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The Use of Coconut Fibre Ash as a Partial Replacement for Cement

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The cost of cement used in the concrete works is on the increase and unaffordable particularly in the rural areas, yet the need for housing and other construction especially sanitation facilities requiring this material keeps growing as population figure keeps increasing. Thus the need to find alternative binding materials that can be used solely or in partial replacement of cement for construction of sanitation facilities. Agricultural waste material, in this case, Coconut Fibre Ash (CFA), which is an environmental pollutant, are collected dried and burnt into ash. Coconut Fibre were obtained locally from Isu village of Anambra State. The fibres were properly dried and taken to National Geosciences Research Laboratory, Kaduna State where the fibres was burnt at a temperature range of 600℃ - 700℃ until the fibre s turned into ash.The initial time before firing the ash was 12 noon and the final time was 1:40 pm. The model of the industrial oven is Kohaszati Gyarepito Vallalat Bupapest. The ash was then allowed to be cool and collected and made to pass through 150 micron sieve. Sample of the ash was taken to determine the chemical composition of the coconut fibre ash, which in turn was used as a pozzolana in partial replacement of cement in concrete production. Concrete cubes were produced using various replacement levels of 0, 10, 30, 50, 70 and 90 percent of ordinary Portland cement (OPC) with CFA. A total of 50 cubes were produced and cured by immersing them in water for 7, 14, 28, 42, 63 & 90 days respectively.

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Properties such as compressive strength, slump test of cubes and flexural strength of beams were determined. The result showed that the compressive strength of cubes of 10 - 30% replacement increased from 9.23 N/mm^2 at 7 days curing to 90 days curing at 22.05 N/mm^2, meeting the requirement for heavy and light weight concreting. Also 10% replacement of OPC with CFA is recommended for concrete beam production.

Keywords: Coconuts fibre ash (CFA); pozzolans; supplementary cementitious material (SCM); curing; crushing; compressive strength.

1. INTRODUCTION

The high cost of construction materials like cement and reinforcement has led to increased cost of construction [1]. This, coupled with air pollution associated with cement production, has necessitated a search for an alternative binder which can be used sorely or in partial replacement of cement in Construction Industry [2]. More so, disposal of agricultural waste materials such as rice husk, groundnut husk, corn cob and coconut fibre have constituted an environmental challenge, hence the need to convert the waste to useful materials to minimimize their negative effect on the environment [3,4]. Research indicates that most materials that are rich in amorphous silica can be used in partial replacement of cement [1,5-8]. It has also been established that amorphous silica found in some pozzolanic materials reacts with lime more readily than those of crstalized form [9,10]. The use of such pozzolanas can lead to increased strength [11,12].

The American Society of Testing Materials (ASTM) defines pozzolans as siliceous or aluminous materials which possess little or no cementious properties but will,in the presence of moisture, react with lime at ordinary temperature to form acompound with pozzolanic properties. Examples of pozzolans include class C fly ash, which contains more than 10% CaO, blast furnance slag and silica fumes [13,14]. Also a pozzolan is a siliceous or siliceous and aluminous material which, in itself, possess little or no cementitious value but which will, in finely divided form and in presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementious properties [15,16]. The broad definition of pozzolan imparts no bearing on the origin of the material, only on its capability of reacting with calcium hydroxide and water. A quantification of this capability is comprised in the term pozzolanic activity.

Mixtures of calcined lime and finely ground reactive (alumino-) silicate materials were pioneered and developed as inorganic binders in the Antique world. Architectural remains of the minoan civilization on crete have shown evidence of the combined use of slaked lime and additions of finely ground potsherds for water proof renderings in baths, cisterns and aqueducts. Evidence of the deliberate use of volcanic materials such as volcanic ashes or tuffs by the acient Greeks dates back to at least 500-400 BC, as uncovered at the ancient city of Kameiros, Rhoodes [6]. In subsequent centuries the practice spread to the mainland and was eventually adopted and further developed by the Romans. The Romans used volcanic pumices and tuffs found in neighbouring territories, the famous ones found in pozzuolli (Naples), hence the name pozzolan, and in Segni (Latium). Preference was given to natural pozzolan sources such as German trass, but crushed ceramic waste was frequently used when natural deposits were not locally available. The exceptional lifetime and preservation conditions of some of the most famous Roman buildings such as Pantheon or Pont du Gard constructed using pozzolan-lime mortars and concrete testify to both the excellent workmanship reached by the Roman engineers and to the durable properties of the utilized binders.

