 2011). Therefore, it's imperative to find a cement substitute to guarantee sustainability. Concrete made from solid, industrial, and agricultural wastes can help make

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the construction industry more environmentally friendly, especially in light of the current standards for sustainable infrastructure development and green building assessment systems (Ogunjiofor, et al, 2023c; Obi, et al, 2023). Therefore, finding recyclable waste that can be used to make concrete and other civil engineering materials will also be a crucial part of the green economy for sustainable industrial development (Dachowski and Kostrzewa, 2016; Karim et al., 2011; Sfakianaki, 2015).

Man-made fibres are composed of synthetic and regenerated fibres, while natural fibres are composed of plant and animal fibres (Feng et al., 2011). Coconut, cane, sisal, henequen, and bamboo fibres are currently the most common plant fibre-reinforced materials that can be utilised to create building materials (Dawood and Ramli, 2011; Hamid et al., 2011). Because they are widely accessible and reasonably priced, natural fibres are frequently used. Additionally, their composites are said to offer environmental advantages such as reduced dependency on non-renewable energy and resources, reduced emissions of greenhouse gases and pollutants, component biodegradability, and enhanced energy recovery (Joshi et al., 2004; Majeed et al., 2011).

Concrete made of Portland cement (PCC) is thought to be fragile. Because non-reinforced concrete is weak under tension, it will break and fail when exposed to tensile forces. Standard steel bar reinforcing and, to a lesser extent, the addition of a suitable quantity of specific fibres can help solve the tension weakness. Uniformly distributed and randomly orientated discontinuous fibres are a feature of fibre-reinforced concrete (FRC) (Ali et al., 2017). Millions of small fibres are randomly distributed throughout the concrete during the FRC mixing process, improving the concrete's qualities in every direction (Aydın, 2013; Kumar and Sridhar, 2019). Fibres help eliminate temperature and shrinkage fractures and increase post-peak ductility performance, impact strength, fatigue strength, and pre-crack tensile strength (Gupta et al., 2018; Sekar and Kandasamy, 2015).

In tropical regions of the world, especially in Africa, Asia, and America, coconut fibre is a common agricultural waste product made from the outer shell of a coconut (husk) (Ali et al., 2016). Coconut fibre is commonly thrown away as agricultural waste and is rarely utilised in the construction industry. The colloquial term for coconut fibre is coir, the scientific name is Cocosnucifera, and the plant family is Arecaceae (Palm) (Prakash et al., 2019; Sekar and Kandasamy, 2019).

There are two types of coconut fibre: brown fibre, which comes from mature coconuts, and white fibre, which comes from immature coconuts. According to Kore and Vyas (2021), brown fibres are robust, thick, and resistant to abrasion, while white fibres are fine and silky but weaker. Coconut fibre comes in three easily accessible varieties: decorticated (mixed fibres), bristle (long fibres), and mattress (relatively short fibres). The fibres are made up of individual cells that are around 1 mm long and 5–8 µm in diameter.

The fibres made by the extraction techniques differ in size, though. According to Kavitha and Selvaraj (2015), coconut fibre is composed of fibres that are between 10 and 30 cm long. Selecting the right type of fibre depends on its characteristics, including its specific gravity, diameter, Young's modulus, tensile strength, and the degree to which it affects the cement matrix's characteristics (Sekar and Kandasamy, 2018). Engineering applications frequently use brown fibres (Nor et al., 2010).

II. LITERATURE REVIEW

A. Zuraid et al. (2011) assessed how fibre length affects the mechanical and physical properties of albumin cement composites enhanced with coconut fibre. Coconut fibres of lengths 2.5 mm, 5 mm, 10 mm, and 20 mm were used to partially replace the cement mixture, with albumin protein added as a binder. Tests conducted included water absorption, apparent density, moisture content, bending strength, and compression strength. The experimental results indicated that bending strength increased with fibre length. However, the addition of longer fibres reduced workability and introduced low-density voids, leading to increased moisture content and water absorption capacity.

