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Investigative Study of Chicken Feather and Synthetic Hair Fibre on Mechanical and Microstructural Properties of Interlocking Concrete Block

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Abstract
Efforts have been made to improve the quality and performance of concrete structures especially its permeability and durability properties. Concrete is a heterogeneous material containing several components (sand, aggregate, cement, etc.) which vary in size and geometry, and their positions in the concrete enclosure are randomly distributed, giving them defects even before experiencing any form of mechanical loading. In this study, the compositions of Chicken Feather Fibre (CFF) and Synthetic Hair Fibre (SHF) by weight were varied by 0%, 1.5%, 2.5%, 3.5% and 5% for Samples A to E respectively. Physical and Mechanical properties such as water absorption (WA), thickness swelling (TS), compressive and split tensile strength were determined. Results showed that WA and TS property of the fibre reinforced concrete block decreased with decrease in percentage by weight of CFF and SHF and curing days with highest value being 10.01 to a lowest value of 0.14. Also, compressive strength (CS) for sample A increased with increase in curing days from 16.98MPa at 7 days to 20.66MPa at 28 days and sample B has its highest CS at 14 days with 9.98 MPa while other samples decreased progressively. Split Tensile Strength (STS) for sample A increases with increase in curing days from 9.84MPa to 13.64MPa while sample B decreases from 7 to 21 days of curing from 5.43MPa to 4.79MPa and increased at 28 days to 4.92MPa. Samples C, D and E follow same trend as sample B. The SEM study shows that the interlocking concrete block (ICB) containing 0% of chicken feather and synthetic hair fibre has brittle characteristics while other samples containing different percentage by weight of chicken feather and synthetic hair fibre shows ductile characteristics. CFF and SHF enhanced WA, TS, CS and STS of fibre reinforced concrete.

Keywords: Concrete, Synthetic Hair Fibre, Chicken Feather Fibre, Split tensile strength, Compressive strength, Curing.

Introduction
It is very obvious that concrete is weak in tension and hence some measures must be adopted to overcome this deficiency. Introducing hair fibre, which is strong in tension and readily available in large quantity, into the concrete will help in overcoming this challenge. Fibre reinforced concrete has been reported to be convenient, practical and economical method of overcoming micro-cracks and other deficiencies in concrete (Pawar *et al*., 2015; Nila *et al*., 2015).

According to Qianand and Stroeven (2000), there are many kinds of fibres widely used in concrete engineering for their divers' advantages and as a matter of fact, no single reinforced concrete has the perfect mechanical properties. There are problems associated with concrete which are low strength, higher water absorption, low fire resistance and high porosity. It is important to note that moisture content affects strength, development and durability of earth blocks thus having a significant influence on the long-term performance and the effectiveness of the bonding with the mortar at the time of construction (Riza *et al*., 2010). Many researchers have addressed the short comings of concrete and some of them have made great effort to improve the performance of concrete, especially permeability and durability of concrete because these shortcomings are of major concerns to researchers (Guneyisi *et al*., 2008). Hence, to improve properties of concrete like low tensile and low strain capacity, Fibre Reinforced Concrete (FRC) has been developed (Sivakumar and Santhanam, 2007; Vandewalle 2007. Jamshidi and Karimi (2010) studied that incorporation of fibers into the cement-based materials can produce materials with improved tensile strength, ductility, toughness and durability performance. The improvement is achieved by preventing or controlling the initiation, propagation or coalescence of cracks.

The use of CFF as a composite reinforcement has certain desirable properties that includes light weight, high thermal insulation, excellent acoustic properties, non-abrasive behaviour and excellent hydrophobic properties. The CFF has the lowest density value compared to the all-natural and synthetic fibres (Barone *et al*. 2005; Bullions *et al*. 2006; Huda and Yang, 2008). Martinez-Harnandez *et al*. (2007) found that the CFF keratin bio fibres allow an even distribution within and adherence to polymers due to their hydrophobic nature. It was also reported that CFF reinforced composites have good thermal stability and low energy dissipation. The unique characteristics of keratin have generated interest in investigating the use of waste chicken feathers for a number of potential applications ranging from reinforcement in plastics to microchips (Aluigi *et al*., 2008; Huda and Yang, 2008). In 2011 Uzun *et al*. found that the impact properties of the CFF reinforced composites are significantly better than the control composites however both the tensile and flexural properties of the CFF reinforced composites showed poorer values compared to the control composites. Final results obtained revealed that CFF reinforcement improves impact strength of the composite. The use of chicken feather as a matrix component in composite manufacturing leads to high specific strength and the large amount of waste utilization.