Coconut fibre are agricultural waste products obtained in the processing of coconut oil and are available in large quantities in the tropical regions of the world, most especially in Africa, Asia and America. Coconut fibre are not commonly used in the construction industry but are often dumped as agricultural wastes. However, with the quest for affordable housing system for both the rural and urban population in the developing countries, various schemes focusing on cutting down conventional building material costs have been put forward. One of the suggestions in the forefront has been the sourcing, development and use of alternative, non-conventional local construction materials including the possibility of using some agricultural wastes and residues as partial or full replacement of conventional construction materials. In countries where abundant agricultural wastes are discharged, these wastes can be used as potential material or replacement material in construction industry [17,18]. One such alternative is coconut fibre, produced in abundance has the potential to be used as substitute coarse aggregate in concrete [16]. The huge amount of coconut fibre waste that are produced in the factories. The current waste disposal practice of incineration within the industry is normally done in an uncontrolled manner and contributes significantly to atmospheric pollution. Thus, these residues are becoming expensive to dispose by satisfying the requirements of environmental regulations. In such a situation, efforts are going on to improve the use of these by-products' through the development of value-added products. One of the ways of disposing these wastes would be the utilisation of coconut fibre into constructive building materials. Oil Palm Shell (OPS) are the hard endocarp that surrounds the palm kernel.

Extensive research and development in the understanding and applications of fibre concrete materials are still taking place all over the world. These activities include, amongst other things, the development of new, stronger fibres, better fibre reinforced composites and new substitutes [4]. Mechanical properties of coconut fibres reinforced polyester composites conducted by [11]. In this work, chemical modification of the coconut fibres by alkaline treatment was determined in order to use them as reinforcement in polyester resin. The mechanical properties were evaluated by tensile and fatigue tests. The surfaces of the fractured specimens were examined in order to assess the fracture mechanisms. The test results presented a decrease in fatigue life of composites when applied greater tension, due to bonding interfacial, which was not adequate.

[8] have investigated the possibilities of using coconut shell as aggregate in concrete. The findings indicated that water absorption of the coconut shell aggregate was high about 24% but the crushing value and impact value was comparable to that of other lightweight aggregates. They found that the average fresh concrete density and 28-day cube compressive strength of the concrete using coconut shell aggregate were 1975 kg/m^3 and 19.1 N/mm^2, respectively. It is concluded that crushed coconut shells are suitable when it is used as substitute for conventional aggregates in lightweight concrete production.

Previous study by [17] has shown that coconut shell is suitable as substitute for conventional aggregates in the structural concrete production. The results also indicated cost reduction of 30% for concrete produced from coconut shells. Apart from its use in production of fibre-roofing material, the other possibility of using coconut fibre as an aggregate in concrete production has not been given any serious attention. However, Adeyemi [19] carried out for one mix ratio (1:2:4) the suitability of coconut fibre as substitute for either fine or coarse aggregate in concrete production. It is examined that the coconut fibres were more suitable as low strength-giving lightweight aggregate when used to replace common coarse aggregate in concrete production.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for this study include coconut fibre which was obtained locally from Isu Village of Anambra State, Dangote Portland Cement, fine and coarse aggregated and water.

2.1.1 Coconut Fibre Ash (CFA)

The coconut fibre were properly dried and burnt at a temperature range of 600℃ - 700℃ in an oven at the National Geosciences Research Laboratory, Kaduna, until the fibres turned into ash (after about 1 hour forty minutes). The ash was allowed to cool and collected and the sieved using 150 micron sieve. A sample of the Coconut Fibre Ash (CFA) was collected and analyzed to determine the chemical composition.

2.1.2 Ordinary portland cement

This was purchased locally along the road at Awka, Anambra State, the brand was Dangote Cement.

2.1.3 Aggregates

The coarse and fine aggregates were obtained from the Civil Engineering Departmental Laboratory of Nnamdi Azikiwe University Awka. The size of the coarse aggregate used was 19 mm which allowed for easy compaction. The fine aggregate was of natural river source which was washed, dried and sieved to remove the finer particles or dust particles and organic matter and graded.

2.1.4 Water

Clean water was used for the concrete batching for adequate workability and ease of compaction. The water: cement ratio was 0.55.

2.2 Methods

The Coconut Fibre Ash (CFA) was mixed with cement in the following proportions: 0, 10, 30, 50, 70 and 100% replacement of cement by Coconut Fibre Ash (CFA). These proportions of Coconut Fibre Ash (CFA) to cement were used each to produce concrete mix of 1:2:4 for each CFA to cement ratio, concrete cubes were cast using 150 mm x 150 mm x 150 mm steel moulds and immersed in a water bath after slump test to determine the workability of the concrete. The results of the slump test are presented in Fig. 3. The optimum water: cement ratio used was 0.55.

