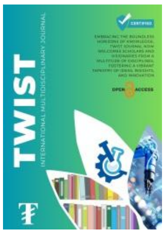
DOI https://doi.org/10.5281/zenodo.10049652#129

TWIST, 2024, Vol. 19, Issue 2, pp. 53-62

TWIST

Journal homepage: www.twistjournal.net



Assessment of the Behaviour and Performance of Napier Grass Fibers in a Natural Fiber Reinforced Concrete

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Abstract
The prevalent issue with agricultural waste has led researchers worldwide to create new materials that will enhance the environmental quality of products. Utilizing composites shaped from raw and renewable natural fibers has become more common as the demand for new eco-friendly materials arises due to their low cost, superior mechanical qualities, and low energy consumption in their production. Napier grass fibers, as a sample of cellulosic fibers, had proven their performance compared to synthetic fibers. This paper aims to examine the results of mechanical properties such as compressive strength and flexural strength to determine the optimum fiber concentration and fiber length in Napier fiber-reinforced concrete (NFRC). Treatment of fibers is crucial because it increases the interfacial adhesion that strengthens the matrix's bonding. This study showed that adding Napier grass fibers enhanced the mechanical properties of concrete. However, a more significant aspect ratio may harm the NFRC's compressive and flexural strength.

Keywords
Aspect Ratio, Fiber Loading, Mechanical Properties, Natural Fiber Reinforced Concrete, Scanning Electron Microscopy

INTRODUCTION

Urban life's growth and development resulted in a rise in demand for an array of construction materials [1]. Concrete, a commonly used construction material with steel, glass, and synthetic fibers as reinforcement, has raised environmental issues during production [2]. Simultaneously, agricultural crop waste problems, including those involving sugarcane bagasse, elephant grass, rice husks, and palm oil fuel waste, have become a severe problem. As a result, several researchers have investigated whether it is feasible to use these agricultural waste products as building materials to satisfy the demands of the construction industry and reduce current non-renewable resources [1]. In recent years, natural fibers have attracted a lot of interest from the construction industry as a reinforcing material; with their natural characteristics and properties, natural fibers have been recognized for cost-effective production and better performance than synthetic fibers [2, 3]. By 2025, it is anticipated that the size of the world market for cellulose fibers will have increased quickly to 41.5 billion USD [4].

Fibers from Napier grass will be used as they come from nature without any preparation and ensure a low-cost building material. Moreover, Napier fibers are cellulosic fibers, renewable resources that lessen the influence of related products on the environment [5]. Concrete is characterized by its mechanical properties, and it is known to have a high compressive strength but a very low tensile, which results in rapid crack propagation and brittle failures [6-8]. As a result, studies involving the addition of short, uniformly dispersed discontinuous fibers in concrete mixtures have proven to be an acceptable solution for reducing these constraints [9, 10]. Most researchers work to enhance the extraction method to improve the cellulose's physical and mechanical characteristics in Napier grass fibers [11]. Treatment of fibers is highly advised as it disrupts hydrogen bonds in the network structure and results in an increase in surface roughness that reduces the water absorption of fibers and improvements in the adhesion at the fiber-matrix interface Does alkaline treatment bring about the main changes [12, 13].

Concrete's strength qualities have improved by adding natural fibers, and fracture propagation has been reduced [10], [14]. As the percentage of natural cellulosic fiber approaches up to 2%, the formed concrete specimen with cellulosic fiber reinforcement shows an improvement in tensile and compressive strength. [15]. However, a higher rise in the concentration of fibers would degenerate some of its mechanical properties [16].

Although many studies connect *Pennisetum purpureum* (Napier grass) as a great reinforcement, the data's limitations on the natural fiber's loading in the concrete matrix are challenging. Studies for the past years have shown that a higher fiber loading will either enhance or deteriorate the cement's mechanical properties simultaneously. Moreover, the placement and distribution of the fibers should also be observed and investigated to develop a good concentration and mixture in the cement matrix [17].

This study's general objective is to create a fiber-reinforced concrete block and provide a satisfactory concentration of fibers in the cement matrix for slabs on grade, utilizing the fibers of Napier grass for reinforcing. The specific objectives are as follows: (1) to design and obtain a concrete mixture from different volume fractions of Napier fibers, (2) to determine the physical properties of fresh concrete in terms of slump test and density, (3) to assess the influence of Napier grass fibers on the strength of the mechanical characteristics of concrete, (4) to investigate the performance of Napier grass fibers in resisting micro-cracks and crack propagation using Scanning Electron Microscopy (SEM).

The significance of this study is that it develops fiber-reinforced concrete blocks (precast walls) and slabs on grade for low-cost housing projects. An eco-friendly material will be used in civil engineering projects as this study uses natural renewable resources.

This study focuses on using *Pennisetum purpureum* (Napier grass) as the fiber reinforcement of the concrete. No other materials or substances will be added, and only the standard concrete mixing will be performed. Its flexural and compressive strengths are the only mechanical properties of fiber-reinforced concrete intended to be recognized and studied.