Human hair can be used as fibre in fibre reinforced concrete as well owing to the various reasons. It imparts higher tensile strength which can be equal to the tensile strength of copper wire having same diameter (Jain and Kothari, 2012). Human hair not only offers higher compressive strength but also serves up the purpose to reduce the micro cracking and increasing structural stability (Kumar *et al*., 2015). Ganiron (2014) also stated that human hair is strong in tension and can be used as a fibre reinforcement material. It is an alternate non-degradable matter that is available in abundance at a little or no cost, but creates environmental problem for its decompositions.

Materials and Methods

Major materials used for this study to test for physical and mechanical properties of the interlocking concrete block are chicken feather, synthetic hair popular known as hair attachment in Nigeria, Portland cement, stone dust and water. These materials were mixed together at different percentage using concrete mixing machine to ensure even distribution of the constituents making up the total composition of the mixture. Waste chicken feather were locally sourced from NABEST poultry farm, Ikose in Ogbomoso area of Oyo state Nigeria and brought into the lab. The waste chicken feathers were washed with water and detergent to remove extraneous materials (blood, manure stains and other unwanted substances) present in the feather. The feathers were exposed to direct sunlight in an open atmosphere to reduce water content in the feather and ensure that there is complete evaporation of water from the chicken feather. The fibre was further processed by grinding using the Wiley mill machine to further reduce the size of the CFF. Also, used SHF was collected from different hairdressing saloons in Ogbomoso environs, and were similarly washed properly using cool water and wig shampoo. The synthetic hair was exposed to sunlight for proper drying. The hair was cut into smaller length using scissors.

Portland cement (42.5R (3X) CEM II) was used as binding material that holds all the other components of the interlocking concrete block. Cement was added at constant proportion to the CFF and SHF and stone dust in the required ratio as shown in Table 1. The stone dust was obtained from FAGAD Investment Global Service Limited, Quarry Section, Iresa-Pupa, Ogbomoso, Oyo State (8.0563^{o} N, 4.3462^{o} E). Water was used in the correct proportion.

Preparation, casting and curing of interlocking concrete block (ICB)

A total of two hundred (200) pieces of interlocking concrete blocks were cast which represents 40 samples each for sample A to E, the interlocking blocks consist of different mixed proportion in percentages of stone dust, cement and CFF and SHF in this order of samples A (75% stone dust,25% cement, 0% CFF and 0% SHF), B (74% stone dust, 25% cement,0.5% CFF and 0.5% SHF), C (72% stone dust,25% cement,1.5% CFF and 1.5% SHF), D (70% stone dust,25% cement,2.5% CFF and 2.5% SHF), E (68% stone dust,25% cement,3.5% CFF and 3.5% SHF), respectively as shown in Table 1. The CFF and SHF were used to partially replace stone dust while Portland cement remains constant using Sarada *et al*., 2018 approach. Portland cement, stone dust, CFF and SHF were mixed using concrete mixer. The concrete molds were cleaned of all contaminants by cleaning and rinsing. The wet mixture was poured into the mold and compressed. The excess mixture from the surface of the mold was scraped off and leveled with a straight edge rammer.

Determination of water absorption and thickness swelling of ICB

According to the ASTM (1995), effects of blends of CFF and SHF on the absorptive and dimensional stability of the ICB were determined after the immersion of the samples in water at room temperature. Excess water was drained and the change in the amount of water absorbed, thickness and the final weight of the samples were measured. The thickness swelling was measured from two points marked along the length of each sample with a sliding caliper. Water absorption and thickness swelling are expressed as a percentage of the original weight and thickness, respectively. Ten samples were used for each curing days. Equations 1and 2 give the formula for percentage water absorbed and thickness swelled, respectively.

$$\%\ \text{Water absorbed} = \frac{W_2 - W_1}{W_1} \times 100\% \qquad (1)$$

$$\%\ \text{Thickness swelled} = \frac{L_2 - L_1}{L_1} \times 100\% \qquad (2)$$

where w_1 and L_1 are the weight and thickness of the dry sample and w_2 and L_2 are the weight and thickness of the wet sample after immersion.

