Use of Coconut Husk Fiber for Improved Compressive and Flexural Strength of Concrete

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Abstract— Rapid crack propagation, brittle mode of failure and increased overload are common in concrete structures due to the low tensile strength of concrete. Although conventional steel reinforced concrete is the most popular method developed to reduce such problems, it is rather becoming expensive in terms of its costs and sustainability issues. Because of the huge capital investment to run the steel industry, many manufacturers in the developing nations try to cut corners by reducing the quality of steel thereby reducing the strength. This has led to a lot of challenges including building collapse accompanied by devastating economic and human loss. For these drawbacks, the development of contemporary concrete technologies such as eco-friendly and affordable coconut fiber reinforced concrete needs more investigation. This research studies the effect of coconut fibers on the strength of concrete which includes the compressive and the flexural strength of normal concrete. The fibers were used in different percentages (0%, 0.25%, 0.5%, 0.75%, and 1.0%) of the weight of the fine aggregates. 16 short beams were used for flexural strength at 0%, 0.5% and 1.0% fiber content which were tested after curing for 7 and 28 days. Destructive and nondestructive compressive tests were conducted on 40 concrete cubes to doubly validate the test results. The correlation of the two tests results were very good. The results showed that the compressive strength of coconut fiber-reinforced concrete increased with curing age and with increasing percentage of coconut fiber up to 0.5% then gradually began to decrease from 0.75% to 1.0%. The percentage strength gained at 28 days for 0.25%, 0.5%, 0.75% and 1.0% fiber contents with respect to the control sample are 4.58%, 38.13%, 8.56% and -2.42% respectively. The results for the flexural strength of concrete showed that strength gained at 28 days for 0.25%, 0.5% and 1.0% of coconut husk fiber were 28.82%, 22.15% and 0.42% respectively.

Index Terms— Coconut Fiber, Compressive Strength, Flexural Strength, Fiber Reinforced Concrete, Nondestructive Test.

1 Introduction

Concrete have been in use since the era of the Roman Empire and the earliest form of concrete was made from quicklime, pozzolana and an aggregate of pumice. Concrete was a new and revolutionary material to the Romans. Recent tests show that the Roman concrete had as much compressive strength as modern day Portland-cement concrete but had tensile strength far lower due to absence of reinforcement. Its mode of application was also discovered to be different [1]. Modern concrete is made from the mixture of Portland cement, fine and coarse aggregates, admixtures and water. Concrete is the primarily material adopted by the construction industry around the globe because of its fresh plastic state that gives it the ability to be molded into different shapes and affordability.

The usage of concrete worldwide is twice as much as wood, steel, plastics and aluminum put together and is only exceeded in the modern world by the usage of naturally occurring water.

Constituent materials of concrete production are at the base of large industries and commercial activities. The concrete production in the United States alone is over $30 billion per year industry. In Nigeria, it accounts for a very high percentage of large industry/commercial activities as the nation is very fast developing. It is the primary business of the Africa's richest man, Aliko Dangote. His cement plants are the largest manufacturer of cement (one of the constituent materials of concrete) in sub-Saharan Africa [2], [3].

Concrete is known for high compressive strength and low tensile strength (about 10% of the compressive strength). For this, ordinary concrete members are unable to resist tensile stresses and therefore is very prone to crack formation. Over the years, concrete technology have evolved through the aid of chemical admixtures and mineral admixtures such as fly ash, slag, etc., leading to increases in the compressive strength while its tensile strength is still very low. As a consequence of low tensile stresses, cracks form already under small loads and widen and propagate very quickly. Moreover, cracks are present even before loading start because of shrinkage phenomena. For this reasons, reinforcing bars are usually adopted to obtain reinforced concrete (RC) structures and this increases the total costs since steel material, labour and control/monitoring operations are expensive.