The compressive strength of the concrete cubes was determined using Universal Testing Machine after 7, 14, 28, 42, 63 and 90 days curing respectively and the mean compressive strength results were presented in Fig. 2. In the compressive strength test two (2) specimens were selected and crushed at the end of each curing period to determine the mean compressive strength for the period of curing. This process was repeated for the various CFA: Cement ratio.

In order to determine the flexural strength of the concrete with the various percentage replacement of cement by CFA, concrete beams were cast using 100 mm x 100 mm x 500 mm long moulds and the same 1:2:4 concrete mix. The beams were immersed in water and one specimen, each was crushed after, 7, 14 and 28 days of curing respectively.

This procedure was repeated for the various CFA: Cement replacement, the moulds were all thoroughly cleaned and oil applied inside to prevent adhesion of the concrete to inner surfaces of the moulds.

3. RESULTS AND DISCUSSION

The result of the chemical analysis carried out on the coconut fibre ash shows that its chemical composition constituted some metallic and non-metallic oxides in different proportions. The various constituents were analyzed in the coconut fiber ash and their implications on concrete were enumerated briefly;

3.1 Silicon Oxide

Silicon oxide (SiO_2) was found to be 88.62%. Silicon oxide improves properties of concrete, in particular its compressive strenght, bond strenght and abrasive resistance. Addition of silicon oxide also reduces the permeability of concrete to chloride ions which protects the reinforcing steel of concrete from corrosion, especially in chloride rich environments such as coastal regions.

3.2 Chlorides

Chlorides contained in the coconut fiber ash were 0.44%. Chlorides particularly calcium chlorides, have been used to shorten the setting time of concrete,however calcium chloride (to a large extent) sodium chloride have been shown to leach calcium hydroxide and cause chemical changes in portland cement leading to loss of strenght, as well as attacking the steel reinforcement present in most concrete.

3.3 Sulphate

Sulphate in solution in contact with concrete can cause chemical changes to the cement, which can cause significant microstructural effects leading to the weakening of the cement binder (chemical sulphate attack). Sulphate solutions can also cause damage to porous cementitous materials through crystallization and recrystallization (salt attack).

3.4 Magnesium Oxide

The magnesium oxide found in the coconut fibre ash contains a quantity of 1.48%. Helps in proper and accurate expansion of concrete. It causes delayed expansion when present in large amounts. ASTM limits all cements to 6.0%.

3.5 Potassiuim Oxide

The alkali content of cement (mostly chloride) is reflected in the amount of potasium oxide and sodium oxide. Large amounts can cause certain difficulties in regulating setting times of cement. Low alkali cements, when used with calcium chloride in concrete can cause discoloration in toweled flatwork surfaces.

3.6 Titanium Dioxide

0.44% of Titanium dioxide was found in the sample analyses of coconut fibre ash. The concrete made with it can be called photocatalytic concrete and also smog eating concrete. It is environmental friendly and the best option for using it is in the construction industry.

3.7 Iron Oxide

Iron oxide contained 1.04% in coconut fiber ash analyzed, it is one of the principal contributors to the grey color of the coconut fiber ash.

3.8 Zinc Oxide

Increased Zinc oxide content of more than 0.02% could increase the flexural strenght of concrete.

3.9 Loss on Ignition (LOI)

Represents the percentage weight loss suffered by a sample of cement after heating to 1832F. Any water bonded to hydrated cement particles is expelled above this temperature. The higher the loss on ignition, the less strength the cement will develop. ASTM limits the loss on ignition to 3.0%. The loss on ignition value of coconut fiber ash analysed was 2.27%.

3.10 Effect of Curing Time on Compressive Strenght

The compressive strength increases at all percentage replacement with curing time as seen in the figure. At 0% replacementof coconut fibre ash compressive strenght increased gradually from 23.91 N/mm to 31.19 N/mm at 90 days.

For 10% replacement of coconut fibre ash also, compressive strength increased from 9.23 N/mm at 7 days curing time to 22.05 N/mm. At 30% replacement of coconut fiber ash compressive strenght increased from 7.60 N/mm to 19.95 N/mm at 90 days. For 50% replacement of CFA Compressive strenght increased from 3.49 N/mm at 7 days to 12.87 N/mm at 90 days.

Also it was observed also that at 70% replacement of coconut fibre ashcompressive strenght increased from 2.35 N/mm at 7 days curing to 11.01 N/mm at 90 days curing time.

For the last replacement of coconut fibre ash, compressive strength increased from 1.56 N/mm at 7 days curing period to 9.07 N/mm at 100% replacement at 90 days curing period.

It can therefore be said conclusively that giving more time for curing concrete cubes the compressive strength increases.

