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WORKABILITY AND MECHANICAL PERFORMANCE ASSESSMENT OF TIGERNUT FIBRE CONCRETE FOR SUSTAINABLE CONSTRUCTION

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Abstract
In the pursuit of an eco-friendly and sustainable environment, innovative research into the incorporation of natural fibers into construction materials particularly concrete has gained increasing attention. This study investigates the effect of tigernut fiber integration on the mechanical properties of concrete. Concrete mixes were prepared with tigernut fiber added at 0% (control), 1%, 2%, and 3% by weight of cement. A mix ratio of 1:1.5:3 and a water–cement ratio of 0.6 were adopted. Workability and mechanical properties were assessed using the slump test, compressive strength test, flexural strength test, and split tensile strength test. The slump test results indicated true slump values across all fiber additions, demonstrating good workability. The average compressive strengths at 28 days were 24.8 N/mm² (0%), 24.2 N/mm² (1%), 22.66 N/mm² (2%), and 20.1 N/mm² (3%). Corresponding split tensile strengths were 2.5 N/mm², 1.97 N/mm², 2.25 N/mm², and 2.48 N/mm², respectively. These findings suggest that while the compressive strength decreases slightly with increased fiber content, the split tensile strength remains relatively stable, indicating improved crack resistance and ductility. The study concludes that tigernut fiber can enhance the crack resistance and workability of concrete, making it a viable eco-friendly alternative for applications in construction of low-load-bearing structural elements, roadside infrastructure, and pavement systems.

Keywords: *Sustainable construction, Compressive strength, Flexural strength, Split tensile, Tigernut fiber*

Introduction

Concrete is a widely used construction material, and maintaining the structural integrity of infrastructure depends heavily on its mechanical properties The addition of non-chemical or natural fibers in specific proportions can enhance the quality of concrete (Yusra et al., 2024). The required strength of concrete depends on the variation of the non-homogenous constitutes materials (Quadri et al., 2023). The elementary concrete composites are been partially replaced or added with different materials to obtain the varying mechanical properties and provide an ecofriendly environment (Pham et al., 2019; Liu et al., 2021). Also, addition of waste materials from natural fiber (mainly agriculture), synthetic and industries in order to reduce the volume of solid waste and its negative effects in the environment (Vanitha et al., 2015; Christopher et al., 2017; Asunmogejo et al., 2024). This process improves infrastructural development and increases productivity of waste materials (Quadri et al., 2023).

Natural fiber are categories into animal, mineral and plant fibers (Geremew et al., 2021). Plant Cellulose fiber (also known as lignocellulose) are more recognized and applicable in construction due to its wide availability, periodical, less expensive and renewable nature (Mishra et al., 2000). The micro-fibril angles of plant fiber enhance the mechanical properties of concrete both technically and ecologically. The societal and environmental awareness of the harm causes by artificial non-renewable resources prompted the innovation of green regulations of unsustainable materials through application of ecological friendly materials such as natural fibers (Mohammed et al., 2015; Ajagbe et al., 2022). Several innovations are been explored by researchers on the improvement of concrete quality and strength by partially replacing some basic concrete composition or incorporating composite components into concrete mix (Liu et al., 2021). This enables the production of more environmentally friendly and sustainable concrete (Kumarasamy et al., 2020; Ajagbe et al., 2022).

Yusra et al. (2023) investigated the effect of adding natural fiber (rattan and bamboo fiber) on the mechanical properties of concrete. The study observed that rattan and bamboo fiber increase the compressive strength, tensile and ductility properties of concrete at 1.5% addition. Adeniyi et al. (2022) also employed the use of microwave cured bamboo fiber and styrene butadiene rubber (SBR) to enhance the mechanical properties of concrete with varying percentage incorporation. The study discovers an optimization in the compressive strength of concrete at 1% and 1.5% addition of the fiber. Geremew et al. (2021) studied the overview of researches on the mechanical properties of concrete using natural fibers. The study observed that the mechanical properties of concrete increases at a particular percentage addition of natural fiber but reduces as the fiber increases in comparison with the control specimen. The study concluded that such modified concrete might still be suitable for low-load-bearing structural elements. Christopher et al. (2017) and Asunmogejo et al. (2024) also applied the use of natural fiber in partial replacement of cement in concrete and Quadri et al. (2023) replaced fine aggregate with biodegradable materials.