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The need for this research emanates from the numerous durability problems effecting the Nigerian construction industry [4], such as frequent building collapse [5] confusion on the design strength of reinforcement steel for normal concrete structures due to declining strength of steel bars used in Nigeria [6]. The British Standard [7] stipulates reinforcement strength 460N/mm², while lack of integrity is driving manufacturers to produce steel reinforcement of very low strength which is forcing the design engineers to adopt values of 410N/mm² and a times as low as 380N/mm². This makes the overall strength of Nigerian reinforced concrete structures to be quite low while elsewhere like in Europe, a minimum strength of 500N/mm² is the norm. The use of fibers reinforced concrete could help to cover up to a certain extent for the weakness in tensile strength, thereby limiting and impeding the number of building collapse in the country and also providing more stability to concrete structures. Therefore, this research carries out various forms of tests and analyses to determine the effect of using coconut husk fibers on the compressive and flexural strengths of concrete for different percentage fiber volumes. The major aim of this research is to examine the composite effect of coconut husk fiber on the strength of concrete.

To realize this aim, laboratory tests were carried on concrete cube samples to obtain compressive strengths of concrete using Portland cement, a mix ratio of 1:2:4, and 0%, 0.25%, 0.5%, 0.75% and 1% percentages of coconut husk fiber. Destructive and Non Destructive test with Schmidt Hammer Test were carried out on concrete cubes as to define a correlation between its readings and destructive compressive strength. Flexural tests were carried out 150mm x 150mm x 350mm concrete beams using same cement type and mix ratio, and 0.25, 0.5 and 1.0 percentages of coconut husk fiber. A correlation between the concrete strength and the percentage of coconut husk was established.

2 MATERIALS AND METHODS

2.1 Fibers

A Fiber is a fine hair like structure of an animal, vegetable, mineral, or synthetic origin. Fibers that are commercially available have diameters ranging from less than 0.004 mm (0.00015 in) to 0.2 mm (0.008 in) and they come in several different forms: short fibers (chopped), continuous single fibers (monofilament), untwisted bundles of continuous filaments (tow), and twisted bundles of continuous filaments (yarn). Fibers can be categorized according to their origin or chemical structure. High-strength fibers are used as reinforcements in composites materials and these include steel fibers, glass fibers, synthetic fibers and natural fibers [8]. Each of them can lend varying properties to concrete since concrete is a composite material per excellence. Fibers have been used as reinforcement in concrete since ancient times. Horse hair, asbestos fibers [9] and other alternatives were used and the notion of composite materials have grown over the years [10] causing fiber-reinforced concrete to remain a noteworthy topic of research interest.

Synthetic fibers are specifically engineered for concrete and they are made from man-made materials that can withstand the long-term alkaline environment of concrete.

Natural Fibers are made from plant, animal and mineral sources and they come in the form of leaf, skin, fruit and stalk fibers. The increase in the use of synthetic fibers after World War II saw to the significant decrease of natural fibers. Now, with the increased environmental considerations and the need to reduce waste of world natural resources, the use of natural fibers have resurged within the building industries. The interest in natural fibers within the building industry is basically technical and economical: technical because of its good insulation and safety properties and economical because of its favorable cost implications.

Coconut husk is the fibrous material found between the hard, internal shell and the outer coat of coconut. It is fundamentally used in the modern times for the production of floor mats, doormats, brushes, mattresses etc. while in the past times it was basically used as ropes and cordage. The known properties include improves resistance to explosive spalling in case of fire, improve impact resistance, improve structural strength, improve mix cohesion, reduction of steel reinforcement requirements and improved ductility.

2.2 Coconut Fiber

Coconut fiber is extracted from the outer shell of a coconut. Its scientific name and the plant family of the coconut fiber is "Cocos Nucifera" and "Arecaceae (Palm)" respectively, while it is commonly referred to as "Coir". The cultivation of coconut is concentrated in the tropical belts of Asia and East Africa [11]. There are two types of coconut fibers, white fibers that are obtained from immature coconuts and the brown fibers obtained from matured coconuts. Coconut fibers have low thermal conductivity while being tough and stiff [12]. According to [13], Coconut fibers can be easily gotten in Nigeria from local farmers in Badagry area of Lagos and in many Nigerian villages.

The stress-strain relationship for coconut fibers have been reported by some researchers [14]. Coconut fiber amongst all natural fibers is the most ductile. Coconut fibers have the capacity of taking strain 4-6 times more than that of other natural fibers as shown in Figs. 1a and 1b.