3.11 Effect of Coconut Fibre Ash as Partial Replacement for Cement on Compressive Strenth

The compressive strenght decreases with increase in the percentage replacement of coconut fibre ash for all the curing time as seen in Fig. 2.

For 7 days curing period,compressive strenght decreased from 23.91 N/mm^2 to 1.56 N/mm^2 at 100% replacement of coconut fibre ash. At 14 days curing time compressive strength decreased from 25.97 N/mm^2 at 0% replacement to 2.67 N/mm^2 at 100% replacement of coconut fibre ash. Also at 28 days curing period, compressive strenght decreased from 28.81 N/mm^2 to 5.37 N/mm^2.

At 42 days curing period compressive strenght decreased from 30.15 N/mm^2 at 0% replacement to 7.81 N/mm^2 at 100% replcement of coconut fibre ash. Also at 63 days curing period compressive strength decreased from 31.15 N/mm^2 at 0% replacement of coconut fibre ash to 8.99 N/mm^2 at 100% replacement of coconut fibre ash.

Finally for 90 days curing period it was observed that the compressive strength decreased from 31.19 N/mm^2 at 0% replacement of coconut fiber ash to 9.07 N/mm^2 at 100% replacement of coconut fiber ash.

It can therefore be said conclusively that compressive strength decreases with increase in the percentage of replacement of coconut fiber ash.

Fig. 3 shows the result of the slump test. It can be observed that increasing the percentage of the coconut fibre ash decreases the value of the slump. This indicates that the concrete becomes less stiff as the coconut fibre ash increases. Percentage replacement between 0 and 30% have slump values of between 120 mm and 85 mm which is good as standard slump values ranges from 75 mm – 150 mm.