Table 1: Composition by Weight of the Interlocking Concrete Block Containing CFF and SHF

Sample	Chicken Feather Fibre (% Weight)	Synthetic Hair Fibre (% Weight)	Portland cement (% Weight)	Stone Dust (% Weight)	Number of Samples
A	0	0	25	75	40
B	0.5	0.5	25	74	40
C	1.5	1.5	25	72	40
D	2.5	2.5	25	70	40
E	3.5	3.5	25	68	40

Determination of compressive strength of ICB

Compression testing machine was used as shown in Plate 1 to obtain the compressive strength of each of samples A to E which were prepared for each of the ICB after water absorption test. Maximum compressive loadings were also determined. The readings were recorded and computed using Equation 3 for the compressive strength for each sample tested and the average value for three trials were recorded.

$$CompressiveStrength = \frac{P}{A} = \frac{P}{LB} \quad (3)$$

Where, P is the applied load, A is the cross-sectional area, L is the length and B is the width

Determination of splitting tensile strength of ICB

Splitting tensile strength test was performed at room temperature on the cured interlocking concrete block samples using Universal testing machine in Plate 2 at a constant loading rate of 0.2 mm/min, following ASTM C496/C496M-11. The splitting tensile strength was calculated using Equation 4.

$$T = \frac{2P}{A} \quad (4)$$

Where:
T: Tensile strength (MPa)
P: Measured load at failure (N)
A: Area of failure plane (mm^2)
Three samples each were tested for each of sample A to E with respect to the period of curing. The average of the measured values were analyzed.

Plate 1: Compression Strength Test

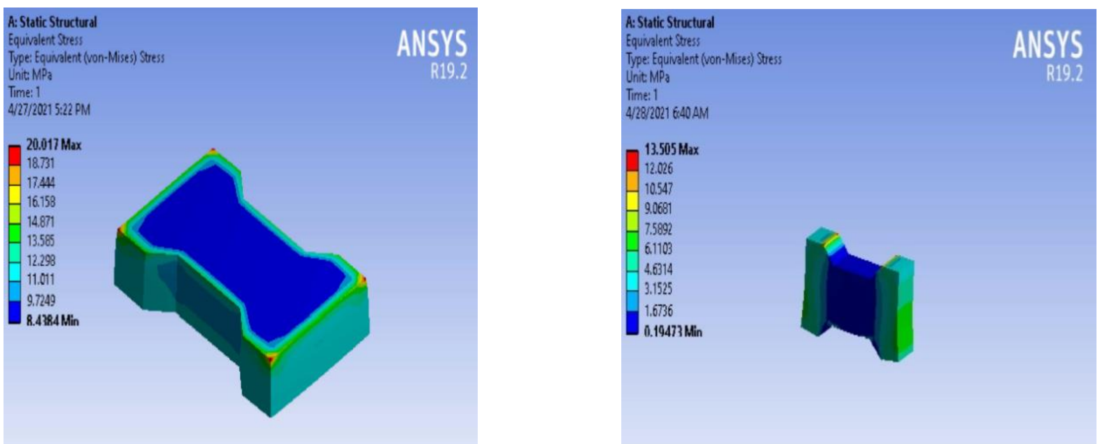
Plate 2: Split Tensile Strength Test

Structural simulation of ICB

The stress distribution and displacement of the concrete during the compression and splitting tensile tests were simulated using Ansys Workbench 19.2 finite element software. It was also used to determine the maximum loading of the interlocking block. The geometry of the interlocking concrete block was designed on Ansys workbench geometry modeler. Under engineering data, new materials were created and the properties were specified according to the experimentally obtained compressive strength and tensile strength for each sample of interlocking concrete blocks for different curing days. The material was assigned in solid under geometry and a fine mesh was generated with 0.5mm sizing. For compressive test, the base surface was set as fixed support while a compressive force was applied on the other surface until the maximum stress approach the ultimate compressive strength of the material. Similarly, for the splitting tensile test, one lateral side surface was set as fixed support while compressive force was applied on the other side until the maximum stress approach the ultimate tensile strength of the material. This procedure was repeated for all samples for each curing days based on the principle shown in Fig. 1a and b respectively.

Scanning electron microscopic (SEM) analysis of ICB

The morphology of the tensile fracture surfaces of the interlocking concrete blocks were analyzed at International Institute of Tropical Agriculture (IITA) in Ibadan, Oyo State using scanning electron microscopic model JOEL-JSM 7600F. Prior to the SEM-EDS analysis, all samples must be of an appropriate size to fit in the specimen chamber and are generally mounted rigidly on a specimen holder called a specimen stub. Samples were coated with platinum coating of electrically conducting material, deposited on the sample either by low-vacuum sputter coating or by high-vacuum evaporation.



b

a b

Figure 1: Simulation of the (a) Compressive Strength Test and (b) Split Tensile Strength Test

Results and Discussion

The results of the water absorption and thickness swelling properties of the fibre reinforced interlocking concrete blocks are shown in Figure 2 and 3, which indicated the percentage change in weight and thickness of the concrete block at the initial weight and thickness of the blocks respectively. Figure 2 shows that the water absorption property of CFF/SHF reinforced ICB increases with an increase in fibre content and the number of curing days. Sample E with 3.5% of CFF/SHF has the greatest water absorption value of 31.29% at 28 days of curing, while sample B with 0.5% of CFF/SHF has the lowest water absorption value of 10.80% at 7 days of curing. Generally, sample A (control sample) with 0% of CFF/SHF has the least value of 5.20% at 7days of curing. Figure 3 shows that the thickness swelling of CFF/SHF reinforced interlocking concrete block increases with an increase in fibre content and curing days for sample A and D but sample B, C, E shows an irregular pattern for the curing days.