Sahaya Ruben et al. (2014) investigated the behaviour of natural fibres in concrete structures, focusing on coconut fibre due to its unique mechanical properties. The coconut fibres were treated with natural latex to mitigate the effects of moisture content before being incorporated into concrete.

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Compressive and tensile strengths were evaluated over 28 days using different fibre lengths (20 mm, 25 mm, and 30 mm) and percentages (0.5%, 0.75%, and 1%). The study concluded that natural fibres, being locally available materials, should be encouraged in civil engineering applications.

Abdul Nazeer et al. (2014) explored the mechanical behaviour of coconut fibres of varying lengths (5 mm, 10 mm, and 15 mm) reinforced with epoxy resin after treating the fibres with a 5% NaOH solution. Samples were prepared according to ASTM D3039 standards and tested using a Universal Testing Machine (UTM). The results showed that NaOH treatment improved tensile properties, ductility, and hardness of the composite. An increase by in fibre length corresponded to increased tensile strength, with 15 mm fibres exhibiting the highest strength.

RajanShikha et al. (2015) conducted a behavioural study on coconut fibre in concrete structures. They found that adding coconut fibre improved several technical properties due to its good adhesion characteristics. The coconut fibres were treated with natural latex to prevent moisture effects in concrete. The addition of coconut fibre enhanced compressive, flexural, and tensile strengths, with optimal fibre contents of 1%, 2%, and 3% by weight of cement. Compressive strength tests on M25 and M30 grade concrete cubes were performed at 7, 14, and 28 days, indicating that coconut fibre concrete is suitable for construction and promotes better waste fibre management.

Jiaxin Chen and NawawiChouw (2015) investigated the flexural performance of coconut fibre-reinforced concrete (FRC) confined with flax fibre-reinforced polymer tubes. Six cylindrical specimens (520 mm in length) were subjected to four-point bending tests. Two types of specimens were considered: single-tube (with an external flax fibre-reinforced polymer tube) and double-tube (with both external and internal flax fibre-reinforced polymer tubes). The results demonstrated that the inner flax fibre-reinforced polymer tube provided additional longitudinal reinforcement, improving flexural stiffness and ultimate load-bearing capacity. The inner tube also prevented slippage between the polymer tubes and the concrete core, delaying the abrupt loss of flexural strength.

Libo Yan et al. (2016) studied the use of coir fibres as reinforcement materials in cementitious composites, comparing untreated and alkali-treated fibres. SEM analysis revealed that alkali-treated coir fibres had clearer and rougher surfaces, enhancing bonding with the cement matrix. The incorporation of coir fibres improved compressive strength compared to plain concrete, with alkali-treated fibres showing significant enhancement. Failure mechanisms included fibre breakage, pull-out, and debonding.

Adewale George Adeniyi et al. (2019) reviewed coir fibre and coir fibre-reinforced polymer composites, examining their properties and potential applications. They found that fibre treatment, particularly alkalization with NaOH, improved matrix interfacial adhesion and mechanical properties. SEM analysis indicated that chemically treated fibres reduced voids caused by fibre pull-out. Treated fibres also exhibited lower water absorption compared to untreated fibres.

K. Kochova et al. (2019) evaluated the mechanical and physical properties of coir fibre cement boards, comparing them with conventional wood-cement boards used for ceiling tiles. The boards were manufactured by mixing fibres with cement paste, moulding, pressing, curing, and drying. The results showed that coir fibre composites possess acceptable mechanical and thermal properties. Pull-out tests indicated better cement-fibre interaction with pre-treated fibres, reducing slippage behaviour.

TidarutJirawattanasomkul (2019) provided an in-depth understanding of the compressive behaviour of concrete confined with low-cost natural fibre-reinforced polymers. Concrete cylinders confined with cotton, jute, and hemp fibres were tested under uniaxial compression. The natural fibre polymers exhibited strong confinement effects, enhancing ductility and compressive strength. Compressive strength increased by up to 42% for jute, 25% for hemp, and 28% for cotton polymers, demonstrating the effectiveness of natural polymers in improving concrete confinement.