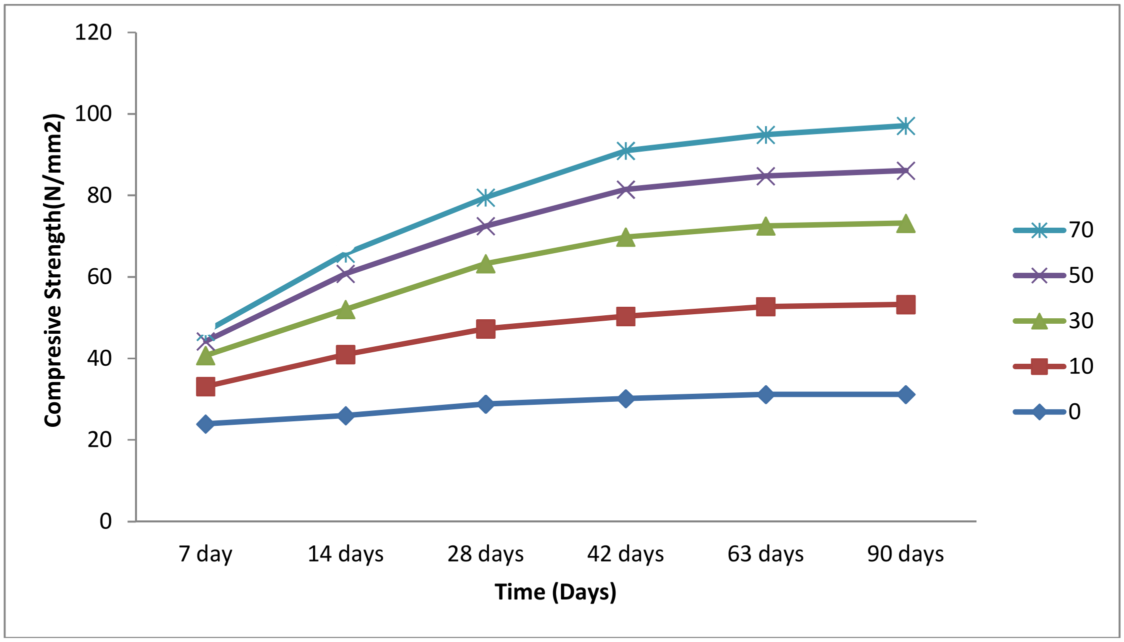

Fig. 1. Effect of curing time on compressive strength

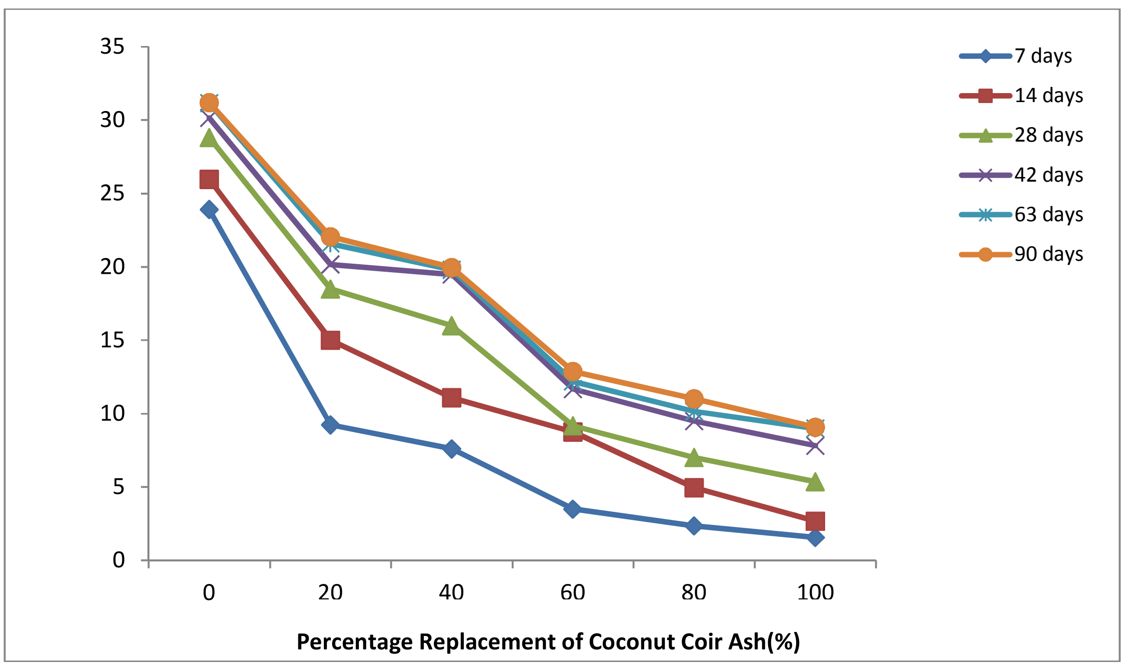

Fig. 2. Effect of coconut fibre ash as partial replacement for cement on compressive strenght

3.12 Effect of Curing Time on Flexural Strenght

The flexural strenght increases with curing time. At 0% percentage replacement of coconut fiber ash, flexural strenght increased from 4.52 N/mm^2 at 7 days curing period to 6.32 N/mm^2 at 28 days curing period. At 10% replacement of coconut fiber ash, flexural strenght increased from 1.76 N/mm^2 at 7 days curing period to 4.23 N/mm^2 at 28 days curing period. At 30% replacement of coconut fibre ash, flexural strenght increased from 1.44 N/mm to 4.09 N/mm^2 at 28 days curing period.

