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Abstract: Presence of cracks in concrete affect the integrity. It reduces the life expectancy of concrete structures and is often responsible for collapse of structures, especially in the developing nations. At the root of these cracks is the very low tensile strength of concrete. Various techniques have been suggested for the enhancing the tensile strength, among which is the use of discontinuous micro fibers of various nature. This research investigated the use of *Momordica angustisepala* (Ma) fiber to enhance concrete strength. Concrete containing coconut fiber was adopted as a control. Slump test, air entrainment test, compression test and split tensile test were carried out on specimens. Results of the research indicate that an optimum *Momordica angustisepala* fiber contents of 0.25 and 0.5% enhanced respectively the compressive strength by 4.37% and the tensile strength by 10%. The results clearly show that this renewable material has the potential to enhance the compressive and tensile strengths of concrete.

Subjects: Composites; Concrete & Cement; Structural Engineering; Environmental Health

Keywords: *Momordica angustisepala* fiber; natural fiber; concrete; compressive strength; tensile strength; building collapse; sustainability

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PUBLIC INTEREST STATEMENT

Over the years, the quest by the construction industry to attain sustainability have pushed the industry towards continuous novelty in a bid to deliver a safe and economic structures. Furthermore, investigation by various researchers into the incessant building collapses in some developing countries pointed to the low quality and strength of the concrete used on site as one of the major causes of these collapses. Consequently, one of the approach of ending these menace in order to achieve desired safety, strength and good quality concrete on site is using discretely distributed natural fiber in concrete. Persistent attention is now focus on improving the quality of concrete by using locally sourced fiber materials such as *Momordica angustisepala* otherwise called local sponge. The fiber will enhance the production of normal concrete with adequate strength, long term performance and same time attaining sustainability at a very low cost.

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1. Introduction

The world has advanced in construction materials corresponding to technological discoveries. This advancement transitted from the use of earth and mud bricks in ancient times of the Greeks to the implementation of Roman's pozzolana mortar and bricks. Further advancement in construction materials continued to the use of cast and wrought iron in the eighteenth century for bridge constructions in Europe. Furthermore, the advancemment continued in the period of industrial revolution of the nineteenth century where steel and reinforced concrete are majorly adopted for general purposes and high-rise buildings. Finally to modern buildings that respond to environmental stimuli via the use of various composite materials of the most recent times (Ede, Bamigboye, Olofinnade, & Shittu, 2016). This continuous evolution of construction materials' has provoked novelties in the construction industry. Far-reaching researches and advances of new construction methods and materials are currently taking place all over the world. The crux of these recent advancements in construction is to achieved a safer, high quality, more economic and environmentally friendly structures for human comfort and business alike via sustainable materials which leads to the overall improvement of quality of life and working conditions (Bamigboye, Ede, Raheem, Olofinnade, & Okorie, 2016; Hoff, Bilodeau, & Malhotra, 2000; Mehta & Monteiro, 2005; Olofinnade, Ede, & Ndambuki, 2017; Olofinnade, Ndambuki, Ede, & Booth, 2017; Yan & Chouw, 2014).

Many researchers have proved that non adherence to concrete design strengths in some nations have been responsible for frequent building collapses in some developing nations (Ede, 2010; Ede, Olofinnade, & Joshua, 2014; Fernandez, 2014). In addition, Ede, Olofinnade, Bamigboye, Shittu, and Ugwu (2017) mentioned that poor combination concrete constituents causes failure of buildings in developing countries. The gruesome injury and death casualties that accompany incidence of building collapse negates the safety of human lives, his wellbeing and sustainability as implicitly embedded in the UN's Sustainable Development Goals (SDGs) (Ede et al., 2016). Furthermore, Joshua et al. (2017) mentioned that other consequences of not attaining sustainability is depletion of the ozone layer through emission of greenhouse gases (GHG). Consequently, there is a need for more to be done in order to raise the standard of building structures that will contribute to the achievement of the SDGs goals. For instance, selection of building materials should be done after complete review of its strength, economy, long term performance/durability and sustainability in an environmentally compatible set up. In addition, one of the approaches that can be used as a means to reduce economic waste, and achieve desired safety, sustainability and environmental compatibility in construction is the use of discretely distributed fiber reinforced concrete.

Normal concrete is a composite material essentially made of Portland cement, aggregates (fine and coarse), water in particular quantities and admixtures. It hardens to a stony consistency over changeable lengths of curing times (Bamigboye et al., 2015). It has a wide variability of properties like good compressive strength, resistance to deterioration in water action, resistance to fire and so on (Ede & Agbede, 2015; Li, 2011). These excellent properties notwithstanding, concrete also have some shortcomings. Concrete has a high compressive strength but a very low tensile strength, about 10% of the compressive strength. The low tensile limiting property of concrete has been a major problem until the advent of steel reinforcement to meet the tensile and ductility demands of concrete structures. But, these days steel reinforcement is turning out to be increasingly costly and fails to meet full sustainability needs due to the non-renewable nature of its source and the negative impact of corrosion which has remained a major challenge for engineers (Pacheo-Torgal & Jalali, 2011). These factors strengthens the need for the use of environmentally friendly materials to complement steel reinforcement usage in concrete for structural applications.

Among the materials recently adopted for improvement of concrete strengths are fibers of both natural and synthetic origins as well as steel fiber. They have much potentials to improve compressive, tensile stresses, flexural strengths, toughness, impact resistance and fracture energy of concrete, foundations storage tank and all concrete applications that require toughness (Balaguru & Shah, 1992; Behbahani, Nematollahi, & Farasatpour, 2011; Bentur & Mindness, 2007; Ede & Ige, 2014). Moreover, a study by Gassan and Bledzki (2001) mentioned that part of the advantage of using fibers in composites include the cost of materials, density and sustainability.

