STRUCTURAL AND APPLICATION POTENTIALS OF NATURAL FIBERS FOR SUSTAINABLE PRODUCTION OF STRUCTURAL CONCRETE IN NIGERIA: A REVIEW

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Abstract: Fiber-reinforced concrete is yet to enjoy appreciable patronage in Nigeria. Most importantly, fibers from natural source, despite their abundance in Nigeria are rarely considered as material for structural concrete. This paper presents a review of natural fibers in the form of agricultural wastes available in Nigeria. This is for the purpose of using them for construction purpose in other to enhance sustainability in the production of structural concrete. The results of this review show a seeming concentration of researchers on the mechanical properties of concrete with natural fibers like compressive strength, tensile strength, impact energy, etc. Service life or durability properties of concrete with natural fibers are yet to engage the attention of researchers. It is thus recommended that both the mechanical and durability properties of concrete with natural fibers should be given equal attention, when research work on natural fibers is being formulated. This is with a view to bringing to fore, all the properties that will promote its use and thus help in enhancing sustainability in the production of structural concrete.

Keywords: Concrete composites, durability, mechanical properties, natural fibers, service life

Introduction

Concrete has become a well-established material for all manner of construction throughout all the known world (Fapohunda and Daramola, 2019). Some of the reasons being that: (i) it can be produced to varieties of strength specifications, (ii) it can be formed into any desired shape (iii) the materials for its production are universally available and (iv) it allows variations in composition, to the extent that it accommodates even wastes materials to be incorporated in its production. However, concrete suffers from a fundamental flaw. This flaw is that it has a lower tensile strength in relation to its compressive strength. This makes concrete to be brittle and susceptible to crack development under low tensile stress. Although, the normal concrete is usually reinforced with steel reinforcing bars to overcome this problem, it does not solve the problems of cracks and their propagation.

Thus, for some applications, like ground floor concreting, rigid pavement construction, etc., it is becoming increasingly popular to include small randomly distributed fibers. When these fibres of materials like asbestos, glass, plastic, steel, or sugarcane are added to the mortar or concrete composites (Nemati, 2015), fiber-reinforced composites or concrete (FRC) is formed.Fiber Reinforced Concrete (FRC) can thus be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibers. The use of fibers as construction material dates back to antiquity. For example, in the works and writings of Moses, translated by Douay-Rheims (1582), it was shown that fibers (called straw) were used for making bricks for construction works. Many materials have been used as fibers in recent times in mortars and concrete. Kaniraj and Fung (2018) grouped the fibers into four, namely: (i) metallic, (ii) synthetic, (iii) glass and (iv) natural. Metallic Fibers are steel, galvanized steel, stainless steel, copper, aluminium, etc. The synthetic fibers used in concrete include polyethylene, polypropylene, polyvinyl alcohol, etc. The natural Fibers are coir, oil palm empty fruit bunch, sisal, amongst others. In comparison with normal concrete, fiber-reinforced concrete has been found to display improved tensile and flexural strength, crack control performance, ductility, and shear strength (Kanda and Li 1998; Lee *et al*. 2012).

However, with the exception of natural fibers, all other fibers have relatively high cost. This discourages their use in developing countries like Nigeria. The natural fibers, in form of agricultural wastes, despite its abundance in Nigeria, has not been given the due attention as potential construction materials. This is despite the fact that application of natural fibres has been widely used in cement composites and earth blocks as construction materials for many years in some developing countries due to its availability and low cost (Nilsson, 1975; Aziz *et al.*, 1984; Coutts and Ni, 1995; Aggarwal, 1995; Ghavami *et al.*, 1999; Bouhicha *et al.*, 2005 and Binici*et al.*, 2005). Also, several studies by Ramaswamy *et al*., 1983; Aziz *et al*., 1984; Swamy, 1988; Brandt, 1995; Coutts and Ni, 1995; and Ghavami *et al*., 1999 showed that natural fibre scan increase the flexural strength, post-crack load bearing capacity, impact toughness, and bending strength of soil, concrete, and cement composites. Fiber-reinforced concrete is yet to enjoy appreciable patronage in Nigeria. Most importantly, fibers from natural source in form of agricultural waste, despite their abundance in Nigeria, are rarely considered as materials for structural concrete. Increasingly, these wastes are becoming an environmental nuisance because of improper disposal method.