This study evaluates the influence of adding tigernut fiber on concrete mechanical properties. Tigernut fiber is a byproduct of tigernut tuber (Cyperus esculentus) available all year round in Nigeria and some part of East Africa (Bamishaiye and Bamishaiye, 2011). Tigernut possesses several advantages on health and industries. Nevertheless, the fiber is treated as solid waste after extraction of the nutrients, which results to environmental pollution. Tigernut fiber is a natural and biodegradable material, which can be incorporated into concrete as construction material; it aligns with sustainability principles and offers a renewable alternative for enhancing concrete properties due to its favorable properties including good thermal and acoustic insulation, low density, and high tensile strength (Okorie et al., 2020). This study aims at assessing the effect of adding tigernut fiber on concrete's compressive strength, flexural strength, and impact resistance. The study also investigated the optimal mix ratio at which optimal strength was obtained at different concrete mix ratio; 0%, 1%, 2% and 3% in order to ascertain its use as structural material in concrete production. The subsequent sections are divided into experimental methodology to determine the properties, discussion on the result obtained and the conclusion of the study.

Materials and Methods

The tigernut fiber, a byproduct of industrial extraction of oil and juice, was sourced locally and sun-dried to constant weight. The existing moisture content of the fiber was less than 6%. The tigernut fiber was added at different percentages of 0% (for control specimen), 1%, 2%, and 3% respectively. Portland limestone cement of grade 42.5R was used as the binder for the preparation of concrete. Fine and Coarse aggregate used for the experiment has maximum diameter of 4.75 mm and 19 mm respectively. All materials were sourced locally from Ado-Odo local government community of Ogun state in Nigeria.

Experimental Procedure

The concrete mixing and specimen preparation were carried out in accordance with BS 1881-122. The concretes constitute were manually mixed in the laboratory to ensure proper uniformity and tigernut fiber was added in percentage of 0%, 1%, 2% and 3% respectively. Table 1 shows the mix ratio of the concrete incorporated with tigernut fiber. The 36 cube molds properly tapped and compacted with uniformly distributed 25 blows of 16mm diameter tapping rod to ensure equal compaction and remove air pockets. Table 2 indicates the dimensions of the moulds for the strength test. The cubes were in the molds for twenty-four hours after casting at room temperature. The cubes were set aside in an open environment for seven (7) days, fourteen (14) days and twenty-eight (28) days to complete the curing process. This process guarantees that the cement hydrates properly and gains strength (Adeniyi et al., 2022).

Results and Discussion

The result of the various physicochemical laboratory tests, and their limits, in comparison

Table 1: Concrete mix ratio incorporated with Tigernut

Fiber Percentage (%)	Water	Cement	Fine Aggregate	Coarse Aggregate	Replicate
0	0.6	1	1.5	3	5
1	0.6	1	1.5	3	5
2	0.6	1	1.5	3	5
3	0.6	1	1.3	3	5

to Federal Environmental Protection Agency (FEPA) guidelines for interim uniform effluent limits, are given in Table 2.

Table 2: Concrete Mould Based

Mould Type	Dimension (mm)
Cube	150 x 150 x 150
Cylinder	100 x 300
Rectangle Prism	100 x 100 x 500

Tests carried out

Slump Test

The workability of fresh concrete was evaluated using the slump test. The slump values were recorded for each mix and of different fiber addition. Slump test was used to determine the workability of the concrete. The distance between the cone's height and the highest point of the subsided concrete sample was measured as the slump value. This value provides a quantitative assessment of the concrete's workability, with higher values indicating a more fluid and easily placeable mixture (ASTM, 2012).

Compressive Test

The concrete strength was tested at 7, 14, and 28 days, respectively using compression testing machine. Compression test, a total of 36 concrete cubes with the dimension of 150mm x 150mm x150mm were cast per mix with addition of tigernut fiber of 0% for control, 1%, 2% and 3% fiber addition. The crush value was recorded as the load on failure for each sample, to compare the fundamental properties of control concrete. The

Figure 1: Experimental setup of concrete strength test

Compressive strength was calculated using Equation 1 indicating the link between the maximum load failure and the cross-sectional area of concrete cubes (ASTM, 2008).

$$F_c = \frac{F}{A} \quad (1)$$

Where: F_C is Compressive strength (N/mm^2), F is Maximum load at failure (N), A is the concrete cross-sectional area of cube specimen (mm^2).

Flexural Test

The Flexural strength of the concrete incorporated with fiber at 0%, 1%, 2% and 3% was also tested on prisms at 28 days using a universal testing machine. Test prisms were 100 x 100 x 500 mm, placed carefully in a testing apparatus, and the top load position was positioned in the center of the prism length. During testing, the center of each prism received a single focused load. The load was applied without impact or shock, and the maximum applied load was noted (ASTM, 2012). Flexural strength was calculated using Equation 2

$$F_{cf} = \frac{3 \times F \times l}{2 \times b \times d_1 \times d_2} \quad (2)$$

Where: F_{CT} is Flexural Strength (N/mm^2), F is Maximum Load at Failure (N), l is effective Span of the Beam (mm), b is Beam's Breadth (mm), d is Adjacent Specimen Sizes (mm).