The low tensile strength of concrete matrix principally leads to the ever present internal micro-cracks and flaws. The presence of cracks provides a platform for the entry of harmful deleterious agent like chloride and CO_2 in the concrete structure. As concrete structure gets exposed to increasing cracks formation, the permeability of the structure rises thereby adversely affecting the ductility and durability of the concrete (Bentur & Mindness, 2007). After extensive researches worldwide, results have shown that the presence of micro fiber helps to reduce the propagation of crack in concrete structure. The presence of fiber restrains the crack propagation and arrests the development of tensions thereby leading to improved mechanical properties (Romualdi & Batson, 1963). The principal constituents of fiber reinforced concrete are Portland cement, aggregates (fine and coarse), water and discrete discontinuous fibers. Of the known fibers, synthetic fibers are more commonly approved than the natural fibers. However, awareness is growing for the exceptional qualities, long term benefits and the sustainability of natural fiber. This is due to the numerous direct advantages such as high specific weight/strength ratios, availability, light weight, ease of separation, high toughness, non-corrosive nature, low density, low cost, good thermal properties, reduced tool wear, less abrasion to processing equipment and renewability over synthetic fiber (Gassan & Bledzki, 2001). This is why it is receiving ample consideration especially in the improvement of concrete structures. The applications of fiber reinforced concrete (FRC) are gradually gaining ground all over the world as they are being used in structures such as airport and highway pavements, bridge decks, machine foundations, storage tank and all concrete applications that require toughness.

This research proposes to use *Momordica angustisepala* (Ma) fiber (a natural fiber) for the improvement of concrete. This natural fiber can be found in large qunatities in the West African forest zone and in particular in nations of Cameroon, Nigeria, Benin, Ghana and Cote d'Ivoire. It is of the "Cucubitaceae" family and is scientifically referred to as "*Momordica angustisepala* harms". The Ma fiber is obtained by pounding the thick stem of the plant and then thoroughly washed to removed impurities, leaving only the yellowish grey fibers. In Nigeria, Ma fiber is readily available in the wild and can also be cultivated legally in commercial quantities. It is traditionally reffered to as "local sponge" and as such used mostly for scrubbing and bathing. Further, Ma fiber is also utilized as filter for the process of palm oil and palm wine production and for woven traditional face mask. It is a locally accessible materials which is inexpensive and possesses unique properties which would likely influence positively the properties of conventional concrete.

In Ghana and some parts of west Africa, Ma fiber is used as a washing sponge, while the decorticated and washed twigs of the fiber are chewed. Moreover, extract of *Momordica angustisepala* is used as an abortifacient in local medicine in Southern parts of Nigeria (Achigan-Dako, 2012). A study by Atuanya, Ebunoha, Isaac, and Aigbodion (2012) found that the Ma fibers contains no toxic materials. However, the Ma fibers comprises mineralogical phase characteristic comparable with other agro-waste currently utilized in polymer composites. Further, the chemical analysis shows the dominant presence of Carbon (C), Oxygen (O) and hydrogen (H). The surface morphology of the Ma fiber material viewed in back scattered electron (BSE) was reported to be irregular in space, solid and longitudinal in nature as shown in Figure 1 (Atuanya et al., 2012).

The Ma fiber is not particularly known worldwide, therefore very limited researches has been done to examine the properties as potential constituent for fiber reinforced concrete (Ede, Olofinnade, & Awoyera, 2015). Few works have used Ma fiber to improve concrete strength. Study by Atuanya et al. (2012) showed the potentials of *Momordica angustisepala* fiber and that it can be used for composite material production due to the verified tensile modulus of 2–4.4 × 10^3 GPa and a tensile strength of 35–57.93 MPa. A comparison of various type of fibers including *Momordica angustisepala* fiber are presented in Table 1, while images of the Ma fibers and coconut fiber are shown in Figure 2.

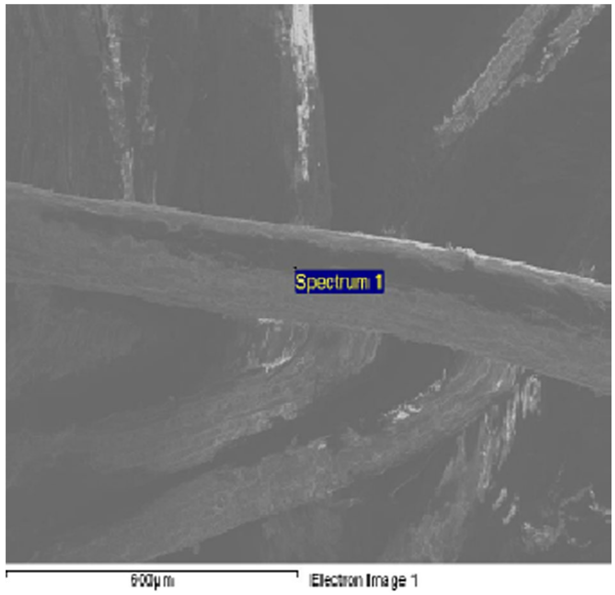


Figure 1. Typical surface morphology of Ma fiber (Atuanya et al., 2012).

Table 1. Properties of various fibers including Ma-fiber

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (GPa)
E-Glass	2.56	290–350	10
S-Glass	2.57	665	12.25
Aramid	1.44	435–455	9–10
Carbon	1.67	580	33–35
Ma-fiber	1.1	35–57.93	2–4.4
C-fiber	1.20	85	0.6–0.9
Jute	1.30	55–110	3.8
Sisal	1.50	75–90	1.4–3.2