Thus, the aim of this paper is to review research works on natural fiber that are found in Nigeria with a view to presenting an informed platform that could enable and enhance their innovative application in structural concrete production in Nigeria. The specific objectives will: (i) assess the properties that are of structural relevance for each of the natural fibers reviewed, and (ii) highlight some of the areas that are yet to be covered so that a whole structural response of concrete with Nigerian natural fiber can be captured, for effective structural application.

Natural fiber materials in Nigeria

The structural potentials of many natural fiber have been investigated, but the following review (in alphabetical order) is limited to those that are available in Nigeria.

Banana fiber

Banana fibers (Fig. 1) are wastes obtained from banana stems. According to Mostafa and Uddin (2015), over 10 million hectares of banana plantation, with an average of 1500 plants per hectare, exist in more than 160 countries globally, with Nigeria contributing about 389,000 hectares (FAO, 2006). Harvesting of banana creates tons of banana stems as waste. These wastes, in form of the stems, which are usually left to decompose, emit a huge amount of greenhouse gases like methane gas and carbon dioxide.

Fig. 1: Banana fibers under treatment (Mostafa and Uddin, 2015)

From the works of Kesavraman (2017) and Shanmuga and Thirumalini (2018), the length of banana fibers ranges between 50 – 300 mm; the specific gravity between 1.12 – 1.30; diameter between 0.05 – 0.15 mm density. The composition of banana stem fiber obtained from elemental analysis is presented in Table 1. It can be seen that banana fibers are generally ligno-celluloses material. The cellulose content serves as a deciding factor for mechanical properties along with micro fibril-angle.

Table 1: Elemental Composition of Banana Stem (Bilba *et al.*, 2007 and Samrat *et al.*, 2008)

Constituents	Percentage (%)
Cellulose	46. 25 – 56.00
Lignin	15.07 – 17.00
Extractives	4.46 – 7.00
Moisture	9.74 – 11.00
Ashes	8.65 – 9.00

A high cellulose content and low micro-fibril angle impart desirable mechanical properties for banana fibers. Lignins are associated with the hemicelluloses and play an important role in the natural decay resistance of the lignocelluloses material (Bilba *et al*., 2007). The ash content and the values of the extractives were relatively high. Thus, it may be necessary to pre-treat the plant in order to remove the extractives before the fiber is processed into composites (Ogunsile and Oladeji, 2016).

Structural properties

Mostafa and Uddin (2015) investigated the effects of treated and untreated banana fibers on the compressive and flexural strengths of compressed earth blocks (CEB). Two fiber lengths 25 and 50 mm were used, while the percentage of the fibers in the composite varied between 0 and 0.35% by weight of the composites. The results of all the 60 specimens of CEB tested showed that the average compressive strengths range between 3.76 – 5.92 N/mm^2. These values are more than minimum compressive strength for load bearing blocks of 3.45 N/mm^2 recommended by NIS-87 (2004). Also, the observed values for water absorption capacity averaged at 10.6%. All these values are lower than the maximum value of 12% set by NIS-87 (2004). Kesavraman (2017) studied the effects of banana fibers on metakaoline-based concrete. The percentage of fibers used varied from 0.5 – 2.0 % by weight of concrete. The results showed inclusion of banana fibers up to 15% not only increased 28-day compressive strength in relation to the control, but also improved impact resistance of the concrete. The numerical values of the compressive strength were 58.6, 55.9, and 51.9 N/mm^2, respectively at 0.5, 1.0 and 1.5% banana content. These values demonstrated that, inclusion of banana fibers can result in concrete with structural potential.

Coconut fiber

Coconut fiber is extracted from the outer shell of a coconut, which is common in areas along the coast in Nigeria with Lagos state accounting for over 70% placing Nigeria at 18th position of global coconut production (Olakulehin, 2018). According to Olakulehin, Nigeria is under-utilizing coconut and its product at 20%. According to Esmeraldo (2006), coconut fiber has cellulose content of 36 - 43% and lignin content of 41 – 45%, hence its greater resistance and hardness. The results of Scanning Electron Microscopy (SEM) conducted by Hasan *et al*. (2012) showed that the surface of coconut fibre is rough and thus expected to form a good bond within concrete composites.