MATERIALS AND METHODS

Materials and Resources

Natural fiber-reinforced concrete is produced using cement, aggregates, and natural fibers. The natural fibers used are five to six-month-old Napier grass stems collected from a local grass plantation in Catalunan Pequeño, Davao City. On the other hand, by the ASTM C150 rules established by the American Society for Testing and Materials, Type I Ordinary Portland cement was used as a binder. We have purchased coarse and fine aggregates in the nearest quarry recognized by the Department of Public Works and Highways (DPWH).

Methods and Procedures

Using the standard water retting method for seven days, fibers of Napier grass, or *Pennisetum purpureum*, a member of the Poaceae family, have been extracted from the grass' internodes. The extraction process started with the grass stalks; they were initially smashed using a mallet, and the broken stem pieces were submerged in water before being thoroughly cleaned and then sun-dried. The separated fibers were thoroughly washed in distilled water to remove as much moisture as possible and dried outside for a week. [18]. Extracted fibers underwent an alkali treatment to eliminate any impurities in the fiber. The Napier fiber strands were soaked with a 4.5% solution of NaOH (Sodium Hydroxide) for 2 hours. Finally, the fibers were dried at room temperature after being cleansed and rinsed with distilled water.

Characterization of Fibers

Mechanical Properties of Fibers

A random sample of 20 fibers measuring 80 mm in length was taken from the treated and untreated fibers. Mechanical properties will undergo the standard procedure for Tensile Properties for Single Tensile Fibers (ASTM D3822/D3822M-

14). In positioning the fiber strand to the machine, the gap between the tensile clipping must be put in the interval set in the fibers. Also, an initial deformation rate of 1.00 mm/minute was then used in the testing. A mobile phone was used to determine the real-time results for reviewing the maximum load and elongation using Young's modulus of elasticity.

Quality Test for Aggregates

The aggregates underwent a sieve analysis following the ASTM C136 procedure. Moreover, the study followed the ASTM C33 to determine its compliance with grading requirements. The unit weight, water absorption, specific gravity, and moisture content of the aggregates, both fine and coarse, were determined based on ASTM C29, ASTM C127, ASTM C128, ASTM C70, and ASTM C566, respectively.

Preparation of specimens

Nine mixed proportions of the concrete mixture were tested in this study. The concrete mixing was performed by manual mixing procedure, and the number of fiber strands, or the volume fraction of the fibers, will vary from 1.5%, 2.0%, and 2.5% of the total weight of fine aggregates. Three different fibers with lengths of 20, 30, and 40 mm were employed in each mix design ratio, as indicated in Table 1. The natural fiber-reinforced concrete's compressive strength was measured using a cube specimen measuring 150mm x 150mm x 150mm, which exhibits higher strengths due to uncapped end conditions; the flexural strength was measured using a beam-sized sample measuring 150mm x 150mm x 525mm [19].

Table 1 Mixed Design Combination of Napier Grass Fibers

Fiber Length	Napier Grass Fiber Concentration		
	1.5%	2.0%	2.5%
20 mm	NGF 20x1.5%	NGF 20x2.0%	NGF 20x2.5%
30 mm	NGF 30x1.5%	NGF 30x2.0%	NGF 30x2.5%
40 mm	NGF 40x1.5%	NGF 40x2.0%	NGF 40x2.5%

Fiber Reinforced Concrete Mixing Procedure

The process for mixing natural fiber-reinforced concrete adheres to ASTM C192, commonly referred to as the industry standard procedure for fabrication and curing laboratory concrete specimens. Load coarse and medium aggregates were mixed with approximately 75% water at the start of the process. Fine aggregate, cement, and 20% water (including the remainder of the mixture) are then added, one at a time, in decreasing sequence of particle size. Following the mixing procedure, the slump test, ASTM C143 Standard Test Method for Slump in Hydraulic Cement Concrete, is conducted to determine whether the concrete is workable before adding the fibers for comparison. After the slump test, the concrete was returned as fibers were introduced. All of the fiber should have been incorporated within the initial minute of the five-minute mixing time. For 24 hours, a molder filled with fresh concrete was placed in a curing box. Finally, the samples were cured for 28 days [20].

Testing Procedures

The whole study focuses on the behavior of Napier grass fibers in natural fiber-reinforced concrete. Factors that may influence the composite, such as the orientation and dispersion of the fibers, are shown in Figure 1, which also presents a scheme or summary of the terms and tests investigated in this study. The UTM, or Universal Testing Machine (UT 150, Unit Test Scientific Sdn Bhd, Malaysia), was used to evaluate and assess the compressive and flexural strengths of natural fiber-reinforced concrete, in conformity with ASTM C109 and ASTM C1609, respectively, given that the purpose of this study is to assess the mechanical properties of concrete with fiber reinforcements. After testing, cracks and fractures were visible, which was evaluated concerning the mechanism of fibers in arresting cracks. Scanning electron microscopy (SEM) was used to inspect the specimen's fractured surfaces directly.