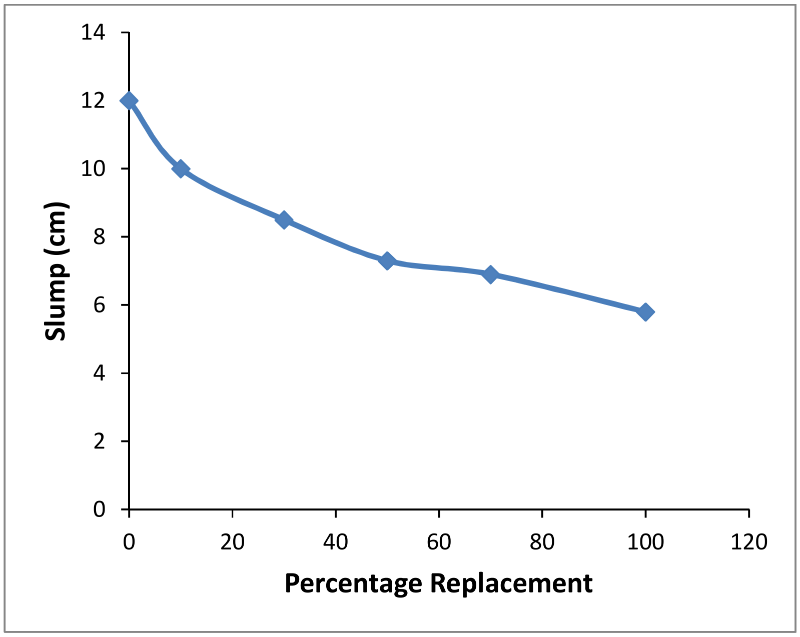

Fig. 3. Graph showing slump values

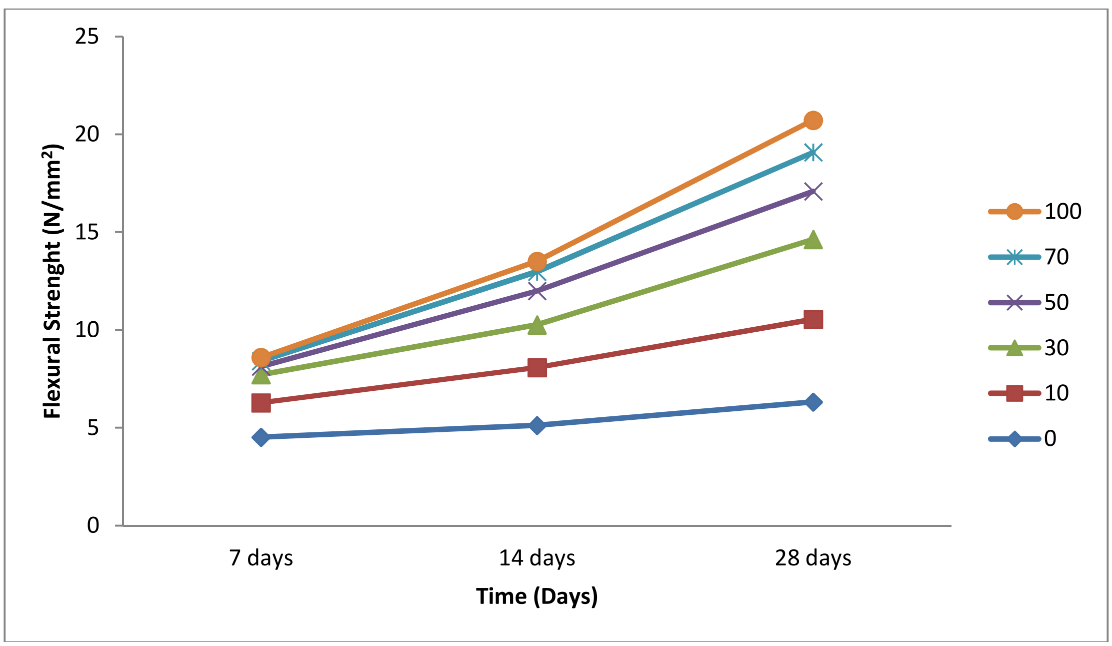

Fig. 4. Effect of curing time on flexural strenght

It was observed that at 50% replacement of coconut fibre ash, that flexural strenght of the beam increased from 0.41 N/mm^2 at 7 days curing time to 2.45 N/mm at 28 days curing time. For 70% replacement of coconut fiber ash the flexural strength also increased from 0.28 N/mm^2 at 7 days curing time to 1.99 N/mm^2 at 28 days curing period.

Finally it was observed that at 100% percentage replacement of coconut fibre ash that the flexural strenght of the beam increased from 0.91 N/mm^2 at 7 days curing time to 1.64 N/mm^2 at 28 days curing period.

Conclusively flexural strenght of beam increases with more curing time.

3.13 Effect of Percentage Replacement of Coconut Fibre Ash on Flexural Strenght

The flexural strenght decreased with increase in percentage replacement of coconut fiber ash. For 7 days curing period, it was observed that the flexural strenght decreased fom 4.52 N/mm^2 at 0% replacement of coconut fibre ash to 0.19 N/mm^2 at 100% replacement of coconut fibre ash, this decrease was 95.80%.

Also at 14 days curing period it was observed that the flexural strenght decreased from 5.12 N/mm^2 at 0% replacement to 0.53 N/mm^2 at 100% replacement this decrease was 89.65%.

Finally at 28 days curing period the flexural strenght decreased from 6.32 N/mm^2 at 0% replacement of coconut fibre ash to 1.64 N/mm^2 at 100% replacement of coconutt fiber ash, this decrease was 74.05%.

Fig. 6 shows the result of the strength of activity index. It can be observed that increasing the percentage of the coconut fibre ash decreases the strength percentage. It further shows that with more curing period the strength of activity index increases. At only 10% replacement of coconut fiber ash with curing period up to 90 days, the concrete cube meets the requirement of 70% strength of activity index which is acceptable minimum of a satisfactory strength of activity index. It was observed that 30, 50, 70 and 100% replacement of coconut fiber ash did not meet the required minimum of the strength of activity index despite the curing age, but progressively increased in strength of activity index with the curing age.

3.14 Statistical Analysis of Concrete Cubes and Beams

Analysis of variance (ANOVA) was conducted using data analysis of the two way without replication at α= 0.05.