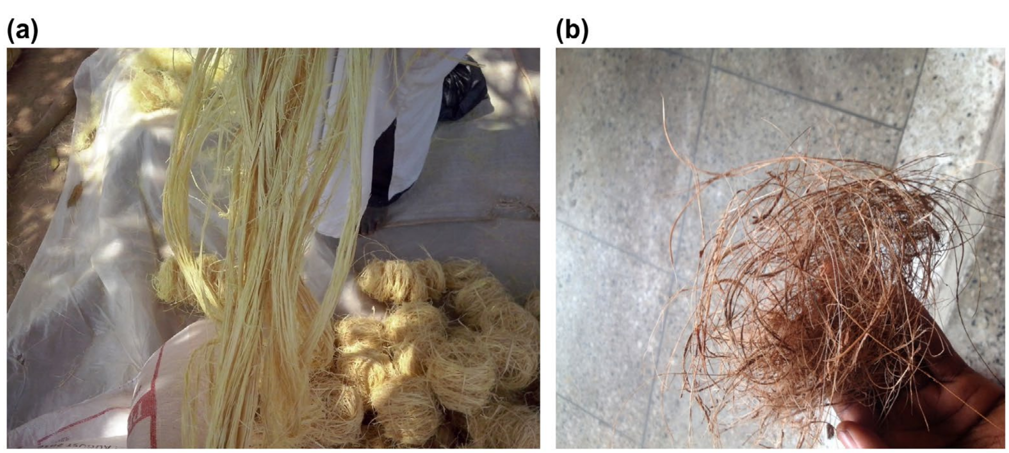
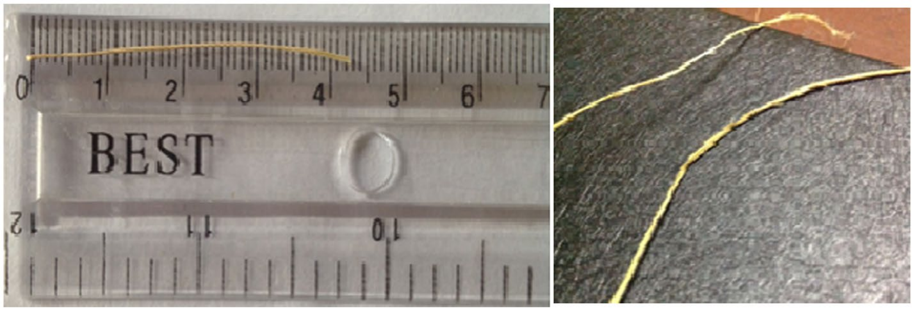


Figure 2. Images of (a) *Momordica angustisepala* fiber; (b) coconut fiber.

2. Methodology

This research presents the work on *Momordica angustisepala* (Ma) fiber reinforced normal concrete (*Ma*-FRNC) and compares it to that of the much known coconut fiber reinforced normal concrete (C-FRNC). It aims to enhance the properties of concrete with *Ma* fibers as the additive. The research

Figure 3a. Image showing the length of the used Ma fiber.



focuses on workability test, air content, compressive strength test and splitting tensile strength test on M*a*-FRNC and C-FRNC. Only one concrete mix ratio of 1:2:4 is considered for this research.

2.1. Material specification

The ordinary Portland cement brand of Dangote cement conforming to British standard (BS EN 197, 2000) was used for all the concrete mixes. River sand and granite aggregates of used for the study were sourced commercially. The size of granite aggregates adopted is meant to foster stability in the concrete structure. The river sand passing sieve openings of 0.075 to 6.0 mm was used in the production of all the concrete specimens while the crushed granite aggregate sizes of 10–20 mm were adopted. Water used was obtained from the University's water supply system. It was used for aggregate material washing, concrete mixing and curing of concrete test specimens. *Momordica angustisepala* and coconut fibers were added into the concrete mixtures for improving the concrete strength. A study by Yalley and Kwan (2006) emphasized that the critical aspect ratio for maximum strength in concrete is 125, any increase of the critical fiber length might leads to a corresponding decrease in strength. Consequently for this study, an aspect ratio of 120 was, that is 42 mm in length and 0.35 mm in diameter for both fibers as shown in Figures 3a and 3b.

2.2. Experimental design

The concrete mix design adopted for this study is 1:2:4 for grade M20. Maximum water-cement ratio of 0.6 was used for strength requirement 25 MPa. Further, 0.25, 0.5, 0.75 and 1% percentages of the fibers were used to replace sand in the concrete mixes. A study by Akinwumi, Awoyera, Olofinnade, Busari, and Okotie (2016) mentioned that natural sand will become more costly and depleted in the nearest future. The samples were cured for 7, 14, 21 and 28 days. The estimated volume of the required quantity of concrete for the research was 0.913 m^3 based on volume of the concrete mould sizes and factoring the shrinkage and material waste tendencies (see Table 2). Workability of the concrete mixes were measure through slump and according to the specification of BS EN 12350-2 (2009). The slump cone was cleaned, oiled and its larger base placed on a rigid, flat surface. Then, the slump cone was filled with the freshly mixed concrete in three layers with each layer approximately one-third of the volume of the slump cone and each layer is tampered 25 times (Figure 4b). Apparatus for air entrainment test is shown in Figure 4a, and test was conducted according to the specifications of ASTM C231, C231 M-14 (2014). Standard cube mould size of 150 × 150 × 150 mm and cylindrical mould of 150 mm diameter by 300 mm were used for the compressive strength and the splitting tensile tests respectively. The tests were carried out following the specfications of BS EN 12390-3 (2002) and BS EN 12390-6 (2002). The moulds were cleaned of dust particles and oiled on all sides before the concrete was poured into them. The specimens were stripped from the moulds 24 h after casting and submerged in a curing water tank until testing. The specimens were removed from the water after 7, 14, 21 and 28 days of submersion in water depending on the required time for testing the strength.

Figure 3b. Image showing the length of the used coconut fiber.

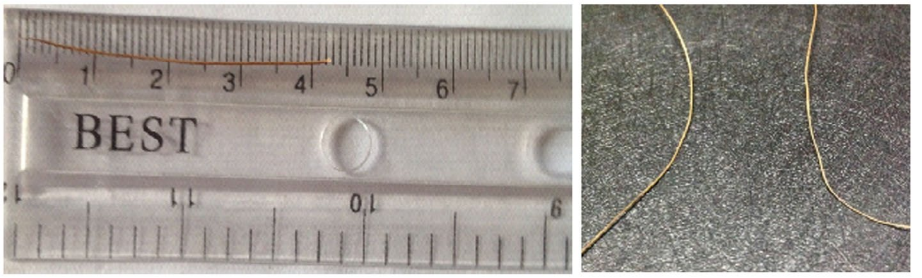


Figure 4a. Air entrainment apparatus.