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) was used to analyze the data gathered from the tests statistically. The study utilized a one-way analysis of variance (ANOVA) to determine if there is a significant difference in the mechanical properties of the concrete of the Napier Fiber Reinforced Composites with different fiber loading concentrations. It was followed with a post hoc test to detect the differences between groups varying in fiber lengths.

RESULTS AND DISCUSSION

Characterization of Aggregates

The properties of aggregates and cement after the quality test of aggregates are shown in Table 2.

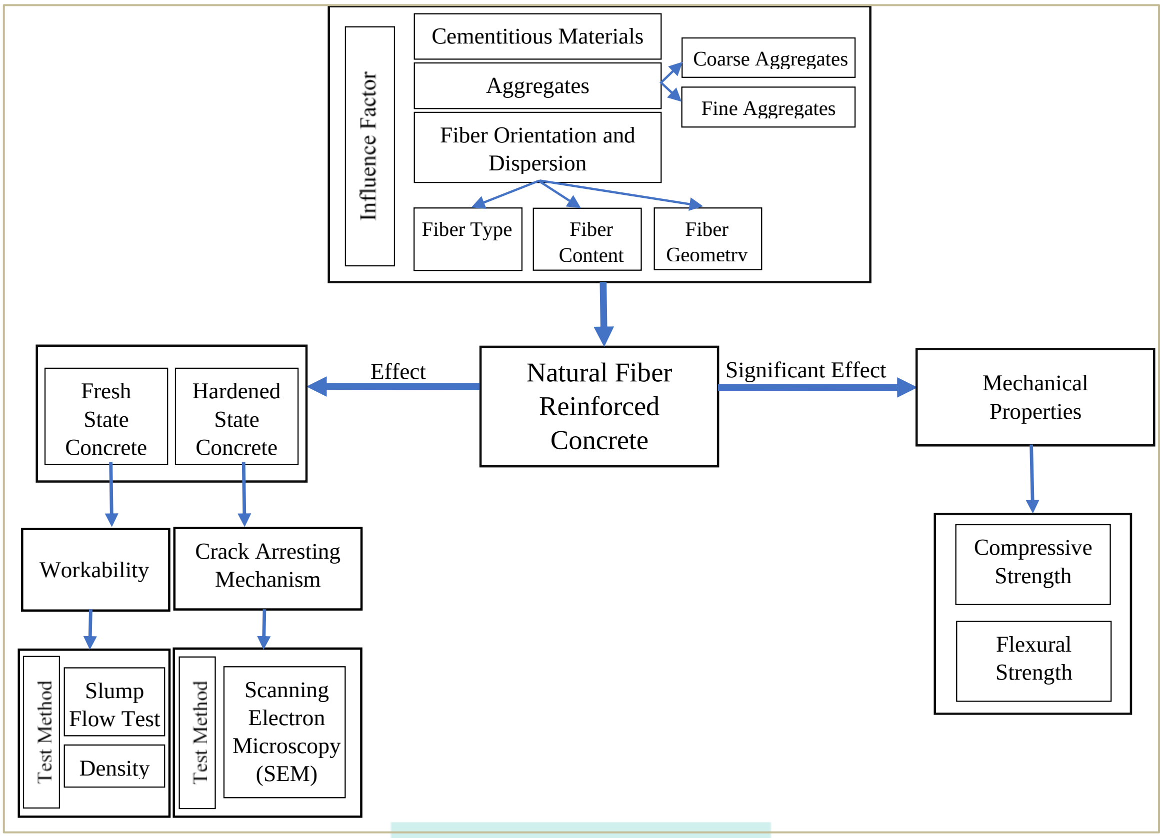

Fig. 1 Scheme of Study Procedure

Table 2 Properties of Aggregates and Cement

	Specific Gravity (Sp. Gr.)	Absorption	Dry rodded Unit Weight	Moisture Content	Fineness Modulus
Cement	3.15	-	-	-	-
CA	2.7469	2.1803	1730.29	3.83712	-
FA	2.534	3.7503	1713.4417	7.51341	2.408

Aggregates are essential components in the construction industry, serving as a foundation material for all various concrete mixtures. Ensuring and understanding their physical properties is necessary as it is the basis for their performance and quality as a construction material. Table 2 is the result of the study's comprehensive aggregate characterization. These properties in aggregates, such as specific gravity, absorption, and moisture content, are crucial to achieving a workable condition, long-term durability, and strength in concrete. Furthermore, these results provide information for the governing mixed design ratio and construction methods.

Characterization of Fibers

Physical Properties

Table 3 shows the Napier Grass fiber's average diameter, linear density, and density before and after being treated with 4.5% sodium chloride.