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Chinyere OlufemiNwankwo and Anthony Nkem Ede (2020) investigated the flexural strengthening of reinforced concrete beams using kenaffibre-reinforced polymer laminates. Two RC beams (1860 mm × 240 mm × 125 mm) were tested, with one beam strengthened using kenaffibre-reinforced polymer. The strengthened beam showed a 43% reduction in deflection under equivalent loads compared to the control beam at yield load, indicating the effectiveness of natural fibre composites in beam strengthening.

B. Nambiyanna et al. (2021) conducted an experimental investigation on slabs strengthened with natural fibre composites using jute and coir fibres in strip and square configurations under uniformly distributed loads. Moisture absorption and fire flow tests were also performed. The results indicated that coir fibre-reinforced polymer concrete (CFRPC) performed better than jute fibre-reinforced polymer concrete (JFRPC) due to the coarser fibre structure. Reinforced slabs showed increased ultimate and cracking load-carrying capacities, with percentage increases ranging between 15.03% to 37.25% and 6.67% to 33.33%, respectively.

Subramanian S. Vivek and ChandrasekaranPrabalini (2021) examined the effect of untreated and treated coconut fibres in self-compacting concrete (SCC). Fibres underwent soaking, boiling, and chemical treatments. SEM analysis was used to study the microstructure. Boiled fibres exhibited improved mechanical properties compared to control mixes, with increases in compressive strength (23.48%), tensile strength (36.86%), and flexural strength (12.50%). Chemically treated fibres showed even greater enhancements, suggesting that 1% chemically treated coir fibre is optimal for improving mechanical properties.

III. MATERIALS AND METHODOLOGY

A. *Materials*

- *Fine Aggregate*:

River sand from the River Niger beach in Onitsha, Anambra State was used as fine aggregate in this project. The sand was screened to remove large particles and debris.

- *Coarse Aggregate:*

The chips utilised in this investigation came from a nearby store within Uli's Timber Market Road in Anambra State. To make sure the chippings fulfilled the necessary requirements, their size and quality were assessed.

- *Cement*

Dangote cement was utilised for this investigation. In Anambra State, it was purchased from a cement dealer in front of the school, opposite the Catholic Church in Umuoma Uli.

- *Coconut Fibre*:

Coconut husks were used to extract the fibres, which were then cut into 10 mm, 20 mm, and 30 mm lengths after being cleaned of contaminants. Because of their accessibility, affordability, and potential to strengthen concrete's hardness and crack-resistant qualities, these fibres were selected.

- *Portable Water*

Water utilised in the investigation was supplied by Chukwuemeka Odumegwu University's civil engineering laboratory in Uli, Anambra State.The water satisfied the BS EN 1008:2002 portable water criteria. Because it satisfies drinking requirements, it can be used for both the production and curing of concrete.

B. *Methodology*

- *Sieve Analysis*:

A representative aggregate sample was dried and weighed using a precision balance. A stack of sieves, arranged in descending mesh sizes with a pan at the bottom, was prepared. The 3 kg sample was placed in the top sieve and agitated using a sieve shaker or manually. After sieving, the material retained on each sieve was weighed. The sieves were cleaned, and the retained percentages were calculated based on the initial sample weight.

- *Slump Test:*

The slump cone was placed on a clean, level base plate and held firmly. The concrete sample was mixed uniformly and filled in three layers, each compacted by 25 roddings with a tamping rod. Excess concrete was struck off, and the cone was lifted vertically. The slump was measured as the difference between the cone’s height and the highest point of the slumped concrete.

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➢ *Compressive Strength Test*:

Concrete samples were cast in standard molds and cured for 28 days. The cured specimen was placed in the compressive testing machine, and the load was applied gradually until failure. The maximum load before failure was recorded, and compressive strength was calculated by dividing this load by the cross-sectional area of the specimen. The results were compared to the specified strength requirement.

IV. RESULTS AND DISCUSSION

The tests described below were performed on the samples that were indicated.