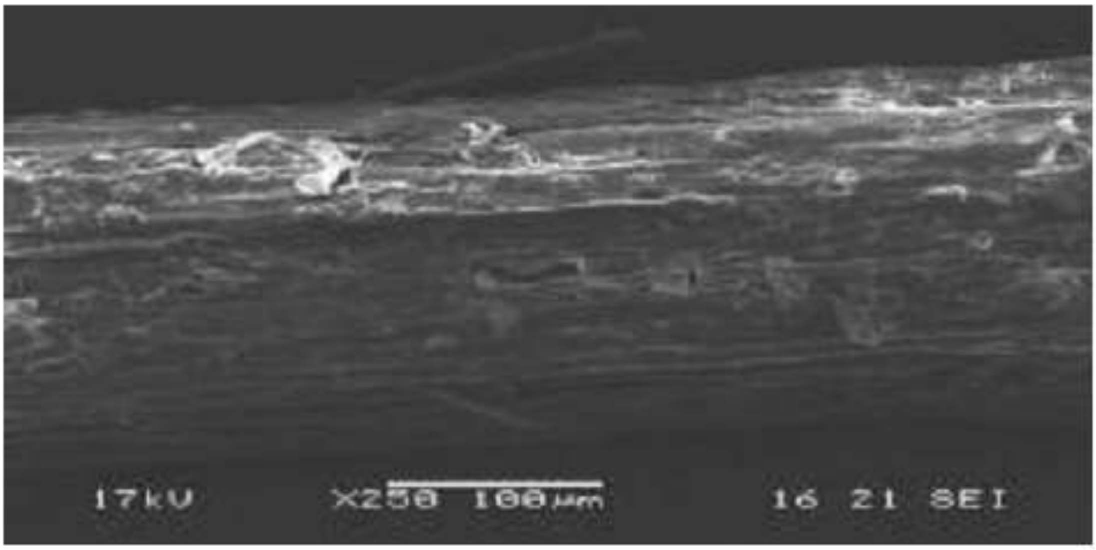

Fig. 2: Scanning electron micrograph showing the surface texture of coconut fiber (Hasan *et al.*, 2012)

Other properties of coconut fiber according to the works of Do Vale *et al*. (2006) and Hasan *et al*. (2012) are: average length of 60 – 230 mm, average thickness of 0.17 – 0.24, density of 1.18 g/cm^3, and tensile strength of 19.51 MPa.

Structural properties

Das Gupta *et al*. (1978) and Das Gupta *et al*. (1979) studied the mechanical properties of cement paste composites for different lengths and volume fractions of coconut fibres. They concluded that the tensile strength and modulus of rupture of cement paste increased when fibres up to 38 mm fibre length and 4% volume fraction were used. The tensile strength of cement paste composite was 1.9, 2.5, 2.8, 2.2 and 1.5MPa when it was reinforced with 38 mm long coconut fibre and the volume fractions of 2, 3, 4, 5 and 6%, respectively. The corresponding modulus of rupture was 3.6, 4.9, 5.45, 5.4 and 4.6MPa, respectively. The results also showed that 4% volume fraction of coconut fibres gave the highest mechanical properties amongst all tested cases. Buruah and Talukdar (2007) investigated the mechanical properties concrete with coconut fibers. The fibers volume fractions ranged from 0.5 to 2%. Their results showed that compressive strength, splitting tensile strength, modulus of rupture and shear strength of coconut fiber reinforced concrete increased with increase in fiber. Indeed, all the parameters mentioned, at 2% fiber volume fraction increased respectively by 13.7, 22.9, 28.0 and 32.7% in relation to the control. According to Hasan *et al*. (2016), the density of concrete with coconut fiber decreased with increase in fiber volume and progressively lower than the specimens without fibers. They thus conclude that concrete with fiber will be suitable for use as lightweight structural concrete. These results are in agreement with the findings of Lumingkewas *et al*. (2017). Ramli and Abas (2013) suggested that incorporation of short, discreet coconut fibers in high strength concrete up to 1.2% of binder volume improved the compressive and flexural strength by 13 and 9% respectively. They also concluded that fibers play a role in restraining the development of cracks. In his own works, Lumingkewas *et al*. (2017) studied the effect of fibres length and fibres content on the splitting tensile strength of coconut fibres reinforced concrete composite. They used fibre content of 1, 2, 3 and 4% by mass cement and fibres length of 5, 20 and 40 mm in the concrete. The results showed that coconut fibre length of 5 mm and fibre content of 3% in the concrete composite gave the composite 1.28 times higher splitting tensile strength than plain concrete. The results of investigation conducted by Sekar and Kandasamy (2018) largely agreed with these findings.