Table 3 Physical properties of treated Napier fibers and untreated Napier fibers

Natural Fiber	Diameter(mm)	Linear density (g/m)	Density(g/cm^3)
Treated Napier Fiber (TNF)	0.110-0.210	0.0096-0.0380	0.8559-1.3879
Untreated Napier Fiber (UNF)	0.206-0.262	0.0468-0.0736	1.1268-1.6853

It demonstrates that Napier grass fibers range in diameter between 0.206mm and 0.262mm when left untreated and 0.110mm and 0.210mm when treated. As the treatment removes the fiber's external surface impurities, the diameter reduces, increasing the fiber's aspect ratio (length to diameter). The fiber diameter determines the tensile strength of a single strand of Napier Grass fibers. Regarding linear density, the treated Napier grass fibers achieved a lower value than the untreated fibers, ranging from 0.0096 g/m – to 0.0380 g/m. Furthermore, Napier fibers' density had decreased from 1.6853 g/cm^ to 0.8559 – 1.3879 g/cm, as the alkaline treatment removes noncellulosic components in fiber strands.

Table 4 compares the diameter and density of other natural fibers after treatment. It is shown that Napier grass fibers have a higher density than corn husks, sugarcane, and sisal fibers. The study of Archbold et al. backed this, and this highlights that incorporating a high-density fiber compared to other natural fiber is important because adding a lower-dense material will decrease the unit weight of the specimens and would have an additional impact on the mechanical properties of concrete composites [21]. Fiber density can be measured in different ways and is crucial as it is used as a basis to determine the weight fraction or the fiber content in a natural fiber-reinforced composite.

Table 4 Physical properties of grass fibers after treatment

Fibers	**Density** (g/cm^3)	**Diameter** (mm)	**References**
Corn husk	0.34	0.186	[22]
Sisal	0.89-0.95	---------	[23]
Sugarcane	1.30	0.232-0.323	[24]
Napier grass	0.8559-1.3879	0.206-0.262	Present work

Mechanical Properties of Napier Grass Fibers
Table 5 displays tensile parameters of treated and untreated Napier grass fiber strands, which include strength, modulus, and elongation at break.

Table 5 Mechanical properties of treated Napier fibers and untreated Napier fibers

Natural Fiber	**Singleotensile (MPa)**	**Elongation(mm)**	**Young'somodulus (GPa)**
Treated Napier Fiber (TNF)	76.048 - 287.689	0.5081 - 1.2111	1.035 - 3.459
Untreated Napier Fiber (UNF)	77.944 - 146.731	0.3776 -1.0006	1.076 - 3.315

The tensile test is the commonly used material test to establish the strength of any material. The higher tensile strength value implies stronger material, and the lower tensile value indicates weaker material. As presented in Table 5, it is noticeable that the treated Napier grass fibers' tensile strength can withstand a higher load that ranges from 76.048 MPa up to 287.689 MPa. The elongation of the treated Napier grass fiber has reached 0.5081 mm up to 1.2111 mm, having it way more stretched before breaking compared to the untreated one with 0.3776 mm up to 1.0006 mm only.

Lastly, treated Napier grass fiber had the most significant magnitude for the modulus of elasticity, ranging from 1.035 GPa up to 3.459 GPa. However, untreated Napier grass fiber is considered to be brittle and less elastic due to the presence of noncellulosic compounds. With these results, it is seen that NaOH treatment is necessary to enhance the tensile properties of natural fibers [25].

Physical Properties of Fresh State Concrete
Slump Test
The workability of freshly mixed concrete is an essential component that determines the quality of concrete. Workability is a short-term attribute yet anticipated to influence the hardened state of concrete and its other long-term properties [18]. Due to its promising properties, fiber-reinforced concrete (FRC) has seen a significant increase in application as a structural material in recent years. However, despite the benefits of adding fibers to a concrete mixture, it reduces the workability of fresh concrete. As shown in Figure 2, including fibers reduces the slump quality of fiber-reinforced mixed concrete in all mix ratios compared to the mixture without fibers (controlled).

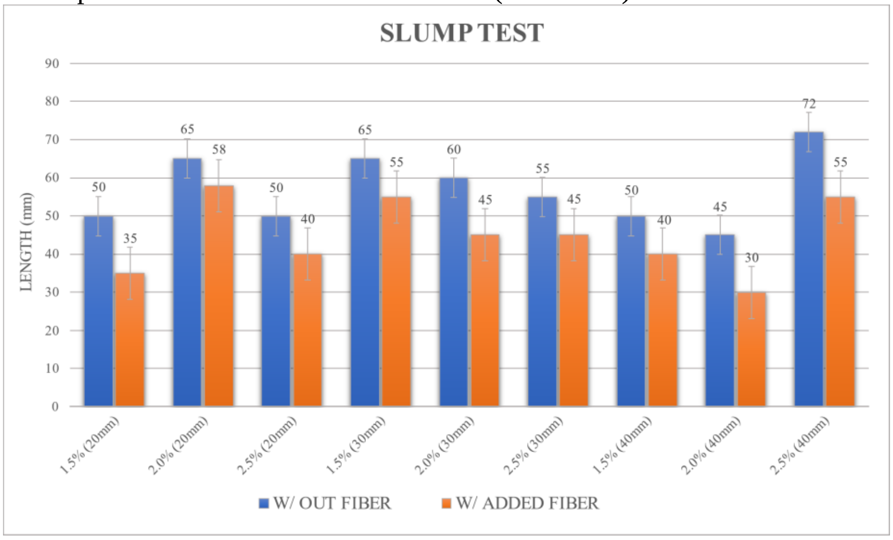

Fig. 2 Slump Test for Concrete Mixtures Before and After Adding Napier Grass Fibers