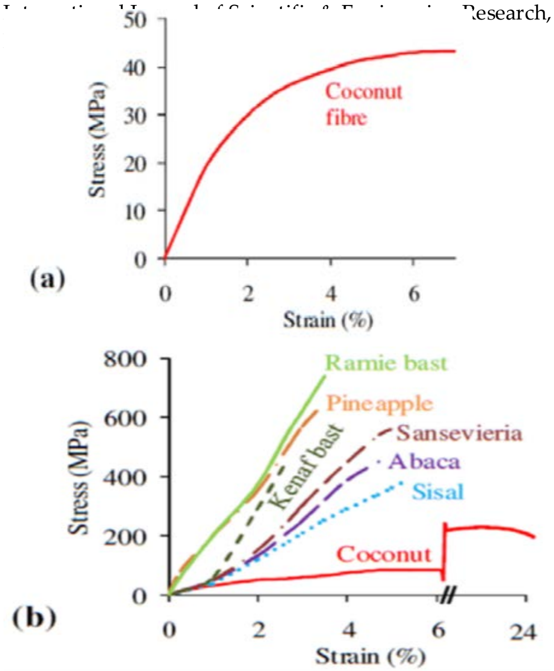

Fig. 1. Correlation of mechanical properties for natural fibres, [14], [15].

2.3 Concrete strength

There are two basic strengths looked out for in construction materials: compressive strength and tensile Strength. The strength of concrete in the hardened state is measured by the compressive strength through compressive test and is performance measure used by the engineer in structural design. The tensile strength is measured through the split tensile test or flexural tests. Concrete tensile strength is low (about 10% of the compressive strength) and is responsible to for the frequent cracks found in concrete structures. Growth of concrete technology have seen the continuous effort of the scientist to improve the tensile strength of concrete structures. In fact, the drive to improve the tensile strength of concrete have been responsible for the various categories of concrete in use worldwide such as mass concrete (no reinforcement), reinforced concrete (with steel re-bars), pre-stressed concrete (pre-stressed/post-tensioned with tendons) and the contemporary concrete made of various additives (including fiber reinforced concrete) [16]. The quest for improved tensile strength of concrete is the driving force behind the novelties and new frontiers of concrete research globally. The characteristic strength of normal concrete measured at 28 days of age should not be less than 27N/mm^2 [7].

2.4 Effects of Fibers on Concrete

The strength of concrete can be considerably increased by the addition of steel reinforcement which has been the norm over the years, but for concrete to have uniform tensile properties and improved micro cracking resisting behavior short fibers are beneficial. According to Visconti [7], it is possible to obtain a close to isotropic behavior for composite materials (such as concrete) with short fibers as compared to the anisotropic behavior of uni-direction fibers (such as steel re-bars of reinforced concrete.) The introduction of fibers in concrete have been increasing the tensile, flexural and compressive strength. Fibers help to stop the initiation, growth and propagation of micro-cracks in concrete thereby increasing the strength, ductility and toughness. Many researches have been conducted on the effects of fibers on concrete [18], [19], [20], [21], [22], [23], [24].

The uniform distribution of fibers throughout the concrete mix provides a near isotropic property not common to conventionally reinforced concrete. Fiber Reinforced Concrete (FRC) have been widely used in various structural applications such as tunnel lining and slope stabilization, runway, aircraft parking and pavements, blast resistant structures, thin shell, walls, pipes and manholes, dams and hydraulic structures, lighting poles and concrete repairs [25].

2.5 Test Methods

All tests were performed at the material testing laboratory of the Department of Civil Engineering, Covenant University Ota, Nigeria. The methodology involved the preparation of specimens of concrete materials and coconut husk fibers for the research. The test samples were prepared using 1:2:4 mix ratio and applying 0%, 0.25%, 0.5%, 0.75% and 1.0% fiber volume. Analysis were carried out on the strength of concrete by performing destructive and nondestructive compressive strength test and a two-point load flexural strength test. The same type of cement was used with fine aggregate (sharp sand), coarse aggregate (granite) and coconut husk fibers. Two cubes each for the five samples of concrete cubes at varying percentage of coconut fiber were used for the compressive test at 7 days, 14 days, 21 days and 28 days of curing. Two beams each for the flexural test of the first, second, third and fifth samples of fiber content were tested at 14 days and 28 days of curing. The average strength were computed for each sample after testing.