Cotton fiber

Cotton fiber is waste from cotton which is a major raw material in the textile industry. Major cotton producing states in Nigeria include Zamfara, Kano, Kaduna, Katsina, Sokoto, Kebbi, Ogun, Ondo, and Oyo.The use of cotton fibers in concrete composites, according to Alomayri and Low (2013) has several advantages which include low cost, renewable, and low weight. Some of the physical properties of cotton fiber are presented in Table 2.

Table 2: Some physical properties of cotton fiber (Fernandez, 2002; Shodhganga, 2019)

Properties	Values
Density	1.4 – 1.60 g/cm^3
Diameter	0.20 mm
Length	30 mm
Water absorption	0.97%
Elongation	7 – 8 %
Tensile Strength	287 – 597 MPa
Young’s Modulus	5.5 – 12. 5 GPa

It can be seen from the Table that cotton fiber has reasonably good tensile strength and Young Modulus of Elasticity that can be employed for structural purposes.

Structural properties

Alomayri and Low (2013) investigated the effects of cotton fibers on the structural properties of geopolymer concrete composites. The fiber contents were 0.3, 0.5, 0.7 and 1% by weight of cement. Their results showed that the compressive strength of the composite increased up to 0.5% fiber content and began to decrease afterwards (Fig. 3). Impact strength and hardness characteristics of the composites also followed the pattern of the compressive strength.

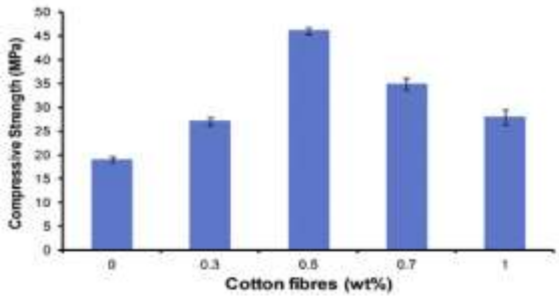

Fig. 3: Compressive strengths development of concrete composites with cotton fiber (Alomayri and Low, 2013)

Also, from the results of investigation conducted by Hettiwatte *et al*. (2019), cotton fiber in concrete showed increase in tensile strength and ductility of concrete, as well as little prone to brittle failure than the control. There is also the potential of concrete with cotton fiber to have improved flexural rigidity and stiffness characteristics. In astudy conducted by Rajpar *et al*. (2014) showed that, in addition to improved tensile strength by as much as 19.78%, the modulus of elasticity of samples with cotton fiber increased by 24.81%. Thus, for a constant second moment of inertia (I) and length (L), the stiffness ($\frac{EI}{L}$) and flexural rigidity (EI) of a structural material improve with addition of cotton fiber.There are however indications that exposition of composites with cotton fiber to elevated temperature weaken its structural capacity. The results of study by Alomayri *et al*. (2014) showed that with increase in temperature, cotton fibre composites exhibited a reduction in compressive strength, flexural strength, fracture toughness and brittle behaviour.

Empty palm oil fruit brunch fiber

Oil palm production is a major agricultural industry in Nigeria, especially in the southern states of Enugu, Imo, Ondo, Edo, Cross River, Delta, Akwa Ibom, Ekiti, Bayelsa, Rivers, Anambra, Oyo, Abia, Edo and Ogun. Globally, Nigeria occupies the 4th position in the production of oil palm (Bassey, 2016). The wastes generated from this industry are not properly disposed, and thus create environmental problems such as fouling and attraction of pests. Although, some of these wastes are burnt, environmental pollution also results. The chemical properties of empty palm oil fruit brunch fiber, as determined by Ismail and Yacoob (2011), are presented in Table 3.

