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Physical and Chemical Characterization of Coffee Husk Ash Effect on Partial Replacement of Cement in Concrete Production

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Abstract: Today researchers all over the world are focusing on ways of utilizing either industrial or agricultural wastes as a source of raw materials for the construction industry. This is used to minimize the emission of CO2 during the manufacturing of cement. One of the agricultural waste products is coffee husk which is found in large amounts in Ethiopia. This paper aims to characterize the physical and chemical properties of Coffee Husks Ash (CHA) by using X-ray diffraction (XRD), Scanning electron microscope (SEM), and Fourier Transforms Infrared Spectroscopy (FTIR) tests, and also the experiment were conducted to determine the compressive, split tensile and flexural strength of the material and durability tests were determined. The result have shown that, when the replacement percent further increases, the crystalline material increases, silicate concentration decreases, and also the micro pores or air void are increases, which may lead to decreasing the strength of concrete. In the case of mechanical property of concrete, there has been remarkable increment up to 5% CHA replacement and also strongly satisfied up to 10% replacement, furthermore increasing CHA replacement up to 20% are optimum dosage of normal concrete mix production of C-25 concrete. Finally, water absorption and sulfate attack of partially replaced concrete is shown as an improvement in the durability of concrete.

Keywords: Pozzolanic materials, coffee husk ash (CHA), FTIR, partial replacement, SEM, XRD

1. Introduction

Concrete is one of the most widely used man-made construction materials in the world(Kadam & Patil, 2014), because of its importance for economic development. Concrete is made by mixing cement, water, aggregate (sand and coarser aggregate) forms a rock-like mass as the paste hardens because of the chemical reaction of the cement and water (Makebo, 2019).

The demand for cement in concrete industries has been increasing to fulfill the needs of infrastructure due to the growing population and industrialization(Mishra & Siddiqui, 2014). However, the production of cement has

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environmental problems due to the emission of greenhouse gases like CO2, NO, etc. by cement Production(Haziman et al., 2021). On another side, a huge amount of agricultural waste is generated during processing (Ogunbode et al., 2021), this may also have an impact on the environment. Therefore, to mitigate the problem, researchers testing agricultural west have its pozzolanic properties. The agricultural waste materials like coffee husk (Alan Carlos de Almeida et al., 2019), banana leaf (Sakthivel et al, 2019), bagasse (Onchiri et al., 2014), wheat straw (Bheel et al., 2021), rice husk (Barua et al., 2018), corncob (Pinto et al., 2012), etc. have pozzolanic property.

Pauline et al., (2010) investigated that, for every kilogram of coffee beans produced, approximately half a kilogram of husk was generated as waste. Previous research showed that Ethiopia has 192,000metric tons of coffee husk cast adrift as a byproduct per year (Sime et al., 2017).

Nowadays, coffee husk ash (CHA) had been tested in some countries for its pozzolanic possessions, which has been found to develop some of the properties of the paste, mortar, and concrete-like compressive strength and water tightness in confident substitution percentages and fineness(Sime et al., 2017).

Different scholars investigated the partial replacement of CHA for concrete production. According to Abebe Demissew, (2011) this investigation found that OPC replacement with CHA from 2% to 10% resulted in better compressive strength and density. Therefore, 10% of CHA replacement is the optimum ratio for C-25 concrete production. And also Reta & Mahto (2019) investigated concrete produced by PPC replacement of cement with Coffee husk ash. The study concluded that coffee husks can be used as a partial replacement for cement in concrete production as well as for walls of building units and other mild construction works, and the replacement is up to 10% for cement as strength produced in making concrete.

Demissew et al., (2019) and Reta & Mahto (2019) investigated that the introduction of CHA in concrete considerably decreased both workability and slump aspects and compressive strength decreased with increasing the amount of CHA but increases compressive strength with curing age up to 10% CHA replacement.

Despite the significant contributions of coffee husk for strength development, those studies did not investigate the effects on physical and chemical characterization of CHA and CHA modified cement and also tensile, the flexural strength of concrete, and durability of concrete. The main objective of this study is the physical and chemical characterization of coffee husk ash's effect on the partial replacement of cement in concrete production.

2. Materials and Methods

2.1. Materials

The cement for the control reference ordinary portland cement (Dangote Grade 42.5) made by Dangote Cement Company in Ethiopia was used. The aggregates used in this study are river sand collected from Konso Zone which was found near Arba Minch, crashed coarse aggregate was used, and their physical properties are shown in Table 1. The maximum aggregate size of coarse aggregate is 37.5 mm. The physical properties of coarse aggregate; like specific gravity and absorption capacity, moisture content, and sieve analysis were determined and shown in Table 1. Potable tap water was used for the study which was satisfactory for concrete mixing and curing. Table 1 shows the Physical property of aggregate.

Table 1- Physical property of aggregate

Test Description	Fine Aggregate	Course Aggregate	Remark
Maximum size	4.75mm	37.5mm	
Moisture content	0.47	0.98%	
Unit weight of aggregate	-	1572.2kg/m3	
Absorption capacity	0.36 %	1.04 %	
Bulk Specific Gravity (SSD)	2.73	2.84	
Bulk Specific Gravity	2.71	2.8	
Apparent Specific Gravity	2.78	2.91	
Fineness modulus	2.65	3.26	

2.1.1. Coffee Husk (CH)

The coffee husk used in the research came from Dalle Woreda which is located in Sidama Regional State, Ethiopia. The collected sample was exposed to the sun to eliminate surface moisture and burnt at a temperature of 550ºC, for three hours to change ash, The CHA was cooled and ground using a grinder, and the pulverized ash was sieved through a 75 µm sieve to determine the physicochemical properties of CHA.