Table 2. Mix quantities per cubic meter of concrete for different fiber content

Mix materials	Mass of materials per cubic meter of concrete				
	0.00%	0.25%	0.50%	0.75%	1.00%
Cement (kg)	64.5	64.5	64.5	64.5	64.5
Sand (kg)	129.00	128.68	128.35	128.03	127.71
Gravel (kg)	258.00	258.00	258.00	258.00	258.00
Fiber (kg)	0.00	0.322	0.645	0.967	1.290

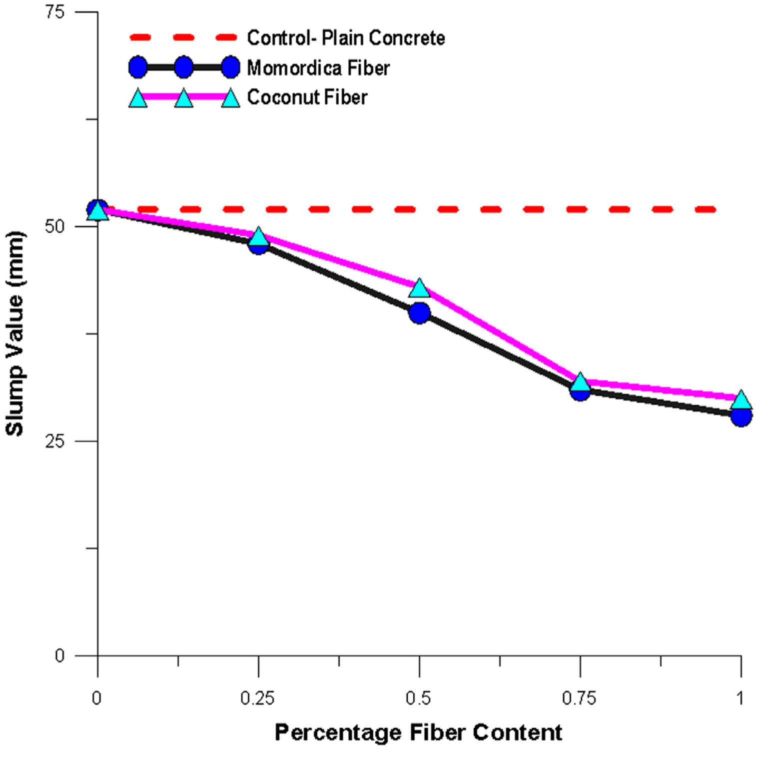
3. Results and discussions

3.1. Slump

The slump test was carried out to determine the workability of the concrete mixes with the results shown in Figure 5. From the figure, a reduction trend of the curve was noticed implying an inverse relation existed between the slump value and the fiber ratio. As the proportion of the fiber content increases the slump was observed to decrease; hence indicating poor workability of the concrete. This may be attributed to the holding capacity of the fibers, the ability of the fiber material to prevent shearing of concrete bring about a low slump value. The slump values for both fiber types are closely similar, however concrete containing coconut fiber possesses a higher slump values than the Ma fiber concrete. This implies that concrete mixes containing coconut fiber are more workable. Moreover, the high workability recorded in coconut fiber reinforced concrete may be due to the smooth surface of the fiber materials compare to the irregular shape and rough surface of the Ma fiber materials.

Figure 4b. Slump test.

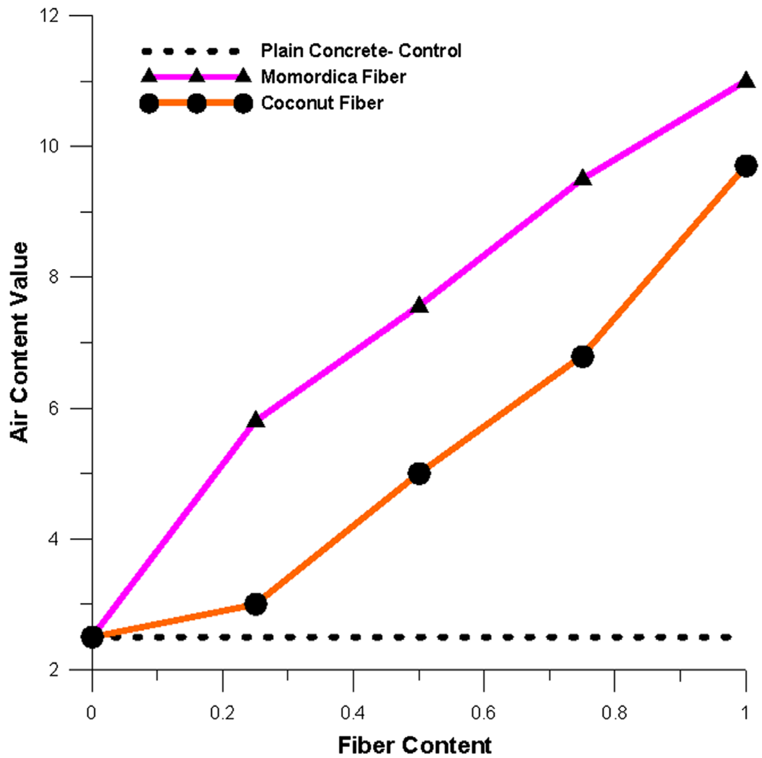
Figure 5. Slump values for the fibers and control samples.



3.2. Air content

Results of the air content test for both fiber types are shown in Figure 6. The results depict an increase in the air content values as the fiber ratio increased. This is as a result of the entrapped air present in the mix due to the presence of the fiber, balling and lumping effect which contributes to the existence of air voids. The *Ma*-FRNC was noticed to have more air content than coconut fiber and this will definitely influence the charateristic strength of the concrete. The rough and seperated

Figure 6. Air content values for the fibers and control sample.



appearance of the M*a* fiber material further enables it to trap air in the concrete unlike the thin and smooth appearance of the coconut fiber material.