Though there are some changes in the slump test, both without fiber and with added fiber are still in their workable condition. It is widely known that mixes with additional fibers require water to lubricate the cement and have a larger surface area that must be wetted. Observing the water-cement ratio in a fiber-reinforced mixture is critical as fiber content increases.

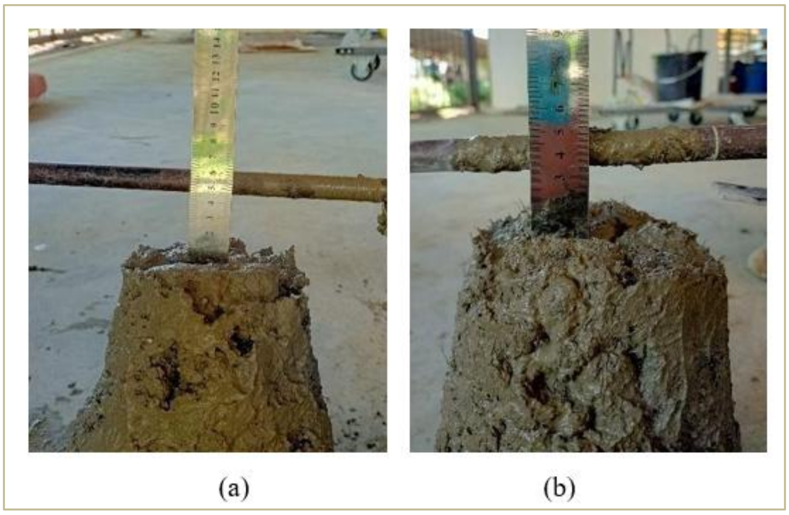

Fig. 3 Slump test (a) without fiber, (b) with 40 mm x 2.0% NGF

The density of freshly mixed concrete

Table 6 shows the density of fresh-state concrete in the absence of fibers and all samples with varying fiber concentrations.

Table 6 Density of NFRC fresh concrete.

Fiber Concentration	Density (g/cm^3)
Controlled	2.598
1.5 %	2.509
2.0 %	2.540
2.5 %	2.556

The result for density varies from the sample with varying fiber concentrations. The lowest fiber content of 1.5%, as indicated in Table 6, has a lower density than other fiber concrete mixtures. It is observed that as the higher fiber concentration is applied, it gets closer to the density of the fresh concrete for the controlled sample. The results indicate that the density of Napier grass fibers slowly contributes to the density of the concrete mixture as the fiber concentration of the Napier grass increases. The importance of using a material with a high density was emphasized in the study by Archbold et al. since adding a less dense material will reduce the density and the composite's unit weight [21].

Mechanical Properties of the Natural Fiber Reinforced Concrete

The impact strength of Napier grass fiber reinforced concrete was investigated in this study, considering the effects of different fiber loading and fiber length. To test and monitor the performance of the Napier grass fiber reinforced concrete, the researchers used the Universal Testing Machine to evaluate its compressive and flexural strength.

Compressive Strength

The compressive strength of Napier grass fiber loading at 1.5%, 2.0%, and 2.5% for fiber lengths of 20, 30, and 40mm is shown in Figure 4. Based on the descriptive statistics of the compressive strength of each group. We can see that the 2.0% NFRC with 20 mm in length has a higher average compressive strength (CS=2946.0 psi) compared to other concretes with various concentrations of Napier Grass Fibers.