Split tensile Test

The Split tensile strength was tested on cylinders at 28 days using a compression testing machine for the fiber variations. The cylindrical concrete specimen measures 100 mm in diameter and 300 mm in length (Gunasekaran *et al*, 2011). The dimension and weight of the specimen were recorded and compressive testing machine was used to apply the load. Load (p) at the concrete specimen failure was also recorded (ASTM, 2008). Split tensile strength was computed using Equation 3. Figure 1 shows the experimental setup of all the concrete testing carried out in the university concrete laboratory (Bell's University of Technology, Ota, Ogun State, Nigeria).

$$T = \frac{2P}{\pi DL} \quad (3)$$

Where: T is split tensile (N/mm^2), P is Maximum load (N), D is Diameter of concrete cylinder (mm), L is Length of concrete cylinder (mm).

Results and Discussion

Slump

The slump test results, as shown in Figure 2, indicate an increase in slump value with increasing tigernut fiber content. The findings is consistent with the result of Quadri et al., (2023). The control mix with 0% tigernut fiber has the minimum slump value of 70 mm while the concrete mixture with 3% tigernut fiber integration has the maximum slump value of 82 mm. The result of the workability test shows true slump values for all addition indicates that the more tigernut fiber added into concrete mixture the higher the water absorption rate and workable the concrete (Siddique et al., 2021).

Compressive Strength

The compressive strength of the cubes were determined at 7 days, 14 days and 28 days of curing at room temperature. As illustrated in Figure 3, the maximum compressive strength of the concrete cubes were obtained at 0% fiber addition at each respective days with 19.56 N/mm2, 22.04 N/mm2and 24.8 N/mm2. The compressive strength decrease as tigernut fiber was added into the concrete. The minimum compressive values were 14.66 N/mm2, 16.5 N/mm2 and 20 N/mm2 at 3% fiber incorporation into the concrete. However, at 1% addition of fiber the compressive strength of the concrete in 14 days was 21.4 N/mm2 and 24.2

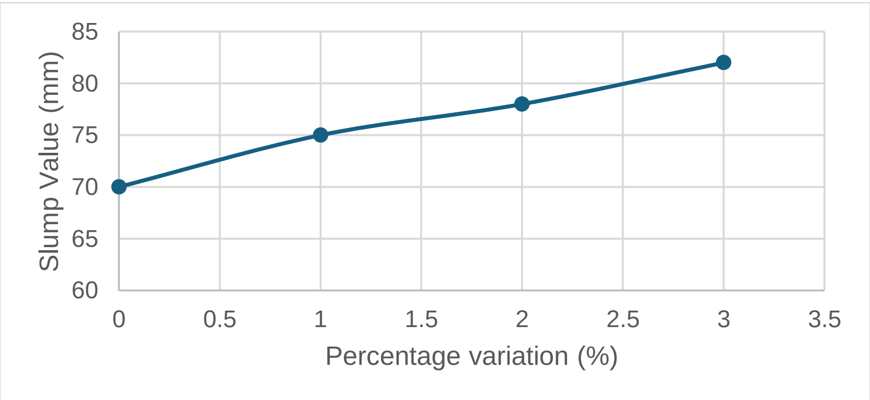

Figure 2: Concrete Slump Value Result with Fiber Variation

N/mm2 at 28days, this indicates that 1% addition of fiber produces well to equivalent compressive strength for concrete and can be used as additive in concrete (Ramakrihna and Sundararajan, 2005; Siddique and Khatib, 2010).