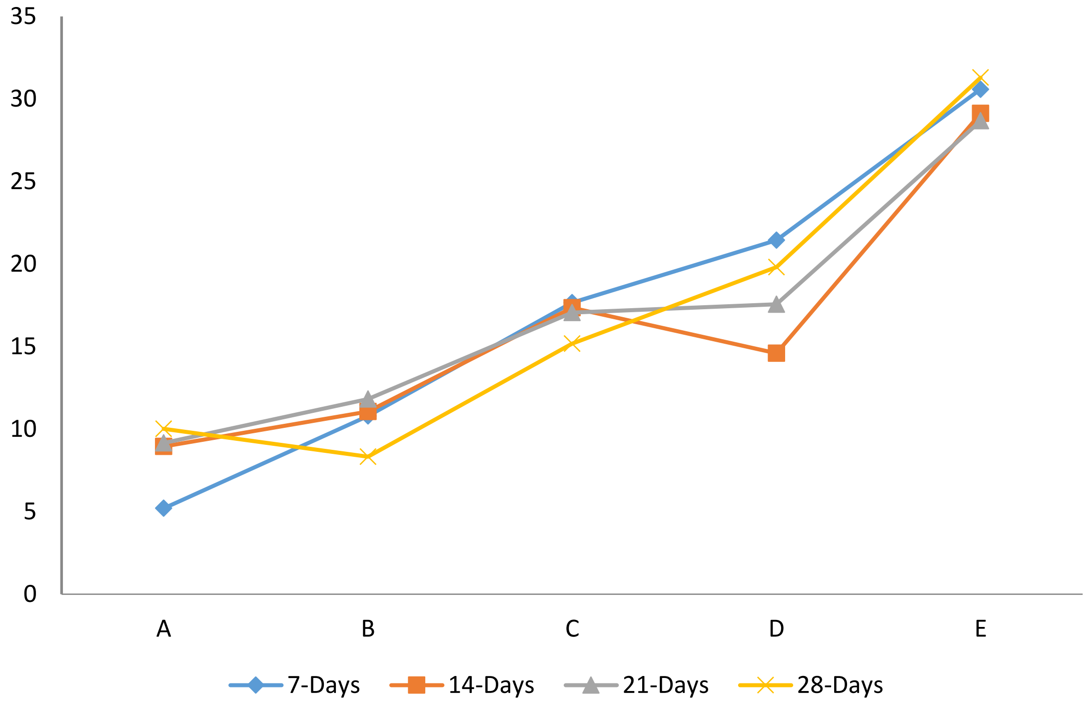


Figure 2: The Percentage Water Absorption of Concrete Samples for Various Curing Days