Table 3: Chemical Composition of Empty Palm oil fruit brunch Fiber (Ismail and Yacoob (2011))

Chemical composition	Value (%)
Hot water solubles	12.8
Hemi-cellulose	2.1
Lignin	25
Cellulose	59
Alkali soluble	28
Pentosans	8.7
Ash	3.2

It can be seen that palm oil residues contain huge amounts of lignocellulosic materials, which is an asset that will help to strengthen the bonding or structure of building materials (Ismail and Hashim, 2008). The physical properties, like density, moisture content, tensile strength and bending stress, according to Ismail and Yacoob (2011), are respectively, 1.3 g/cm^3, 11%, 21MPa and 38 MPa.

Structural properties

Ismail and Yacoob (2011) investigated the possibility of using Empty Palm oil fruit brunch Fiber for load bearing lateritic brick. The fiber content they used ranged from 1 – 5% by weight of cement. Their results, in relation to the control, although showed a decreased in density with increase in fiber, the compressive strength however increased, with maximum strength obtained at 3%. Ramli and Dawood (2010) investigated the effect of Empty Palm oil fruit brunch Fiber on some properties of lightweight concrete. The fiber percentage used ranged from 0. 2 to 1.0% by volume of cement. Their results showed that the use of the fiber increased lightly the density of the concrete. Their results also reveal increase in compressive and flexural strengths with fiber up to 0.8 %. This can be observed in Fig. 4.

Ismail and Hashim (2008) investigated on the effect empty palm oil fruit brunch fiber normal concrete, using a fiber content of 0.25 and 0.5%. Their results showed that addition of fiber resulted in reduced workability. However, both the compressive and tensile strengths increased by as much as 39% in relation to the control samples. Effects of the use of palm oil fiber on durability property of foamed concrete was investigated by Lim *et al*. (2018). Their results showed that specimens reinforced with oil palm fibre and cured under tropical natural weather condition attained lesser variations of dimensional stability and higher 90-day strength performance index than the reference mix without oil palm fibre. The improvement was attributed to the ability of oil palm fiber to bridge the cement matrix and more production of C-S-H gel produced during irregular wetting process under tropical natural weather curing condition. They further reasoned that the gel was able to gradually blocked the penetration of water into the specimens and increased the compressive strength.

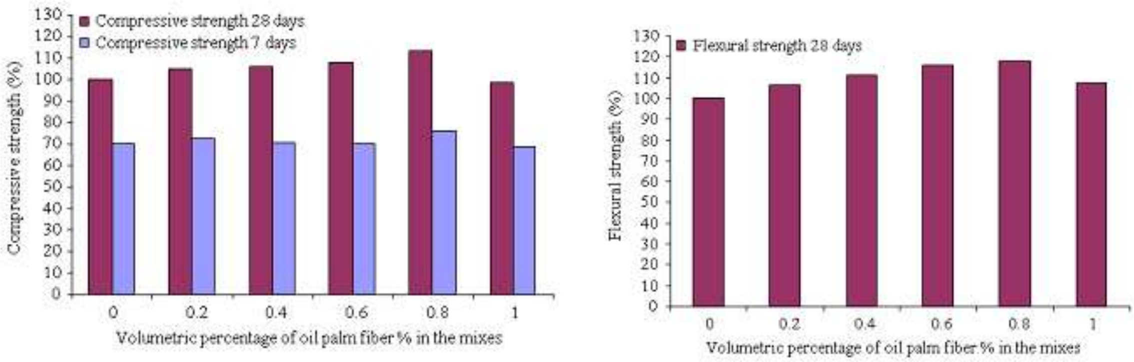

Fig. 4: Effect empty palm oil fruit brunch fiber on compressive and flexural strengths of lightweight concrete (Ramli and Dawood, 2010)