3.14.1 Mean strength concrete cubes

Analysis of variance (ANOVA) was conducted using data analysis of the two way without replication at α= 0.05 at various replacement of coconut fibre ash with ordinary portland cement from, 0%, 10%, 30%, 50%, 70% and 100% at curing time of 7, 14, 28, 42, 63 and 90 days respectively. The result as seen in Table 1 shows that:

There are two null hypothesis for rows and the other for columns. For the rows, H0: there is no significant difference in the compressive strength and the percentage replacement of coconut fibre ash since the P value for the rows is 5.29x10-22 < 0.05 = α or (F = 331.54 > 2.602 = Fcrit).

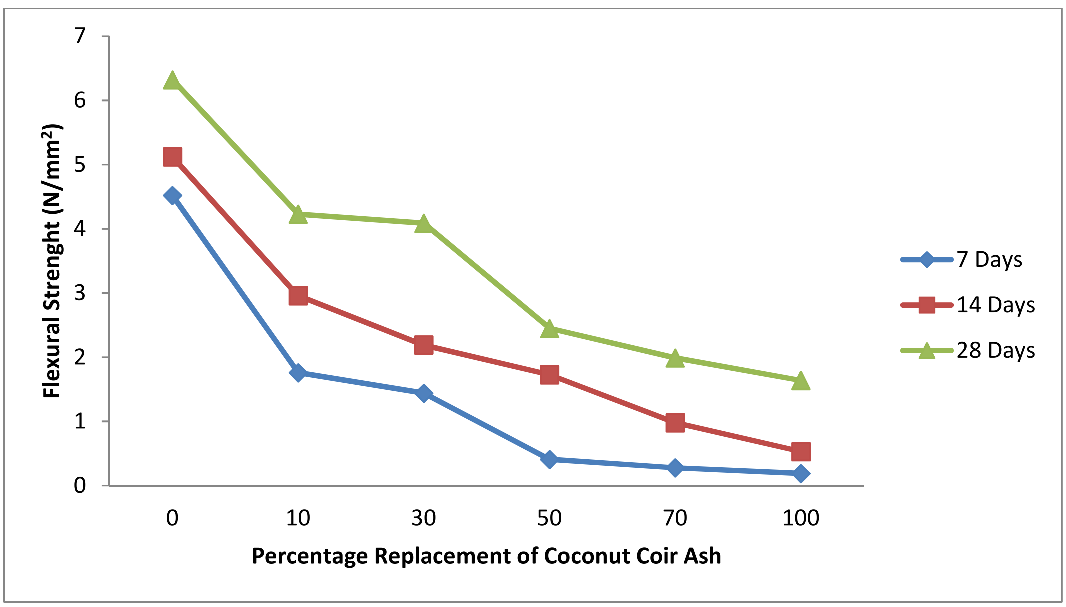

Fig. 5. Effect of percentage replacement of coconut fibre ash on flexural strenght (%)

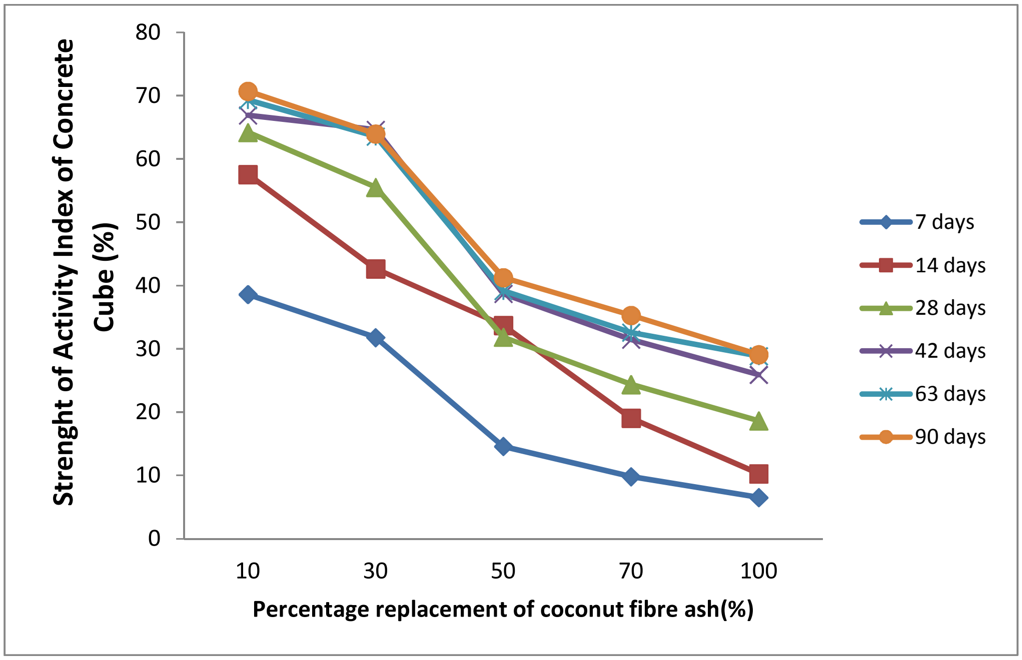

Fig. 6. Strength of activity index of concrete cubes at different curing period

We reject the null hypothesis and so at the 95% level of confidence we conclude there is there significant difference in the compressive strength of the concrete cubes at various replacement of coconut fiber ash.