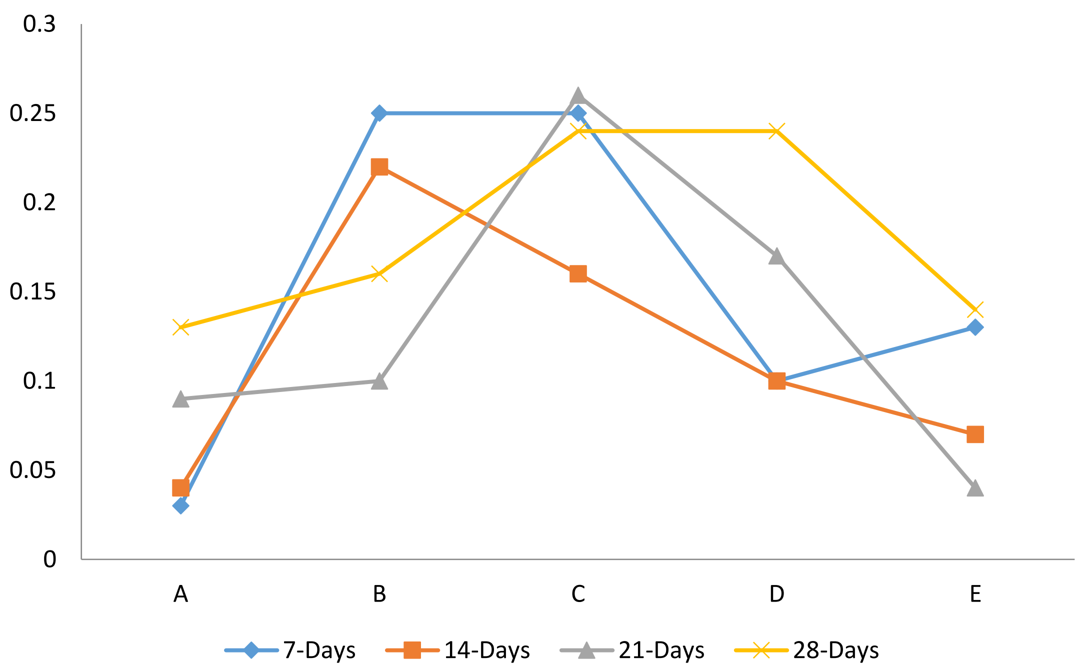


Figure 3: The Percentage Thickness Swelling of Concrete Samples for Various Curing Days

The compressive strength of the interlocking blocks was determined for Sample A to E for 7 to 28 days curing days. Table 2 shows the results of compressive strength of the ICB for 7 to 28 days of curing. The compressive strength for sample A increases with increase in curing days from 16.98 MPa at 7 days to

20.66 MPa at 28 days, while at 14 days sample B has the highest compressive strength of 9.98 MPa while there is a progressive decrease in 7, 21 and 28 days of curing from 9.77 MPa to 3.81MPa. Sample C shows a progressive decrease from 7 to 21 days with a value of 4.29MPa to 2.43MPa but shows an increase in 28 days of curing as 2.84MPa. Similarly, sample D also decreases progressively from 7days to 28 days as 2.56MPa to 1.53MPa while sample E at 21 days has a value of 1.14MPa with a progressive decrease in compressive strength between 7 and 14 days. Sample E at 28days of curing further decrease in compressive strength with a value of 0.9MPa. The decrease in strength is as a result of further increase in percentages of CFF and SHF.

Table 2: Average Compressive Strength of Chicken Feather and Synthetic Hair Fibre ICB at different Curing Days

Sample	% CFF and SHF	Compressive Strength at different Curing days							
		7 days		14 days		21 days		28 days	
		Average Load (kN)	Compressive Strength (MPa)	Average Load (kN)	Compressive Strength (MPa)	Average Load (kN)	Compressive Strength (MPa)	Average Load (kN)	Compressive Strength (MPa)
A	0	408.33	16.98	461.67	19.2	485	20.17	496.67	20.66
B	0.5	235	9.77	240.00	9.98	173.33	7.21	91.67	3.81
C	1.5	103.33	4.29	76.67	3.19	58.33	2.43	68.33	2.84
D	2.5	61.67	2.56	55.00	2.29	47.5	1.98	36.67	1.53
E	3.5	26.5	1.10	26.67	1.11	27.5	1.14	21.67	0.90

Results of splitting tensile strength of the interlocking blocks were obtained according to the curing days for each samples of the block. Table 3 shows the results of splitting tensile strength of the ICB for 7, 14, 21 and 28 days of curing respectively. Sample A shows an increase in split tensile strength with an increase in curing days from 9.84MPa to 13.64MPa while for sample B, split tensile strength decreases progressively from 7 to 21 days of curing at 5.43MPa to 4.79MPa and increased at 28 days to 4.92MPa. Similarly, sample C follows same trend as sample B with the split tensile strength decreases from 2.39MPa to 1.77MPa at 7 to 21 days of curing but increased to 2.02MPa at day 28. Sample D at 28 days of curing has the highest split tensile strength of 1.14MPa and lowest value of 0.63 MPa. Sample E shows a decrease in split tensile strength from 7 days as 1.14MPa to 28 days as 0.38MPa.