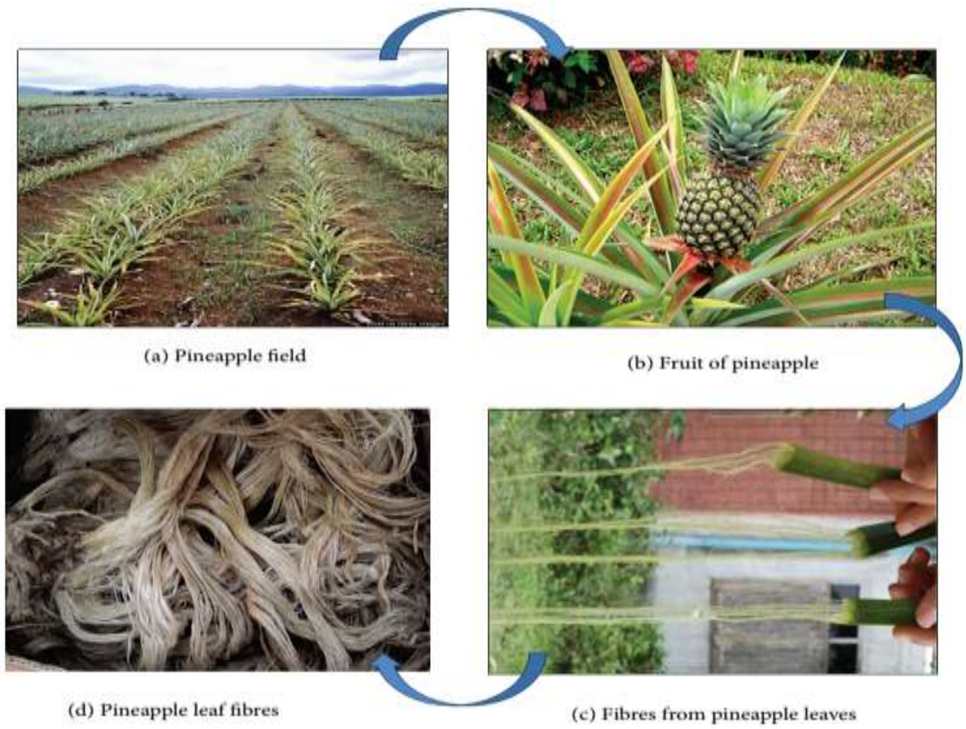

Fig. 5: Sequence of production of pine apple leaf fiber: (a) pine apple plantation (b) pineapple fruit (c) fiber extraction process from pine apple and (d) pine apple leaf fiber

Pineapple fiber

Pineapple is a tropical crop grown in the Abia, Akwa Ibom, Benue, Cross River, Edo, Ebonyi, Enugu, Imo and Ondo States of Nigeria. According to FAOSTAT (2011), Nigeria ranked 7th on the list of world producers, as well as the leading pineapple producer in Africa with a production capacity of 1,400,000 metric tons of fresh pineapple. Harvesting of pine apple, no doubt produces substantial waste in form of leaves out of which fibres are obtained (Fig. 5). There are indications that these fibers can be used as an alternative and renewable source of natural fibres in the production of structural concrete. According to Asim *et al*. (2015), pineapple is one of the natural fires having highest cellulosic content of nearly 80%.

Asim *et al*. (2015) also carried out a comprehensive review of pine apple leave fiber (PALF). Their findings showed that the density of PALF is similar to other natural fires while Young's modulus is very high (34.5 – 82.5 GPa), and tensile strength of between 413 – 1627 MPa, is the highest among the related natural fires reviewed. They therefore concluded that with these properties, PALF are suitable for application as building and construction materials, automotive components, and furniture.

Structural properties

Effect of PALF on structural properties of concrete was investigated by Roselin and Ravikumar (2018) in the proportion of 0.25, 0.50, 0.75 and 1.0% by weight of cement. They found out that the workability of the specimens reduced with increasing content of PALF. Their results also showed a progressive increase in compressive strength up to 0.75% in relation to the control specimens. Similar patterns were also observed in the splitting tensile strength and modulus of rupture results. They thus, concluded that provide that the PALF is not above 0.75% by weight of cement, incorporation of PALF improves the structural performance of the concrete. The flexural with the associated cracking patterns of concrete with PALF were investigated by Riya and Amritha (2018) by using beam specimens. Though, they observed that both the control specimens and the specimens with PALF failed by flexure, the specimens with PALF failed at higher load in comparison with the control specimens. Also, they observed similarity in crack initiation and propagation towards the compression zone, the specimens with PALF developed cracks at high load. They thus concluded that the use of PALF resulted in significant improvement in the flexural performance of the concrete beam specimens. In order to address the hydroscopic concerns of PALF, Nodounon (2018) investigated the effect of both treated and untreated PALF on load-bearing lateritic block. He discovered that all the treated samples displayed improved structural performances in terms of higher compressive strength, splitting tensile strength, modulus of rupture and impact resistance. He thus concluded that the structural performance of concrete with PALF will be enhanced if the PALF is treated prior to use.