The cement used in this experimental investigation is ordinary Portland cement of 42.5 grade (Dangote Cement). The material used as fine aggregate in this project is Sharp Sand. The coarse aggregate used in this research is gravel and they are of 20mm, 10mm and 6mm sizes, crushed angular in shape. Fig. 2 shows the sequence used in this research study.

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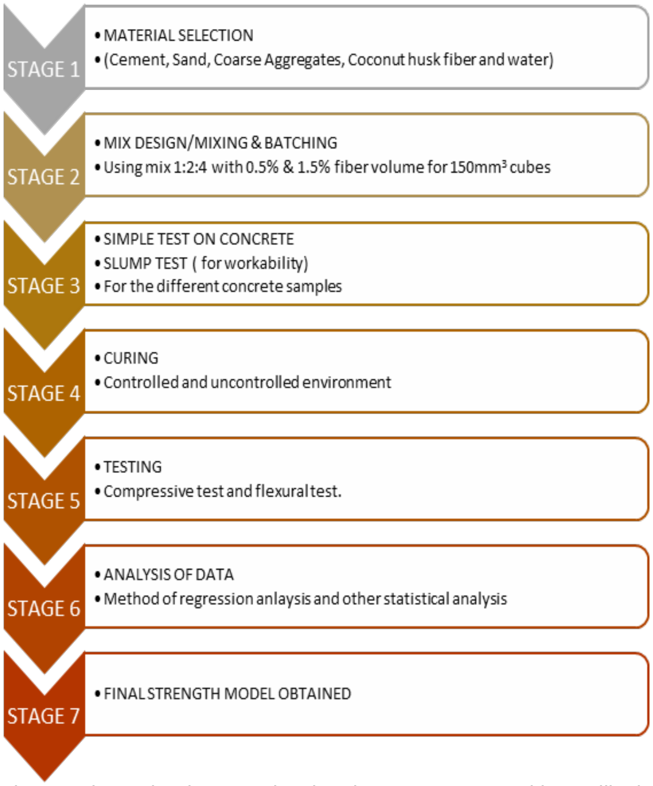

Fig. 2. Schematic Diagram Showing the Sequence Used in Facilitating this Research Study.

A good quality water was used for the concrete mix. The fibers selected for this experimental investigation is the Coconut husk fiber, which could be gotten from any part of Lagos State. They have higher tensile strength as compared to many other natural fibers. The length of the coconut husk fiber was 60 mm and the diameter 0.75 mm meaning the l/d ratio i.e. aspect ratio will be 80. A water/cement ratio of 0.58 (i.e. 14.5kg) was adopted. For the nondestructive test with Schmidt Rebound Hammer, an average of about 15 readings was taken. Fig. 3 show the Schmidt rebound number chart for compressive strength.

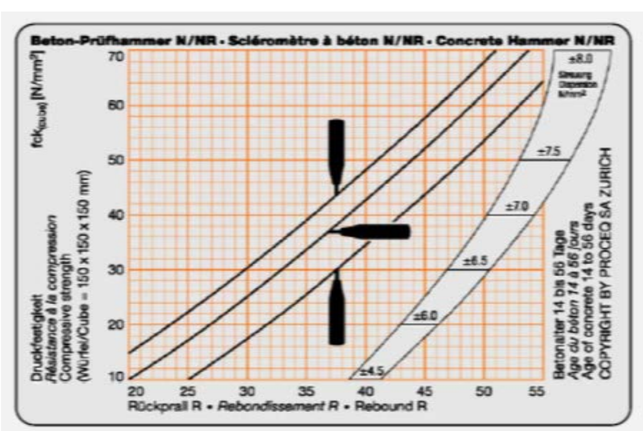

Fig. 3. Schmidt rebound number chart for compressive strength.

The destructive compressive test was conducted as per [26]. The cubes of standard size 150x150x150mm were used to find the compressive strength of concrete. Specimens were placed on the bearing surface of UTM, of capacity 100 tones without eccentricity and a uniform rate of loading of 550 kg/cm² per minute was applied till the failure of the cube. The maximum load was noted and the compressive strength was calculated. A two-point load flexural test was conducted on the beam samples of 150x150x700mm sizes.