3.3. Compressive strength

The compressive strength test results for both *Momordica angustisepala* fiber reinforced normal concrete (M*a*-FRNC) and coconut fiber reinforced normal concrete (C-FRNC) are shown in Figures 7a and 7b, 8a and 8b respectively. Relationship between the strength development and percentage fiber contents can be clearly seen in the Figure 7a for *Momordica angustisepala* fiber reinforced normal concrete (M*a*-FRNC) and in Figure 8a for coconut fiber reinforced normal concrete (C-FRNC). The Figures depicts the effect of varying the fiber content on the compressive strength of concrete. For the M*a*-FRNC, the curve ascends gradually from the 0 to 0.25% fiber content after which it starts to drop as the proportion of fiber content increases. The graph show an increase of 4.37 and 0.6% in compressive strength at 28 days for concrete mixes containing 0.25 and 0.5% Ma fiber respectively compare to the control. Meanwhile, a decrease of 23 and 28% was seen in concrete containing 0.75 and 1.0% Ma fiber compare to the control. However, for the C-FRNC, the curve ascends up to 0.5% fiber content before it begins to drop. The graph show an increase of 9 and 13% in compressive strength at 28 days for concrete mixes containing 0.25 and 0.5% coconut fiber respectively compare to the control. However, decrease of 13 and 24% was seen in concrete containing 0.75 and 1.0% coconut fiber compare to the control. Consequently, for M*a*-FRNC, the fiber content at which maximum compressive strength is obtained is 0.25% while for the C-FRNC is 0.5%. The 0.75 and 1.0% fiber content resulted in a decrease in strength for both fiber types. However, the obtained results for both material addition in concrete clearly indicate that coconut fiber has more significant influence in enhancing the compressive strength of the concrete compare to the Ma fiber material. This can be attributed to the increased presence of voids emanating from poor workability and balling effect during compaction in concrete containing Ma fiber. Figures 7b and 8b also clearly depict the strength development of the concrete specimens with the curing age. Generally, as expected incorporation of fibers at low level percentages significantly enhanced the compressive strength due to improve bonding between the concrete constituents. However, at high level fiber addition, the compressive

Figure 7a. Compressive strength variation with Momordica fiber content.

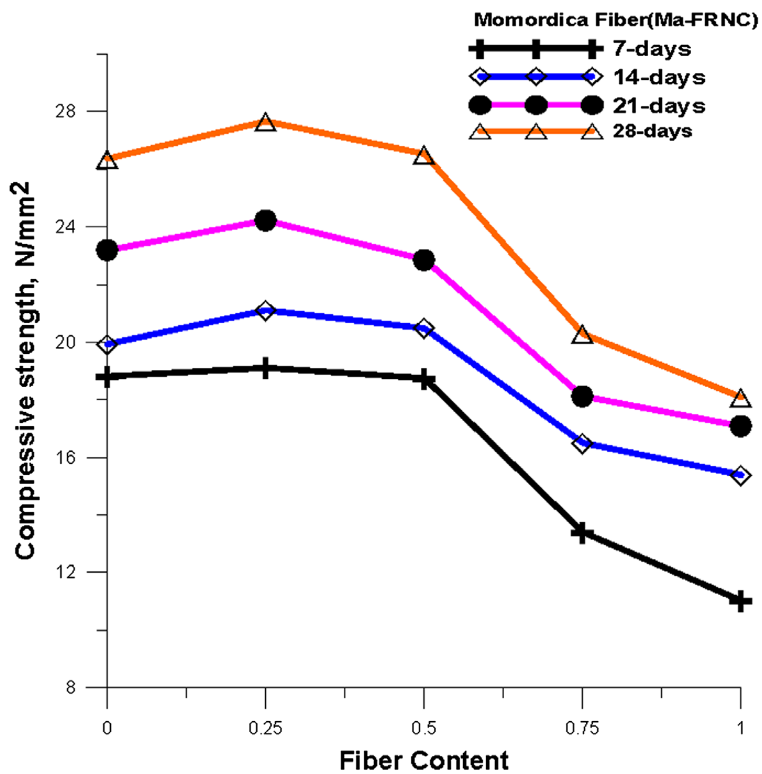


Figure 7b. Compressive strength variation with curing age of concrete containing Momordica fiber.

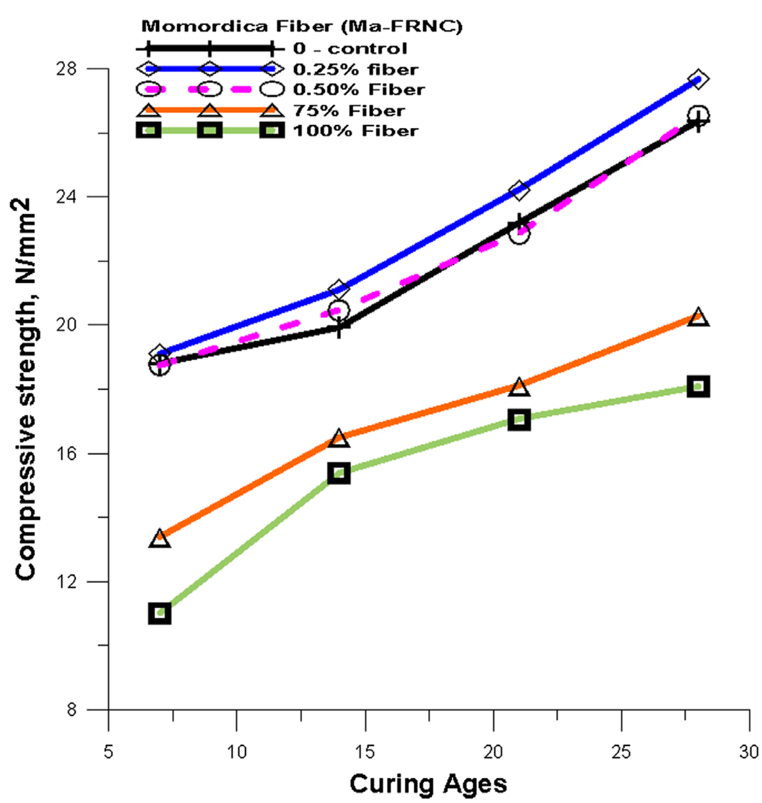


Figure 8a. Compressive strength variation with coconut fiber content.