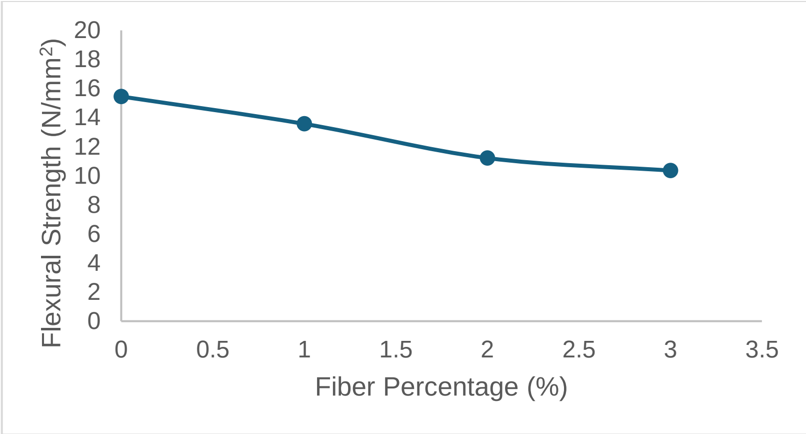

Figure 4: Flexural strength test at 28 days

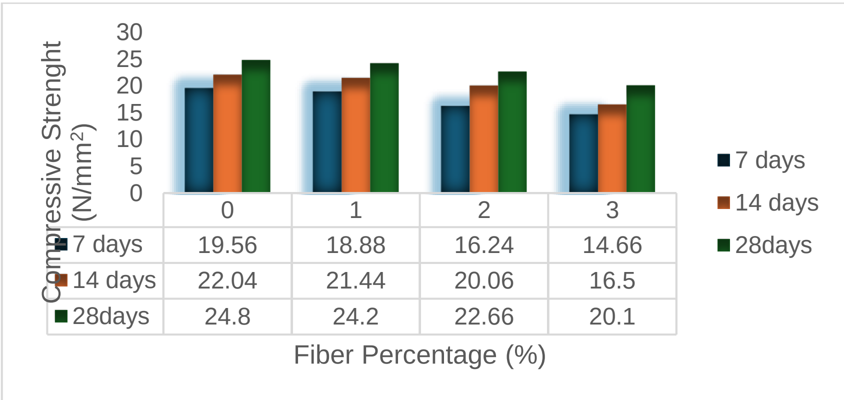

Figure 3: Variation of Compressive Strength at Different Test Age

Flexural Strength

Flexural strength, which measures the ability of concrete to resist bending or tensile strength (Siddique et al., 2021). The flexural strength that was determined at 28 days shows decrease in concrete strength with addition of tigernut fiber similar to the compressive strength. Figure 4 illustrates that the highest flexural Strength of the concrete incorporated with the fiber was observed at 0% addition as 15.45 N/mm2 and the lowest flexural Strength was observed at 3% addition as 10.36 N/mm2 indicating non-reinforced concrete not suitable in tensile (Sharma and Kumar, 2015).

Split Tensile Strength

The results of Split tensile strength conducted on the concrete sample with percentage integration of fiber at 28 days are shown in Table 3. The average split tensile strength of the concrete at percentage integration of Tigernut fiber ranging from 0%, 1%, 2% and 3% are 2.5 N/mm2, 1.197 N/mm2, 2.25 N/mm2 and 2.48 N/mm2 respectively. The maximum average split tensile strength of concrete addition using tigernut fiber was observed at 3% with 2.42 N/mm2 and the minimum was observed at 1% addition of fibre with 1.99 N/mm2. This indicates that the fiber serves as filler and prevents cracking in concrete, the fiber fills the pore or voids of the concrete (Okafor et al., 2017). Figure 5 illustrates the average split tensile Strength of the concrete with percentage variation of the fiber.

Conclusion

These study findings provide useful insights for developing sustainable concrete using natural fiber such as tigernut fiber as admixture. From Slump test, it was concluded that concrete becomes absorbent and more workable at the addition of the fiber. However, the optimum compressive strength of concrete at 28 days of incorporating the fiber can be obtained at 1% with 24.2 N/mm2. Furthermore, the flexural strength decreases with increasing fiber content 15.45 N/mm2 obtained at control (0%) addition and finally, the split tensile strength of concrete increases at the addition of Tigernut fiber. The maximum average split tensile strength was determined at 3% incorporation of the fiber indicating the fiber can serve as filler, which can reduce the occurrence of cracks or rupture in concrete.

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Table 3: Split tensile result at age 28 days

S/N	Fiber Percentage (%)	Split Tensile Strength (N/mm^2)	Average Split Tensile Strength (N/mm^2)
1	0	2.45 2.55	2.50
2	1	2.01 1.97	1.99
3	2	2.33 2.26	2.29
4	3	2.40 2.46	2.42

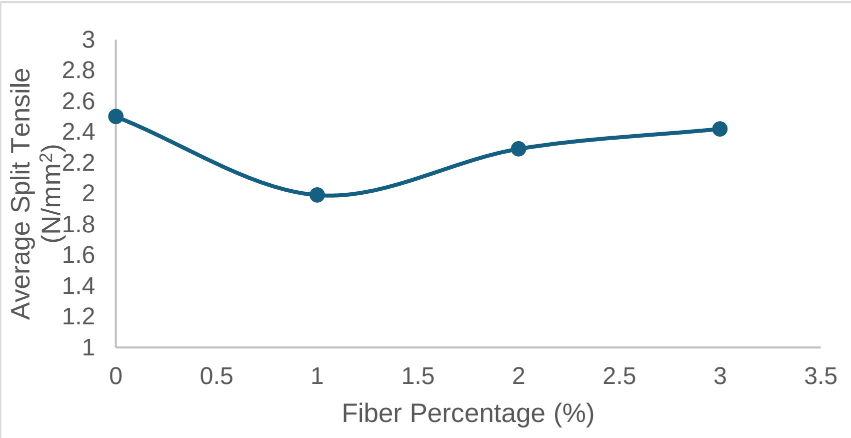

Figure 5: Average Split Tensile Strength at 28 days

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