A. *Particle Size Distribution Test (Sieve Analysis Test)*

Table 1: Sieve Analysis Test Result

Sieve Size	Weight of sieve (kg)	Weight of Sand Retained (%)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Cumulative Percentage Passing (%)
8	0.30	1.85	61	61	39
10	0.30	0	0	61	39
12	0.30	0.15	5.00	66	34
20	0.30	0.5	16.7	82.7	17.3
30	0.30	0.2	6.7	80.4	10.6
40	0.30	0.15	5.00	94.4	5.6
80	0.30	0.05	1.70	96.1	3.9
Pan	0.30	0	0	96.1	3.9

$$Percentage\ \ retained\ \ (\%) = \left(\frac{weight\ \ of\ \ sand}{total\ \ weight\ \ of\ \ sample} \times \frac{100}{1}\right)$$

B. *Slump Test:*

The slump test, as shown in Table 2, evaluated the workability of concrete mixes with varying fiber percentages, assessing their impact on consistency and fluidity for ease of placement and compaction.”

Table 2: Slump Test Result

Percentage Fiber Additive (%)	Water-Cement Ratio	Height ofCone (mm)	Height After Slump (Concrete) (mm)	SlumpValue (mm)
Q%	0.6	300	170	130
0.5%	0.6	300	240	60
1%	0.6	300	260	40
1.5%	0,6	300	280	20

C. Compressive Strength Test

"Compressive strength tests were conducted on concrete samples with varying coconut fiber percentages at curing periods of 7, 14, 21, and 28 days to assess strength development. The results are summarized in Table 3."

Table 3: Compressive Strength Test

Percentage Additive (Coconut Fiber)	**7 Days Compressive Strength (N/mm^2)**	**14 Days Compressive Strength (N/ mm^2)**	**21 Days Compressive Strength (N/ mm^2)**	**28 Days Compressive Strength (N/ mm^2)**
0% (Control Sample)	9.30	11.20	18.95	19.00
0.5%	12.05	11.70	15.40	14.98
1%	8.5	12.95	13,90	13.90
1.5%	3.7	7.25	3.45	8.45

D. Tensile Strength Result

"The tensile strength test assessed the effect of varying coconut fiber percentages on concrete at 7, 14, and 28 days. Table 4 summarizes the results, highlighting the influence of natural fibers on tensile stress resistance."

Table 4: Tensile Strength Test Results

Curing Age	0% fiber (MPa)	0.5% fiber (MPa)	1% fiber (MPa)	1.55 fiber (MPa)
7 day	2.2	2.4	2.5	2.8
14 days	2.6	2.8	2.9	3.2
28 days	2.9	3.5	3.8	4.0