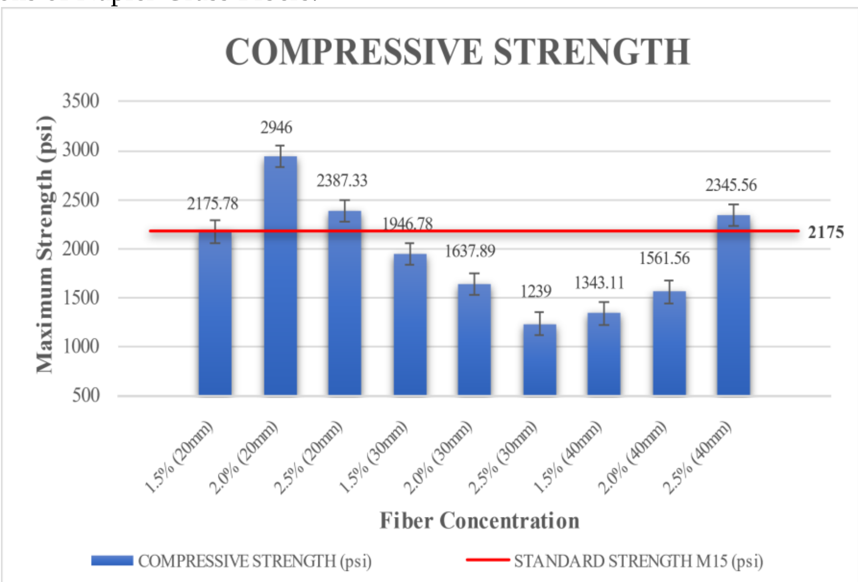

Fig. 4 Influence of Napier Grass Fibers on NFRC's Compressive Strength

Post hoc analysis using Tukey multiple pairwise shows the comparison and differences of the means of each mixture compared to the control group. It was proven that 2.0% with 20 mm length has the highest compressive strength among other concentrations. This means that the concentration of 2.0% with 20 mm fiber length reached a compressive strength with a higher positive difference and indicates a substantial difference compared to the control group, which improved its compressive strength. Generally, this suggests that compressive strength was shown to be affected as the length of the Napier fibers added to the concrete mixture exceeds 20 mm. We can observe that the Napier fibers' aspect ratio (length to diameter) significantly improved the compressive strength of fiber-reinforced concrete. It was supported by the study of Rao et al., who discovered that fiber-reinforced concrete performs better in compressive strength when the aspect ratio is smaller. In contrast, compressive strength with a greater aspect ratio does not significantly increase [26].

Flexural Strength

The flexural strength of the natural fiber-reinforced concrete was evaluated using flexural tests on beam samples. The test beams were subjected to a three-point flexural test following the general requirements in "ASTM C1609." Figure 6 displays the flexural strength of Napier grass fiber loading at 1.5%, 2.0%, and 2.5% for fiber lengths of 20, 30, and 40 mm. Following the Descriptive statistics of the flexural strength of each group shown in Figure 5, we can identify that the cement with 2.5% NFRC (30mm) has higher flexural strength (FS=674.25 psi) compared to the concrete mixtures with various concentrations of Napier Fiber Reinforced Concrete.

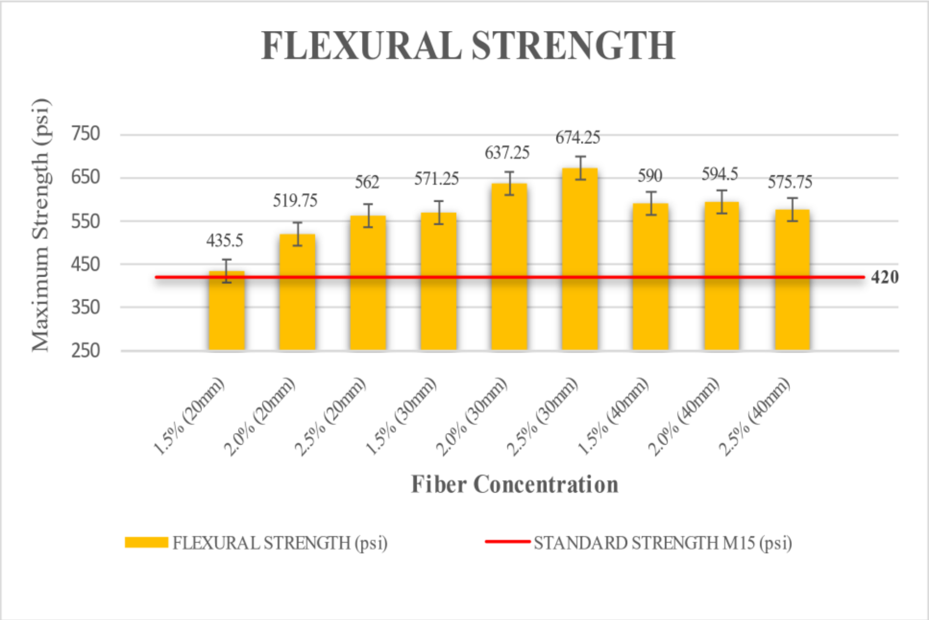

Fig. 5 Influence of Napier Grass Fibers on NFRC's Flexural Strength

Post-hoc analysis using Tukey multiple pairwise showing the comparison and differences of the means of each group. At 5% level of significance, it has proven that 1.5% NFRC (40mm), 2.0% NFRC (30mm), 2.0% NFRC (40mm), 2.5% NFRC (30mm) has a significant positive difference compared to the control group which indicates that the following group of concrete has a significantly higher flexural strength compared to concrete without Napier grass Fibers. Moreover, 1.5%NFRC (30mm), 2.0%NFRC (20mm), 2.5%NFRC (20mm), and 2.5%NFRC (40mm) also show positive difference in means; however, it has proven to not be significant compared to the controlled group which indicates that they do not much differ in terms of their flexural strength. Only the 1.5% with 20 mm fiber length failed to exceed the control group. The flexural strength of the NFRC gradually increased from the control group to the 2.5% fiber concentration with a 30mm fiber length. While the Napier fiber content has a length that exceeds 30 mm, the flexural strength is further reduced.