Table 3: Average Split Tensile Strength of Chicken Feather and Synthetic Hair Fibre ICB at different Curing Days

Sample	% CFF and SHF	Split Tensile Strength at different Curing Periods							
		7 days		14 days		21 days		28 days	
		Average Load (kN)	Split Tensile Stregth (MPa)	Average Load (kN)	Split Tensile Stregth (MPa)	Average Load (kN)	Split Tensile Stregth (MPa)	Average Load (kN)	Split Tensile Strength (MPa)
A	0.00	65.00	9.84	70.00	10.61	75.00	11.36	90.00	13.64
B	0.50	35.83	5.43	35.00	5.30	31.67	4.79	32.50	4.92
C	1.50	15.83	2.39	13.33	2.02	11.67	1.77	13.33	2.02
D	2.50	5.83	0.88	6.67	1.01	4.17	0.63	7.50	1.14
E	3.50	7.50	1.14	6.67	1.01	3.33	0.50	2.50	0.38

The simulated results of maximum compressive strength as applied to samples A to E are shown in Fig. 4 as 20.0170, 9.9081, 2.83850, 2.5239 and 1.1046Mpa respectively. This was attained for samples A at 21 and 28 days and that of B was at 14 days of curing while that of samples C was at 28 days. Similarly, sample D attained its highest value at 7 days and that of sample E was attained at 14 days. Similarly, simulated results of maximum splitting tensile strength of samples A to E as shown in Fig. 5 were 13.5050MPa at 28 day for A, 5.40190MPa at 7 day for B, 2.35720MPa for C at 7 day, 1.13930MPa for D at 28 days and 1.12950 MPa at 28 days for E.

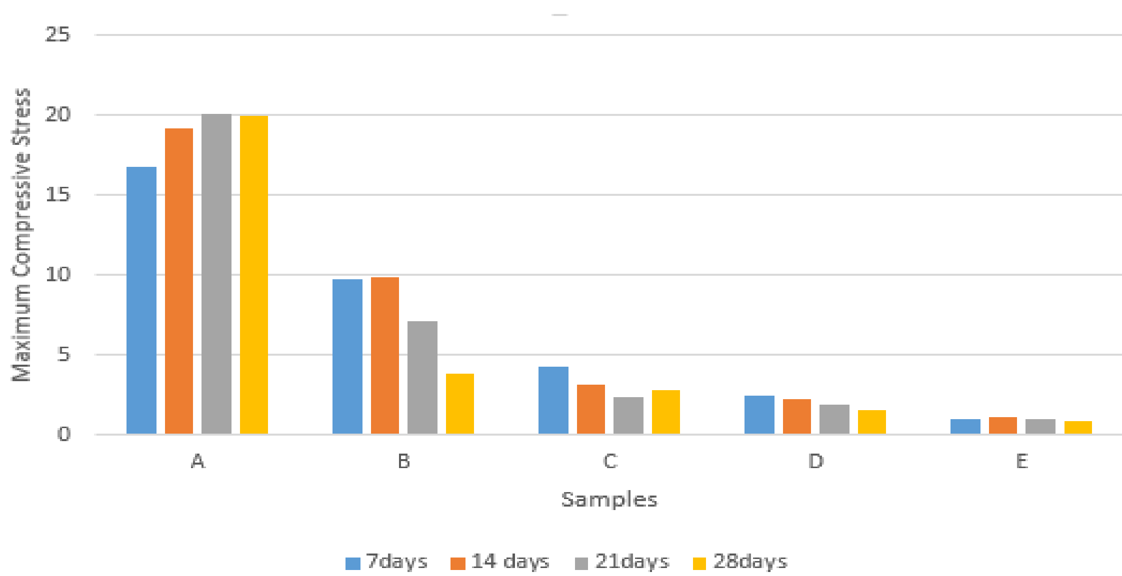


Figure 4: Maximum Compressive Strength of Concrete Sample for Various Curing Days during Simulation

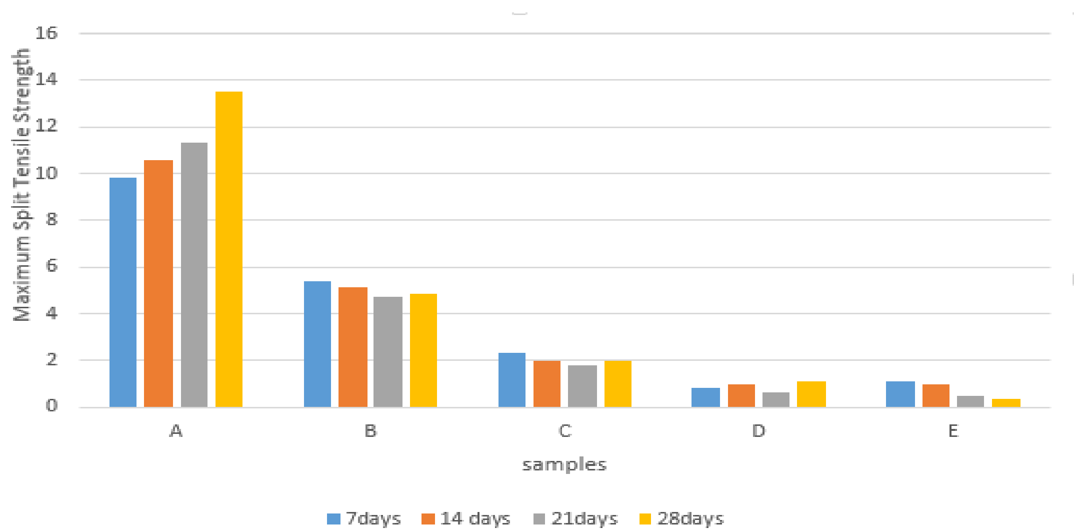


Figure 5: Maximum Split Tensile Strength of Concrete Sample for Various Curing Days during Simulation