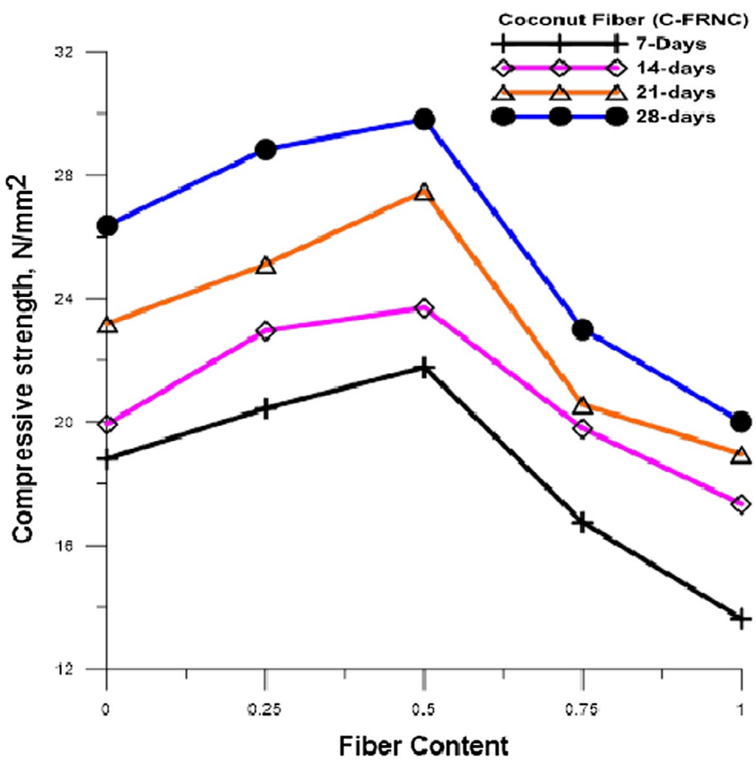


Figure 8b. Compressive strength variation with curing age of concrete containing coconut fiber.

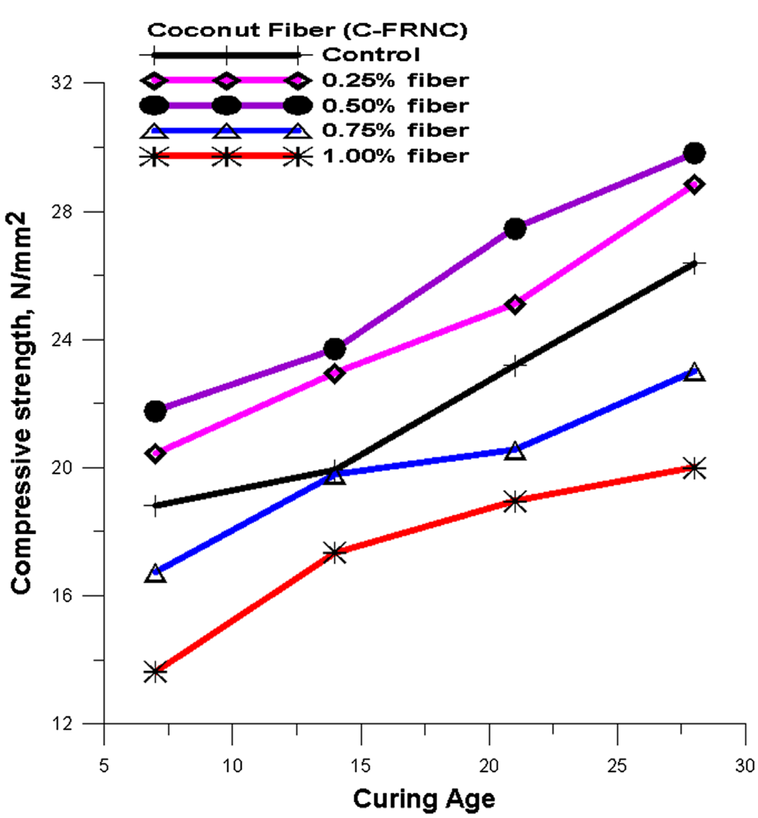
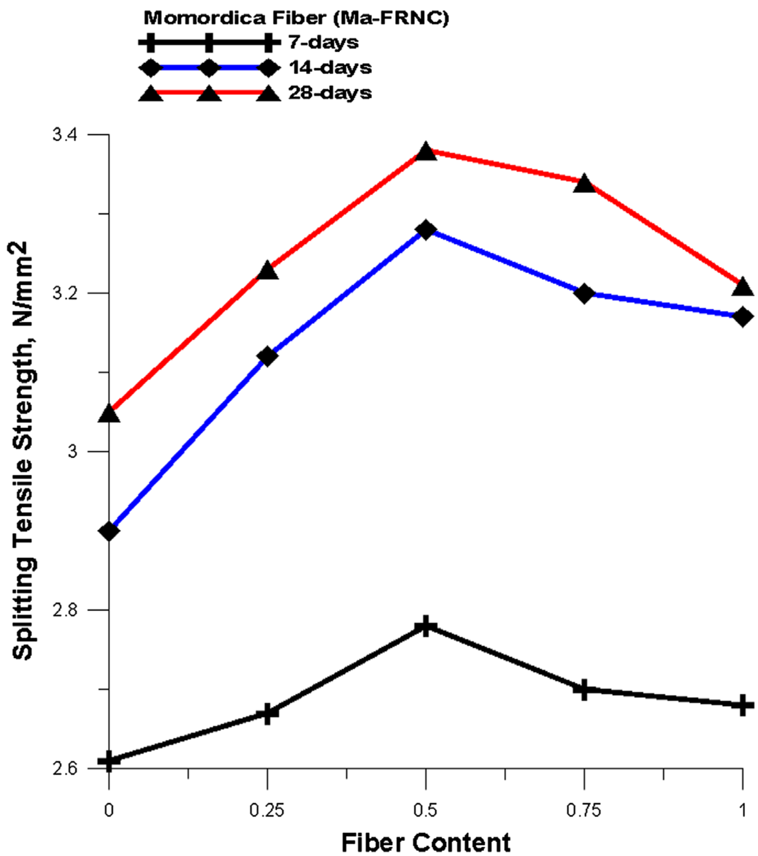


Figure 9a. Splitting tensile strength variation with Momordica fiber content.



strength was adversely affected. As pointed out by Yalley and Kwan (2006) that the low compressive strength might be as a result of difficulties in compaction which leads to more voids in the concrete. Figure 7b clearly shows the optimum effect of *Momordica angustisepala* fiber on the normal concrete to be 0.25%, while Figure 8b indicate the optimum effect of the coconut fiber to be 0.50%.