3 Results and Discussion

The results compares the control samples of concrete without coconut fiber reinforcement and the samples with various percentages of fibers.

3.1 Non Destructive Testing

Each of the two opposite faces were impacted to get at least 15 readings to illustrate the sensitiveness of the test to the presence of aggregates and voids immediately underneath the plunger at the vertical position. Average of rebound numbers and standard deviations were calculated and the compressive strength were read off from the chart Fig. 3.

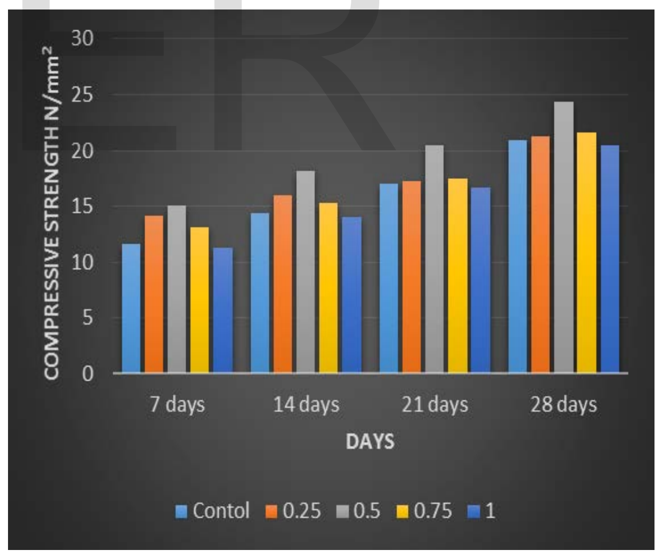

Fig. 4. Bar Chart showing 7, 14, 21 and 28 days rebound no of each percentage of coconut fibers'

Fig. 4 contains the bar chart showing 7, 14, 21 and 28 days strength read off from the rebound number for each percentage of coconut fibers.

Fig. 5 shows the rebound number versus compressive strength for each percentage of coconut fibers for 7 to 28 days curing. From the above results, 0.5% has the highest rebound number for all the samples while 1% fiber recorded the lowest rebound

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number as even the control (un-reinforced sample) had a higher rebound number than it.

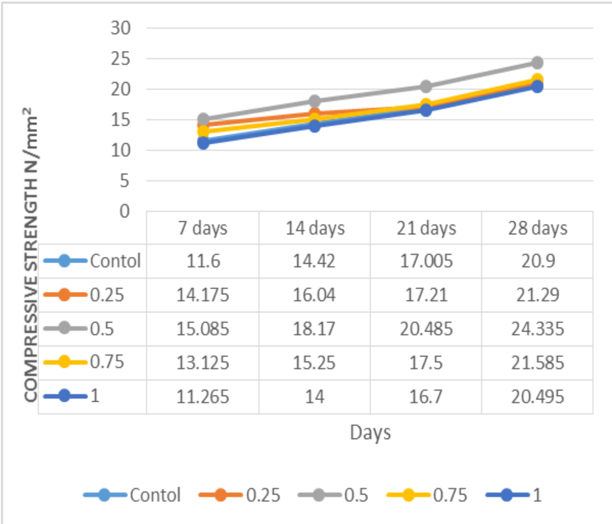

Fig. 5. Line Chart showing the rebound no of each percentage content of coconut fibers over 28 days

3.2 Destructive Test Results

Fig. 6 contains bar chart showing 7, 14, 21 and 28 days compressive strength for the samples. The compressive strength is the average of two cubes at each age of the various samples is shown in figure table 1.

Fig. 7 shows the trend of strength gained by each percentage of coconut fibers content from 7 to 28 days of curing.

Fig. 8 shows the correlation curve of compressive strength for NDT and destructive test results at 28 days. The trends of the two curves are very compatible and attest to the improvements derived from the coconut fiber reinforcement of concrete. It is observed that there is a higher increase in the value of the compressive strength obtained by destructive testing when compared to the nondestructive tests. The values of the NDT can be easily altered by variety of factors such as the smoothness of the cube surface, the presence of voids in the cubes and aggregate angularity within test areas. However the relationship between both the NDT and the destructive tests as expressed in Fig. 8 is good.