Figure 6 (a)-(c) shows the scanning electron microscope (SEM) morphology of fracture surfaces of sample A, B and C after 28 days for samples A and B and 7 days for C. Figure 6a indicates rough surfaces and less tear lines, showing brittle failure mode. Fig. 6b show rough surfaces, which are smooth than that of sample A, indicating brittle failure mode but more ductile than sample A. Similarly, Figure 6c show rough surfaces, poor interfacial adhesion and voids between the concrete matrix and the fiber and more pull out of the fiber from the matrix, which result in the reduction in the tensile and compressive strength of the composites. It can be deduced that the CFF improve the ductility of the interlocking concrete blocks but increased in the proportion resulted in reduction of the tensile strength of the concrete blocks. Figure 7 (a)-(c) show the EDS spectra of samples A, B and C at 28 days of curing. All samples retained the major elemental composition found in cement and stone dust which are Ca, Fe, Si, C and Mg at slightly varying composition. The presence of about 20 wt% oxygen in most of the samples indicate that majority of the metallic elements are in oxidative state or compounds of oxygen which EDS has no capability of reporting.

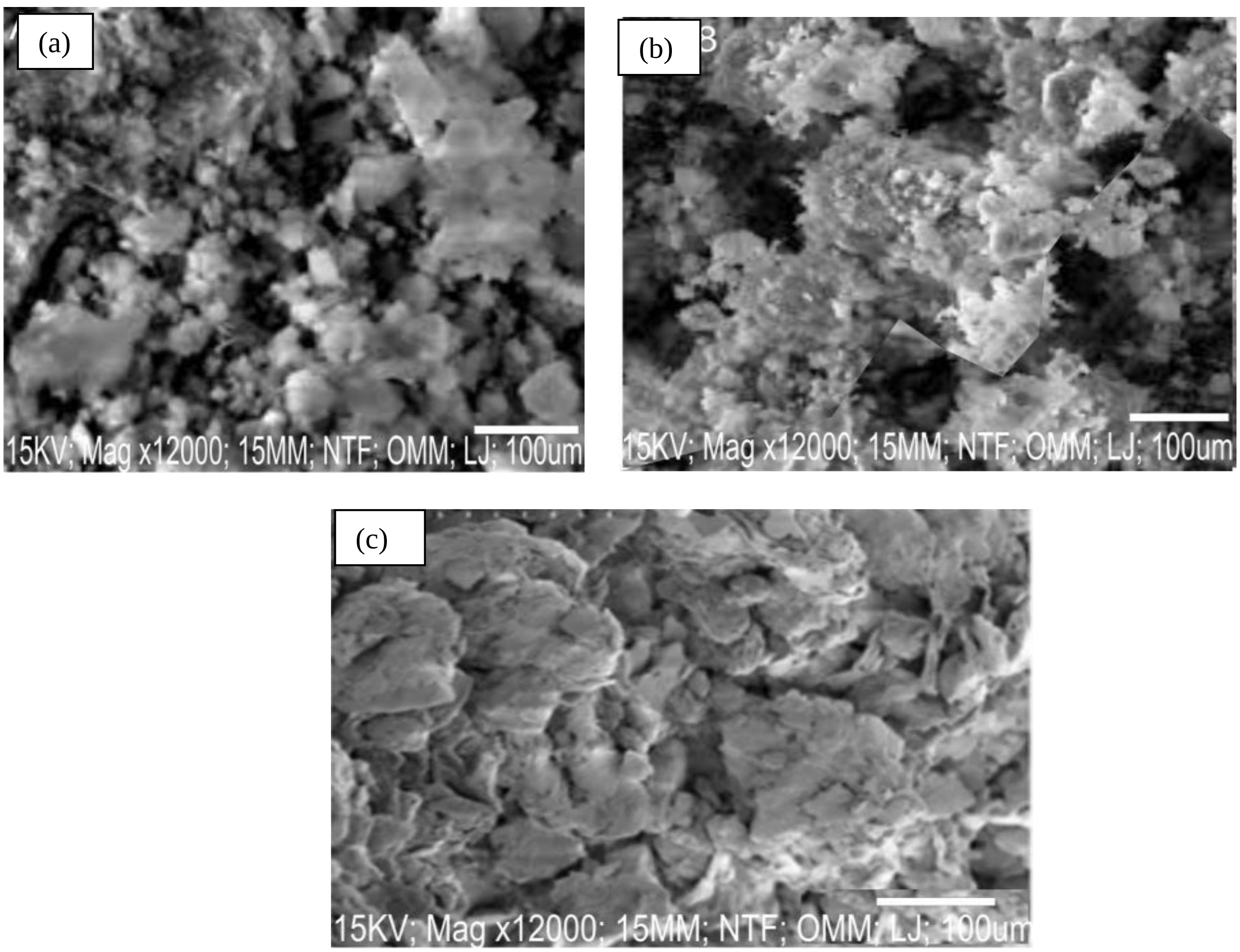
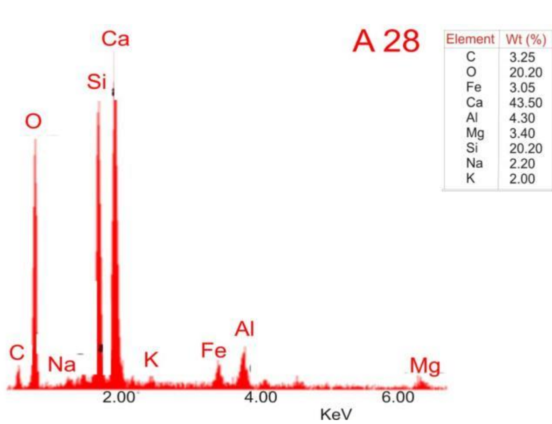
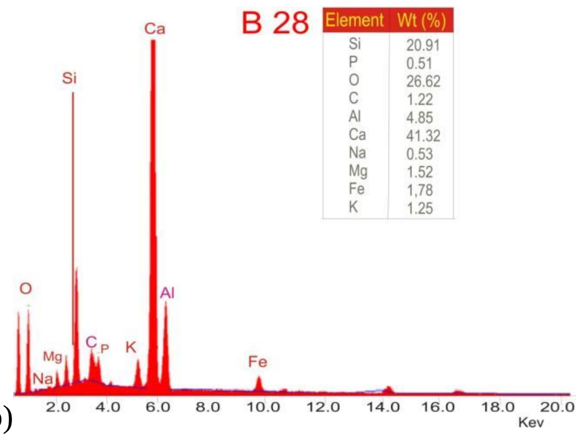