Rice stalk fiber (RHF)

Wastes from rice milling industry are abundant in many parts of the world, and most especially in rice cultivating countries, like Nigeria. The use of wastes obtained from Nigerian milling industry as ash, for concrete production was part of earlier review work by Fapohunda *et al*. (2017). They were able to show that rice husk ash is very pozzolanic, and thus suitable for the production of structural concrete. Indications are now emerging that rice husk or rice straw (Fig. 6) can be used as fibre in concrete, not only to produce concrete of comparable strength in relation to the normal concrete, but specifically for crack control measures.

Fig. 6: Rice husk fiber (Surata et a., 2014)

Table 4: Effects of rice husk fiber on structural properties of concrete (Sivaraja and Kandasamy, 2011)

% RHF in Mix	f_c (MPa)	f_t (MPa)	f_m (MPa)	E (MPa)	f_s (MPa)	IE (KN.mm) Crack	IE (KN.mm) Failure
0	27.33	2.86	4.06	21.06	6.12	940	1020
0.5	27.33	3.12	4.42	22.12	6.22	1266	1550
1.0	27.94	3.26	4.58	23.24	6.26	1454	1896
1.5	27.98	3.48	4.64	23.83	6.68	1525	1947

The influence of rice husk fiber (RHF) on the structural performance of concrete was studied by Sivaraja and Kandasamy (2011). Their results showed that progressive increase in the addition of RHF reduced progressively the workability of the resulting concrete. The summary of results obtained for other properties is presented in Table 4.

In Table 4, f_c = compressive strength, f_t = splitting tensile strength, f_m = modulus of rupture, E = modulus of elasticity, f_s = shear strength, IE = impact energy. From the Table, it can be observed that there are improved performances of the concrete samples with increase the RHF content. The improved in performance was particularly significant for tensile strength, modulus of rupture and impact energy. Other result obtained by them is the absorption capacity of concrete specimens with RHF. They discovered that the usage of RHF brought about a significant increase of between 30 - 60% in absorption energy. The results of Ghofrani *et al*. (2015), apart from the concerns raised about increase in absorption capacity of specimens with RHF, largely agreed with these results.

Summary and potential of agricultural fibers for structural application implications

The above review focuses on agricultural fibers, that are not only available in Nigeria, but also have the potential to be used, or be made fit for use, for structural applications. Though, the review may not have addressed all the potential fibers in Nigeria, for example: bamboo fiber (Kolawole *et al*., 2017, Jute ("ewedu" in Yoruba) fiber (Olaoye *et al*., 2013), etc.; it nonetheless opens our eyes to potential source of materials for sustainable production of concrete in Nigeria, if properly researched into. However, a careful scrutiny of the review works reveals lack of standardization of measures in relation to whether the addition of fibers should be by weight or by volume. While some researchers added the fibers by weight (Mostafa and Uddin, 2015 and Roselin and Ravikumar, 2018), others added it by volume (Buruah and Talukdar, 2007 and Ramli and Dawood, 2010). The same applies to reference for the percentage replacement: is it in relation to the concrete or to the cement. This is necessary for reliable and credible comparison of results and promotion of its use.

Conclusions and Recommendations

From the above review, it can be easily seen that there is abundance of natural fibers in the form of agricultural wastes that can be used to achieve sustainability in the production of structural concrete. However, nearly all the review literature focused their attention on the mechanical properties like compressive strength, tensile strength, impact resistance, etc. of concrete with the fibers. Service life or durability properties of concrete with fibers like shrinkage, permeability, resistance to chloride intrusion, etc. are yet to be researched into. This is necessary to remove the concerns being raised about the ability of concrete with agricultural fibers to maintain its structural integrity during the service life. Thus, for us in Nigeria, when designing our investigation scheme, both the mechanical and the service life performance should be addressed.

Conflict of Interest

Authors declare that there is no conflict of interest.

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