Summary

Figure 6 shows the NFRC's mechanical properties differ in the governing fiber loading and fiber length. For the compressive strength, 2.0% at 20 mm length had reached a strength with a higher positive difference that indicates an improvement in the compressive strength of NFRC. Conversely, it revealed that 2.5% at 30 mm is the highest concentration that governs the flexural strength of the NFRC. This study aims to obtain one (1) satisfactory concentration of fibers in the cement matrix. With the results, the researchers found that 2.0% NFRC (20mm) produced the best compressive and flexural strength performance and found a positive difference in concrete without the added fiber. Therefore, the 2.0% fiber loading at 20 mm length is the potential governing fiber concentration and will used in the final concrete mixture from different fiber loading of Napier fibers.

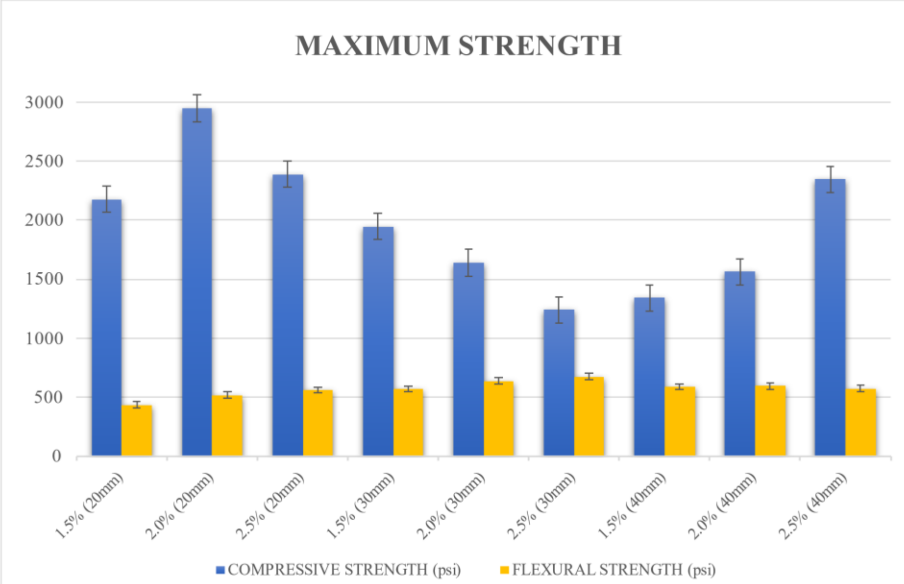

Fig. 6 Influence of Napier Grass Fibers on NFRC's Compressive and Flexural Strength

Scanning Electron Microscopy (SEM) Analysis

Figure 7 demonstrates that Napier Grass Fibers showed both intact and ruptured fibers, which is a greater possibility of providing high uniformity in the NFRC. This indicates that there is a constant tensile strength and orientation that is present in the fibers that are added to the matrix. Napier grass fibers have a rough surface due to the treatment, demonstrating a high friction level among both bonding surfaces. A stronger interfacial adhesion has been anticipated to improve the load transmission process at the contact. Figure 8 shows the treated Napier grass fiber surface, which had a rough appearance and a substantial amount of concrete debris attached. Given that the concrete matrix would have a solid surface to adhere to, this demonstrates the remarkable capacity of the Napier-treated fibers to stick to surfaces. [27].