Fig. 9 shows the 14 and 28 days flexural strength for each percentage of coconut fibers. 0.25% fiber content offered the highest flexural strength and then followed closely by 0.5% fiber content.

TABLE 1
COMPRESSIVE STRENGTH OF CUBES OF THE VARIOUS SAMPLES

% of Fibers	7 days (N/mm^2)	14 days (N/mm^2)	21 days (N/mm^2)	28 days (N/mm^2)
Control	11.40	14.94	16.92	19.14
0.25	12.17	14.755	17.1	20.015
0.5	20.06	22.765	23.26	26.435
0.75	15.3	17.715	20.155	20.775
1	11.115	14.88	15.705	18.675

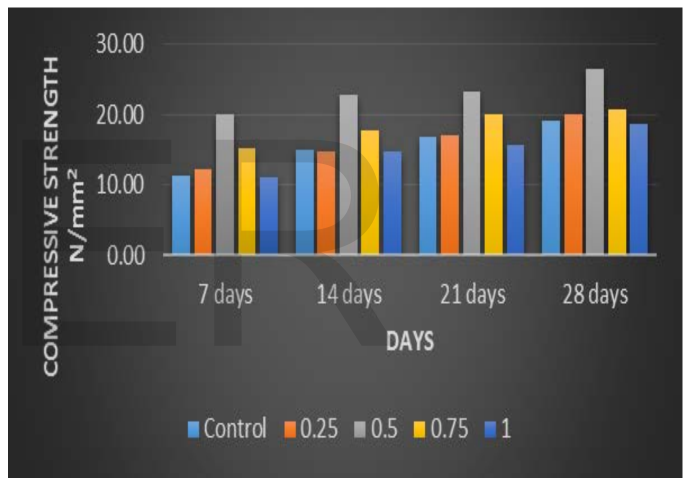

Fig. 6. Bar Chart showing 7, 14, 21 and 28 days compressive strength of each percentage of coconut fibers

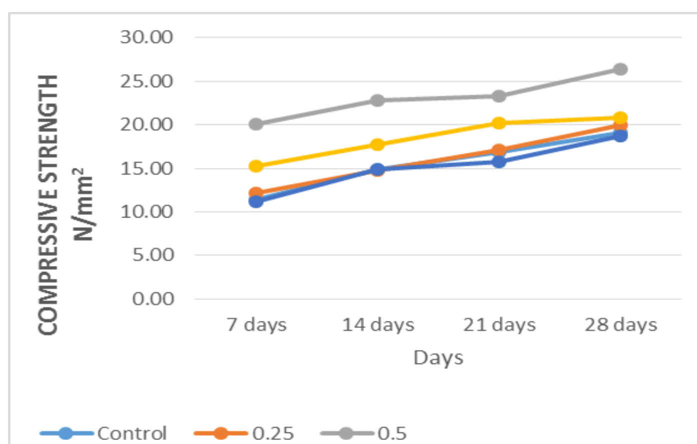

Fig. 7. Line Chart showing the trend of strength gained by each percentage content of coconut fibers over 28 days

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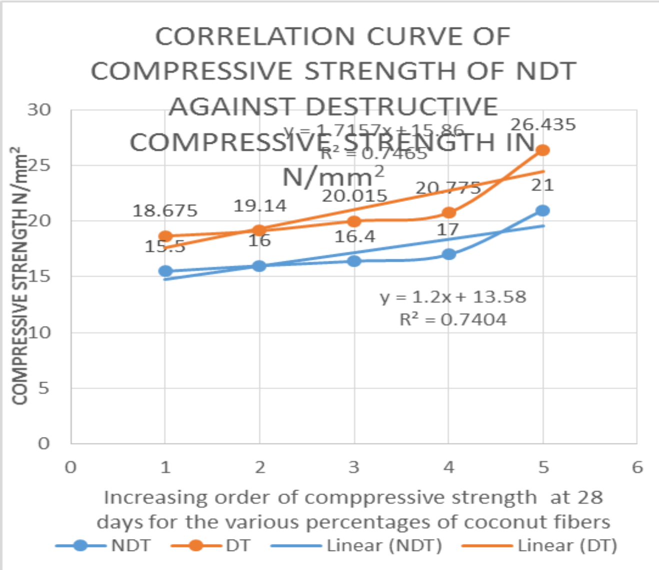

Fig. 8. Shows the correlation curve of compressive strength for NDT and destructive test results at 28 days.