3.4. Splitting tensile strength

For the splitting tensile strength test, the M*a*-FRNC experienced the maximum tensile strength for fiber ratio of 0.5% after which it began to decrease gradually as shown in Figure 9a, while the C-FRNC experienced the maximum tensile strength for fiber ratio of 0.75% (Figure 10a) after which the tensile strength begins to gradually decrease. It can be observed that the splitting tensile strength increases with increase in fiber ratio because of the holding capacity of the fiber which helps in preventing the splitting of the concrete. After attaining the optimal value, the balling effect of fiber due to the incomplete mixing of fiber with the cement matrix drives down the tensile strength. However, both fibers improved the tensile strength of the concrete with M*a* fiber increasing the strength of concrete by 10.8% at 0.5% fiber content while coconut fiber increased the strength by 14.4% at 0.75% fiber volume content compare to the control. It should be noted that the 0% fiber content samples followed the typical indirect tensile strength of concrete of between 2.5 to 3.1 MPa (360–450 psi) according suggestions of (Neville, 1981), but got to the highest values of 3.38 and 3.49 MPa for the M*a*-FRNC and C-FRNC respectively. Figures 9b and 10b show the splitting tensile strength development of the concrete specimens with the curing age. As expected, the tensile strength developement increases with an increase in age. Futher, Figure 9b depicts the optimum effect of *Momordica angustisepala* fiber on the normal concrete to be 0.50%, while Figure 10b indicate the optimum influence of the coconut fiber to be 0.75%.

Figure 9b. Splitting tensile strength variation with curing age of concrete containing Momordica fiber.

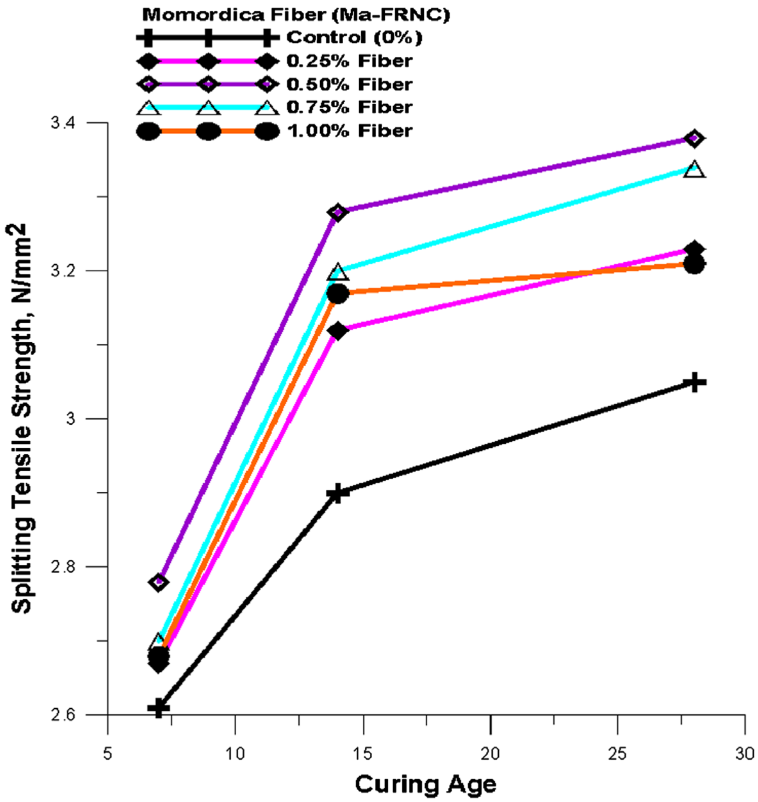


Figure 10a. Splitting tensile strength variation with coconut fiber content.

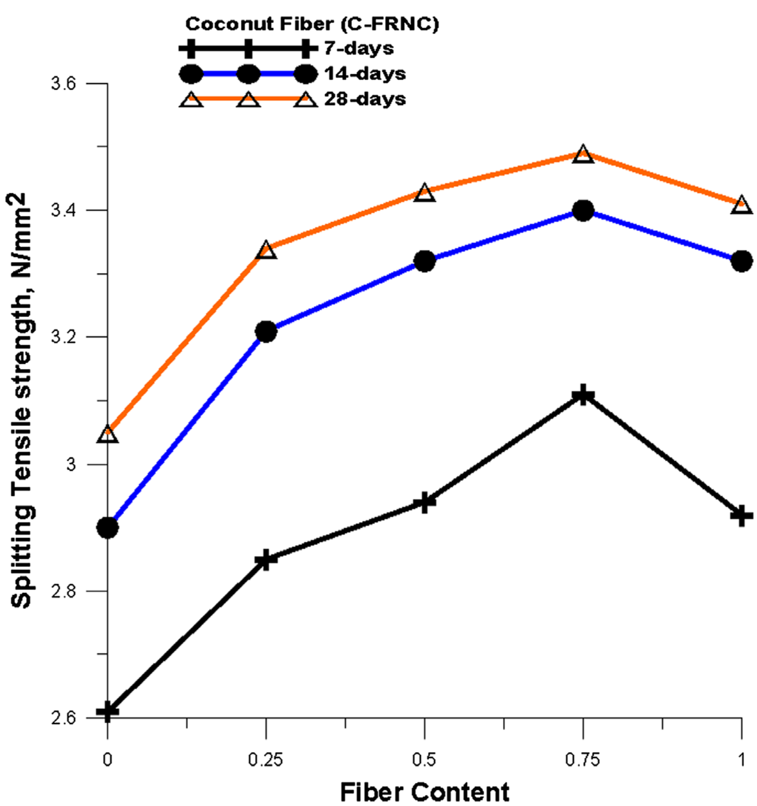


Figure 10b. Splitting tensile strength variation with curing age of concrete containing coconut fiber.