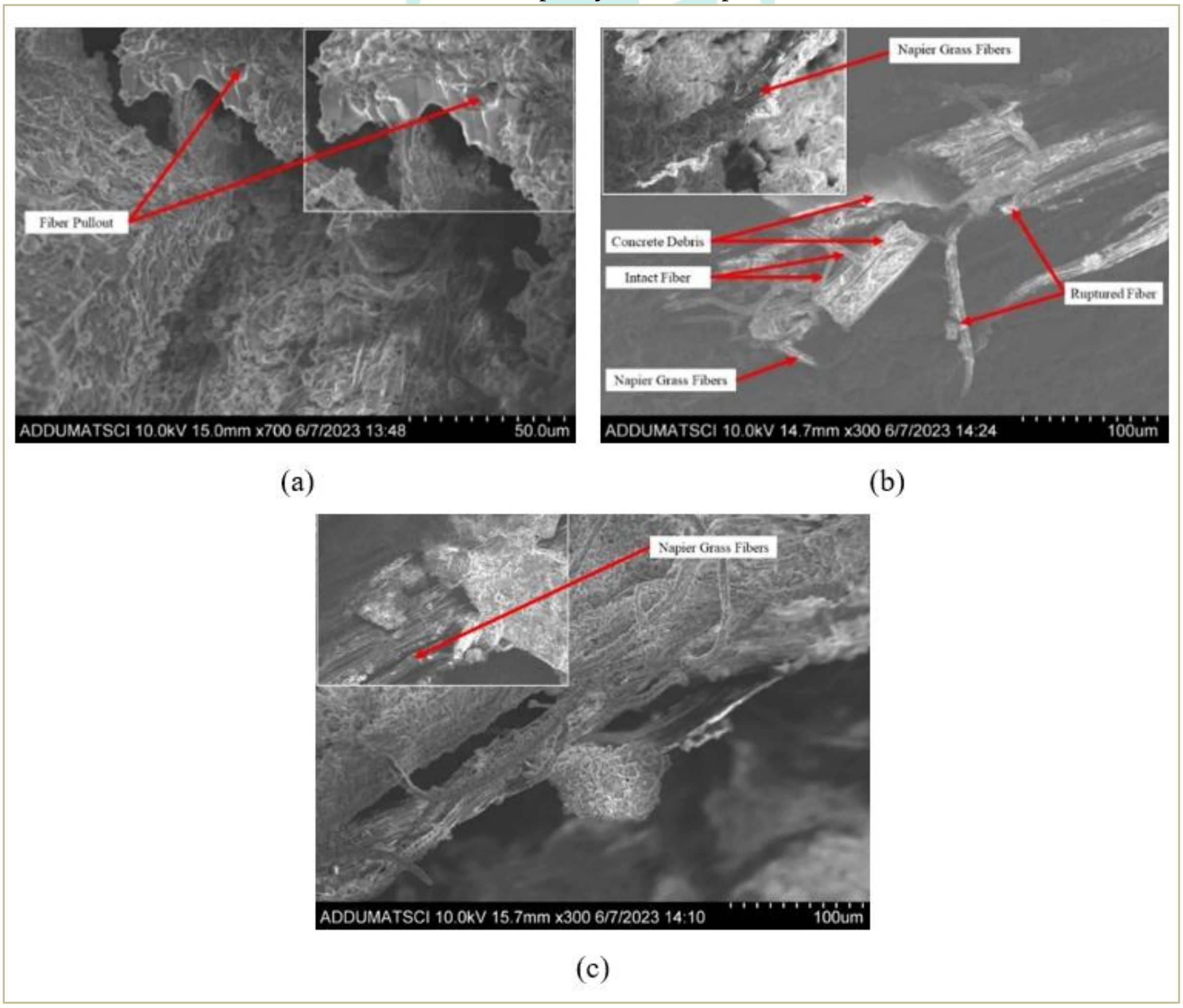

Fig. 7 Napier fiber pull-out (a), Fiber rupture observed (b), and Exposed Napier fiber surface (c) at 1.5%, 2.0%, and 2.5% fiber concentration

CONCLUSIONS AND RECOMMENDATION

Natural fibers, such as the fibers of Napier grass, have demonstrated exemplary performance as an efficient reinforcement material in concrete. It developed a broad interest in the construction industry to consider this product with its natural characteristics, properties, and cost-effective production. The properties and performance of reinforced concrete using Napier grass fibers are investigated in this paper. Based on the results, the researchers formulated the following conclusions.

The workability of a concrete mixture is affected by the hydrophilic properties of Napier grass fibers. However, with the slight change in the slump test gathered before and after adding the fibers, both still reached their workable condition. Therefore, after adding the natural fiber affects the fluidity of the concrete mixture, it is crucial to observe the water-cement ratio. This study reveals how the properties of a natural cellulosic fiber would behave when added to the concrete mix. The mechanical performance of NFRC is determined by its fiber characteristics, such as fiber diameter, fiber concentration, fiber length, and fiber orientation. With the presence of Napier grass fibers, concrete's compressive strength has increased. However, the study also discovered that as the aspect ratio (L/D) of fibers increases, it negatively affects the NFRC's compressive strength.

On the contrary, concrete's flexural strength increased up to a particular limitation for fiber length when reinforced with natural cellulosic fibers. The flexural strength of the NFRC decreases with an additional increment in the fiber length of 30mm Napier fibers. With the proper observation of the behavior and performance of the Napier Grass Fibers in a natural fiber-reinforced concrete based on their respective mechanical properties, it was analyzed that a 2.0% fiber concentration with 20 mm fiber length governs for demonstrating improvement in both flexural strength and compressive strength. These make it possible for natural fiber-reinforced concrete to replace conventional concrete and even fiber-reinforced concrete (FRC) made of synthetic fibers.

This study revealed that adding Napier grass fibers to concrete enhanced its mechanical properties. With this, the researchers recommend developing a fiber extractor machine to reduce the time for the extraction process of the fibers. Furthermore, properly mixing the concrete mixture with added fibers is advised to avoid the fibers "ball up," which happens when added fibers are in an area of the mixture that does not have enough fine aggregates.

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