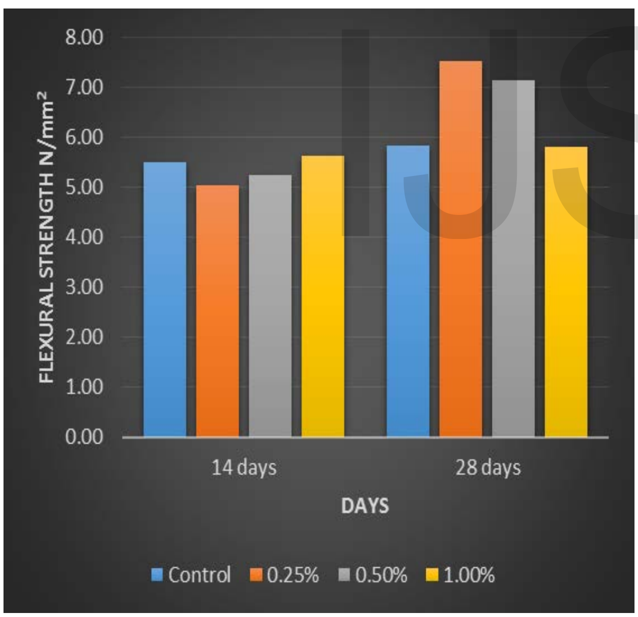

Fig. 9. Bar Chart showing 14 and 28 days flexural strength of each percentage of coconut fibers.

3.3 Discussion:

The differences in the compressive strength and flexural strength with respect to changes in the fiber content can be observed. From the results obtained, it is clear that the compressive and flexural strength of concrete is maximum when the fiber content is 0.5% of the fine aggregate of the concrete.

The coconut fiber reinforced concrete with 0.5% fiber increased by 38.13% for compression and 22.15% under flexural stress compared to the normal concrete. The sample with 0.25% fiber content achieved the optimum flexural strength but has a lower compressive strength gain when compared 0.5% fiber content. This makes 0.5% fiber content the best option to use in construction of concrete structures if coconut fibers are to be considered for compressive and flexural strength enhancement. The increase of fiber content beyond 0.75% will decrease the workability and compaction and thereby reduce the strength of concrete.

The phenomenon of Balling and Lumping of fibers was encountered during the sample preparation stage. The problem was overcame by sprinkling the fibers after the water, cement and sand had been poured into the concrete mixer before adding the coarse aggregates.

4 Conclusion

This research studied the compressive and flexural strength of coconut fiber reinforced concrete using destructive and non-destructive test methods. Conventional compression tests and Schmidt Hammer Rebounds on cube specimens and two point bending test on short beam specimens with different coconut fiber content were conducted. From the results and analysis of this research work it can be concluded that the addition of a 0.5% coconut husk fiber as a constitutive material of concrete affected the rheological properties of the fresh concrete, increased the compressive and flexural strength of concrete by 35.8% and 22.15% respectively. It was verified that coconut fiber content in the excess of 0.75% reduces the workability and drastically weakens the compressive and flexural strength. The presence of coconut fiber significantly improves the toughness and the ductility behavior of concrete. The test results have shown that coconut fiber at 0.5% content is optimal for enhancing the rheological and mechanical properties of concrete. This research proves that coconut fiber can be sustainably adopted for enhancing the properties of concrete especially in the tropics where this fiber abound and are not economically being put to use in the spirit of waste to wealth.
Based on the test results obtained, the integration of coconut fiber in making FRC composite would be one of the promising strategies to improve the performance of concrete. The greater improvement in flexural and toughness behavior of FRC is highly encouraging as the tensile strength enhancement have been one of the biggest challenges of concrete material behavior over the years. The improve toughness behavior will allow the coconut fiber FRC to absorb sufficient amount of energy and hence increase the ductility of structural members and give adequate warning before the ultimate capacity is attained and possibly save lives as fragile collapse is avoided. This will help greatly to reduce the incidence of building collapse in Nigeria. Further researches are recommended for fatigue, shear capacity, durability and field applications to confirm the promising test results obtained in this research.

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