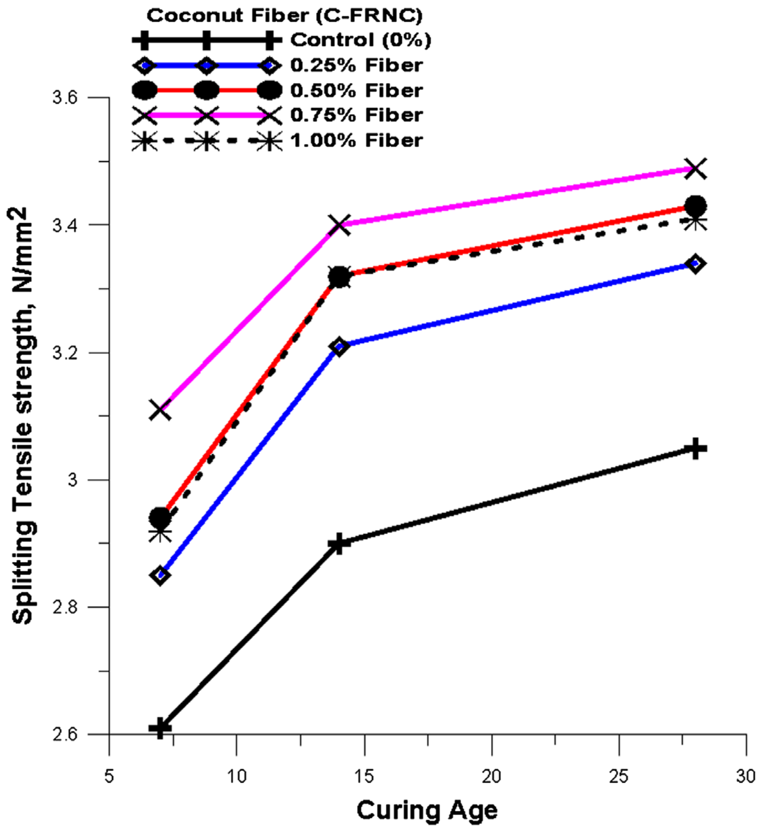


Figure 11. (a) Failed M*a*-fiber concrete cube (b) Concrete cylinder.

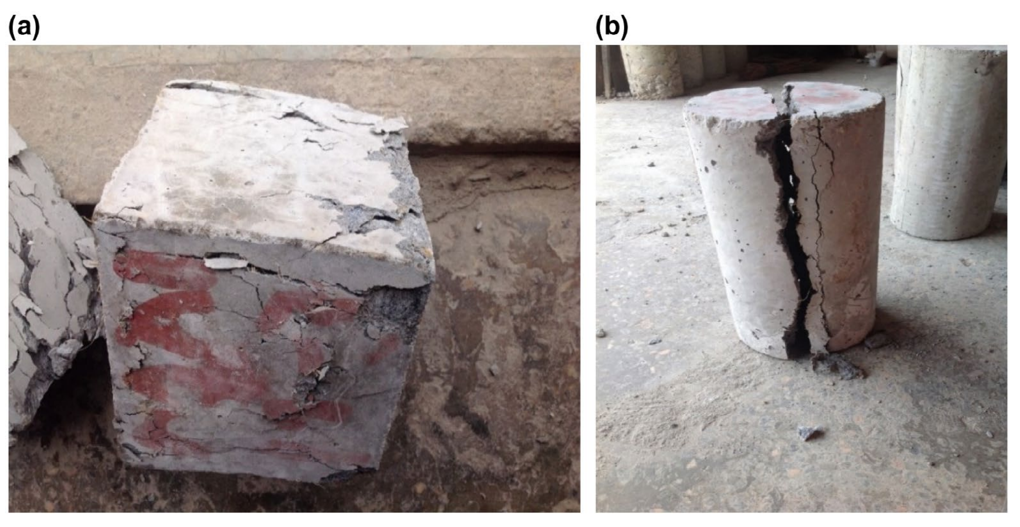


Figure 11(a) and (b) show the states of the failed specimen. When loads were applied to the concrete cube and cylinder via the compression machine, crack was noticed to originate from the trowelled face. This may be due to the direction of compaction since the trowelled face received the least compaction making it very brittle. Figure 12 shows M*a*-fiber concrete cylinder after splitting-tensile test indicating that the concrete was held together after failure. After crushing the samples to failure, the fibers held the samples together instead of falling apart like in the cases of non-reinforced specimen. This further explains the bridging effects of the fibers on the fiber reinforced concrete matrix. It can be seen that the brittle nature of plain concrete is due to the rapid propagation of

Figure 12. M*a*-fiber concrete cylinder after splitting-tensile test.

micro cracking under applied load while the presence of fibers reduces the speed of crack propagation, thereby enabling the fiber-reinforced concrete to sustain more load after the initial cracking. Optimum fiber contents of 0.25 and 0.5% enhanced respectively the compressive strength by 4.73% and the tensile strength by 10% for the M*a*-FRNC, while optimum fiber contents of 0.5 and 0.75% enhanced respectively the compressive strength by 9.37% and the tensile strength by 14.4% for the C-FRNC.

4. Conclusion

From the experimental assessment of compressive and tensile strengths of M*a*-FRNC and the C-FRNC, the following conclusions were drawn:

(1) Higher fiber contents resulted in lower slump values which implies low workability of the concrete.

(2) The optimum fiber content for improved compressive strength of 0.25 and 0.5% were proved for the M*a*-FRNC and the C-FRNC respectively, while 0.5 and 0.75% respectively was proved for the tensile strength.

(3) The optimum compressive strength gain of 4.73 and 9.37% were verified for M*a*-FRNC and C-FRNC respectively, while optimum tensile strength gain of 10 and 14.4% were obtained for the M*a*-FRNC and C-FRNC respectively.

(4) The rough and serrated appearance of the Ma fiber enabled it to trap air in the concrete (increased air entrainment). This explains the lower strength of the M*a*-fiber concrete when compared to the coconut fiber concrete.

Generally, the obtained results from this research clearly demonstrate that the use of this environmentally-friendly natural constitutive material improves the strength of concrete and can ultimately increase safety, reduce cost, improve durability and sustainability of concrete structures.

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