Figure 6: SEM Microphotographs of Cement Composite under 12000 Magnification for (a) Sample A and (b) sample B after 28 days of Curing.(c) Sample C at 7 days



(a)



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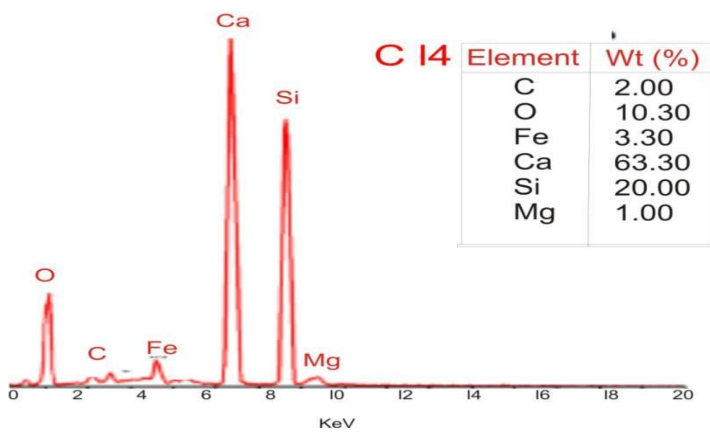

(c)

Figure 7: The Energy dispersive X-ray Spectroscopy (EDS) of (a) Sample A and (b) Sample B after 28 days of curing and (c) Sample C after 14 Days of Curing.

Conclusion

Results obtained in this study showed that the blend of CFF and SHF used as composite materials in the interlocking concrete block has less mechanical properties compared to the control sample containing 0% of chicken feather and synthetic hair fibre. 0.5% blend of chicken feather and synthetic hair fibre would be employed in making interlocking concrete block. Thus, this should be used in the total composition of the concrete mixture because it showed the best mechanical properties of fibre reinforced concrete. This kind of concrete can be employed as light weight concrete for industrial use.

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