The null hypothesis for the column is;

H_1: there is significant difference in the compressive strength at various replacement of coconut fibre ash.

Since the P value for column 918x10^{-14} < 0.05 = α (or F = 68.32 . 2.602 = F circuit) we can reject the null hypothesis and so at 95% level of confidence we conclude there is significant difference in the compressive strength of concrete cubes at different replacement of coconut fibre ash.

<u>3.14.2 Strength of activity index</u>

There are two null hypothesis one for rows and the other for columns as seen in Table 2. For the Rows, Ho: There is no significant different in the strength of activity index of the concrete cubes at various percentage replacement of coconut fibre ash.

Since the P value for rows is 1.03x10^{-15} < 0.05 = α or (F = 194.89 > 2.87 = F crit)

We reject the null hypothesis and so at the 95% level of confidence in the we conclude there is significant difference of the concrete at various percentage replacement of coconut fiber ash.

The null hypothesis for the column is

H_1: There is significant difference in the strength of activity index of the concrete cubes at various replacement of coconut fiber Ash.

Since the P value for columns = 3.34x10^{-11} < 0.05 = α Or (F = 57.801>2.71 Fcrit)

Table 1. Analysis of variance of mean strength of concrete cubes

Source of variation	SS	df	MS	F	P-value	F crit
Rows	2124.32	5	424.864	331.5385	5.29E22	2.602987
Columns	437.7553	5	87.55106	68.31961	9.18E-14	2.602987
Error	32.03731	25	1.281492			
Total	2594.113	35				

Table 2. ANOVA strength of activity index for concrete cubes

Source of variation	SS	df	MS	F	P-value	F crit
Rows	7748.507	4	1937.127	194.8915	1.03E-15	2.866081
Columns	2872.584	5	574.5168	57.80131	3.34E-11	2.71089
Error	198.7902	20	9.939512			
Total	10819.88	29				

Table 3. ANOVA flexural strength of beams

Source of variation	SS	df	MS	F	P-value	F crit
Rows	41.96263	5	8.392526	99.47024	3.4E-08	3.325835
Columns	12.38814	2	6.194072	73.41364	1.05E-06	4.102821
Error	0.843722	10	0.084372			
Total	55.19449	17				

We reject the null hypothesis and so at 95% level of confidence conclude there is significant difference in the strength of activity Index x (%) of the concrete cubes at different percentage replacement of coconut fibre Ash.

3.14.3 Flexural strength

They are two null hypothesis for rows and the other for columns as seen in Table 3. For the Rows, Ho: There is no significant difference in the flexural strength of the beams, since the P value for the rows is $3.4 \times 10^{-8} < 0.05 = \alpha$ (or F = 99.47> 3.33 = Fcrit)

We reject the null hypothesis and so at 95% level of confidence we conclude there is significant difference in the flexural strength of beams at various percentage replacement of coconut fiber Ash.

The null hypothesis for the columns

H_1: There is significant difference in the flexural strength of the beans at various percentage replacement of coconut fiber ash ,since the P value for column = $1.05 \times 10^{-6} < 0.05 = \alpha$ (or F = 93.41 > 4.10) =Fcrit, we reject the null hypothesis and so at 95% level of confidence we conclude there is no significance difference in the flexural strength of the beams at the various percentage replacement of the coconut fiber ash.

4. CONCLUSION AND RECOMMENDATION

From the results obtained, coconut fibre ash mixed showed some promise for use in concrete cubes in pit latrine construction.

The compressive strength of the cubes from 28 days up to 90 days indicates that 10% and 30% replacement levels meet the requirement of BS EN 206-1; 2000 FOR CLASS C20/25 concreting. In conclusion, the study reveals that 10 to 30% partial replacement of Ordinary Portland Cement with coconut fiber ash using W/C ratio of 0.55 is suitable for concrete cube production in pit latrine construction.

Further areas of research are recommended particularly curing of concrete cubes more than 90 days as we saw that with more curing days compressive strength of cubes increased and curing beams more than 28 days as the flexural strength of beams increased with time. This includes the use of coconut fiber ash calcined under controlled conditions, since the calcination temperature and time appears to have a marked effect on the amorphosity of the ash and altering water/cement ratio.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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