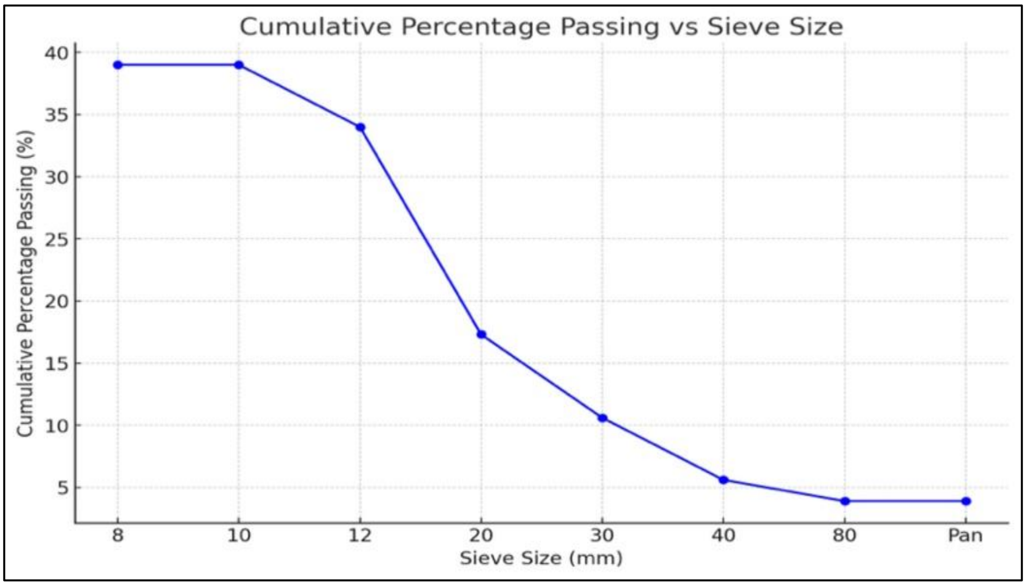

Fig 1: Sieve Analysis Graph

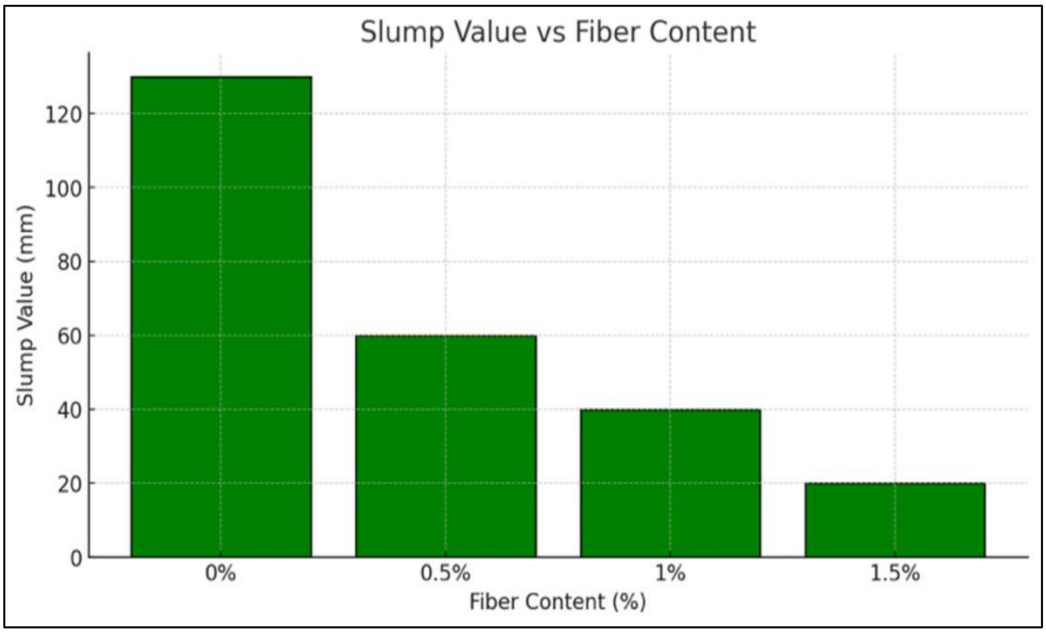

Fig 2: Bar Chart of Slump Value vs. Fiber Content

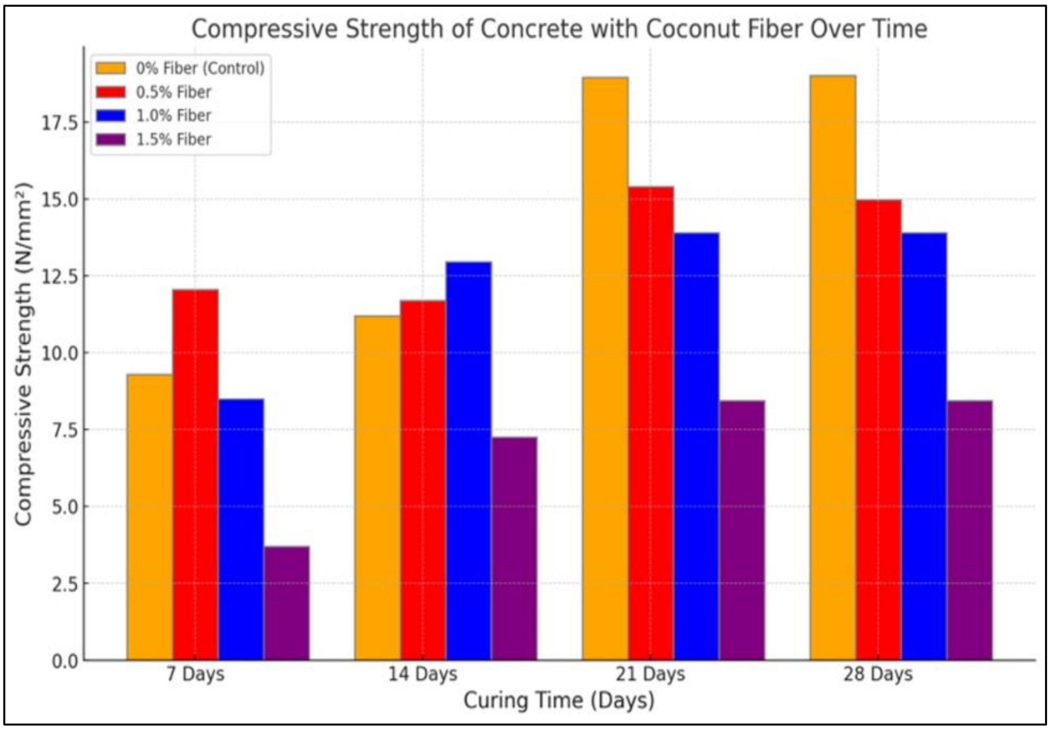

Fig 3: Compressive Strength at Different Curing Times for Varying Coconut Fiber Percentages.

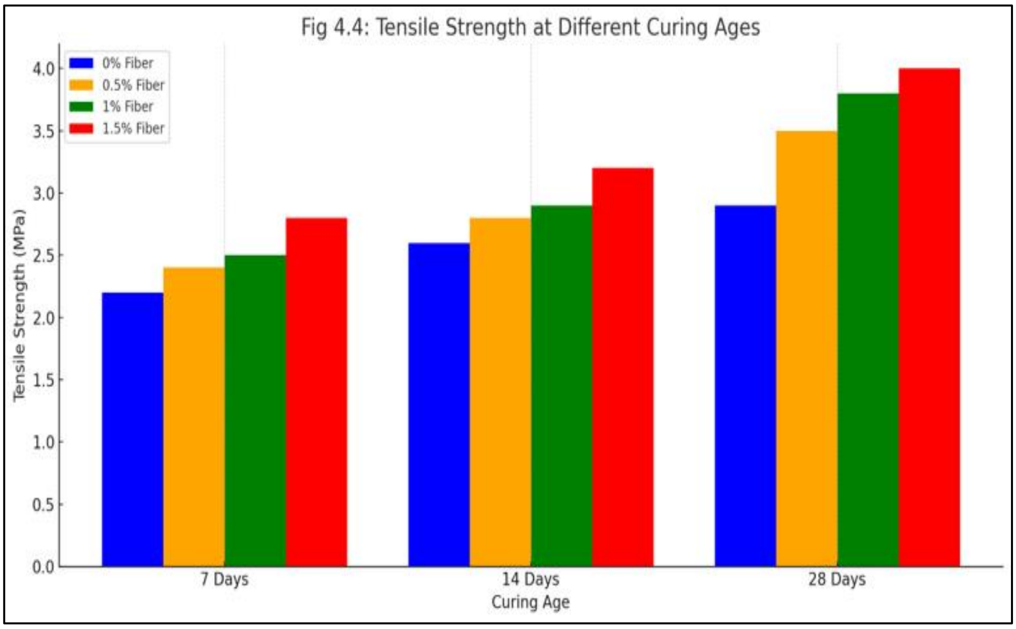

Fig 4 : Tensile Strength at Different Curing Ages.

V. CONCLUSION

This study evaluated micro-reinforced concrete with coconut fiber. The slump test showed reduced workability with increased fiber content. Tensile strength improved with 1.5% fiber, while compressive strength was highest in the control mix. Coconut fiber is a sustainable reinforcement material, but balancing workability and strength is essential for practical applications.

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