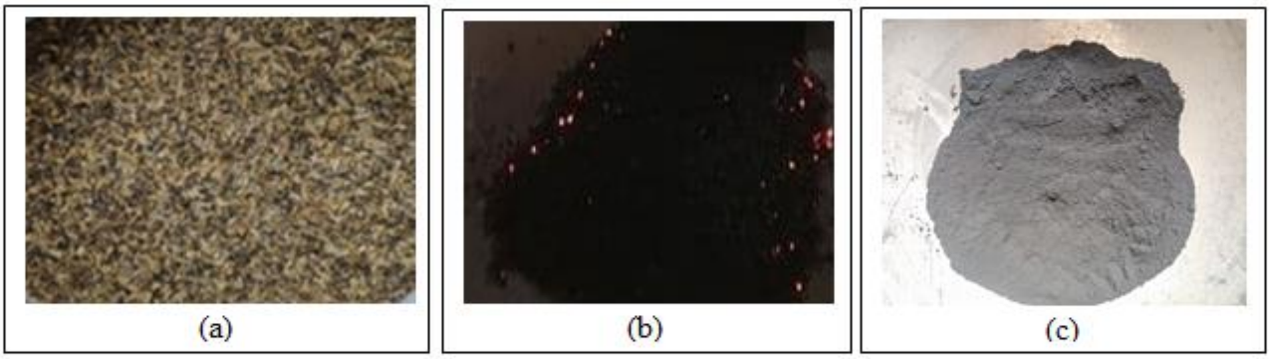


Fig. 1 - (a) Raw CH; (b) burned CH before coaling; (c) ground CHA

The CHA relevant physical and some chemical properties of CHA were presented in the following table below:

Table 2 - Properties of CHA

Particulars	Properties	Remark
Color	Gray	
Shape texture	Irregular	
Mineralogy	Noncrystalline	
Particle size	< 75µm	
Oder	Odorless	
Specific gravity	2.42	
Appearance	Very fine	

2.2 Methods

This study was investigated physical and chemical material characterization of OPC to CHA beyond the strength of concrete in different percentage replacement by using XRD (x-ray diffraction), SEM (Scanning Electron Microscope), FTIR (Fourier transform infrared spectroscopy), and mechanical property like compressive strength, split tensile strength, the flexural strength of concrete and also durability of concrete were investigated.

2.2.1. Physical and Chemical Properties of CHA and CHA Modified Cement

Scanning Electron Microscopy (SEM), Fourier transforms infrared spectroscopy (FTIR) and X-ray diffraction (XRD) is used to determine the physical and chemical properties of the material. The sample was prepared in the form of ash which is passing through 63µm sieve size. Those tests were conducted in the Addis Ababa Science and Technology University laboratory (AASTU) and Adama Science and Technology University(ASTU) laboratory.

Table 3 - Replacement matric

Matrix	Description	Remark
0CHA	0 % Coffee husk ash and 100 %Dangote Grade 42.5	Control mix
5CHA	5 % Coffee husk ash and 95 % Dangote Grade 42.5	Mix-one
10CHA	10% Coffee husk ash and 90 % Dangote Grade 42.5	Mix-two
15CHA	15% Coffee husk ash and 85 % Dangote Grade 42.5	Mix-three
20CHA	20% Coffee husk ash and 80 % Dangote Grade 42.5	Mix-four
25CHA	25% Coffee husk ash and 75 % Dangote Grade 42.5	Mix-five

3. Batching and Mixing Proportion

The replacement of CHA was conducted by the volume batching method instead of weight batching to get similar paste content; this is because the specific gravity of CHA (2.42) is less than that of cement (3.15). ACI 211.1-91(ACI Committee 211, 2002) method was used to specify the quantities and the proportion of concrete ingredients, ordinary Portland cement, and coffee husk ash, Sand, Gravel, and water. To compute the weight equivalency of the CHA, the following equation was used:-

$$\text{Fw} = \frac{1}{1+\left(\frac{3.15}{\text{Gp}}\right)\left(\frac{1}{\text{Fv}}-1\right)} \quad (1)$$

Where: Fw= pozzolanic materials percentage by weight expressed as a decimal factor, Fv= pozzolanic materials percentage by the absolute volume of the total absolute volume of cement plus pozzolanic materials expressed as a decimal factor=5%, Gp= specific gravity of pozzolanic materials=2.42, the specific gravity of cement is 3.15.

Table 4 - Weight equivalency of CHA

Percentage by volume	5%CHA	10%CHA	15%CHA	20%CHA	25%CHA
Fw (Percentage by weight)	3.85%	7.70%	11.60%	15.40%	19.30%

Accordingly, the water to cementitious materials (cement plus CHA) ratio was adjusted in the mix design.

$$\frac{\text{W}}{\text{C+P}} = \frac{3.15(0.535)}{(3.15(1-\text{Fv})+\text{GpFy})} \quad (2)$$

The mix design of the control and CHA concrete mix is shown in Table 3. The first proportion was used as a control mix since it had no coffee husk ash (0CHA). Five batches of the five combinations included 5% CHA, 10% CHA, 15% CHA, 20%CHA, and 25%. As indicated in Table 3, five separate batches were prepared for the relevant coffee husk ash volume fractions.

Table 5 - Mix proportion for 1m^3 concrete mix

Mix code	Cement quantity (kg/m3)	CHA ash (kg/m3)	W/B	Water (kg/m3)	FA (kg/m3)	CA (kg/m3)
0CHA	338.32	0	0.54	181	838.4	1076.957
5CHA	321.4	13.03	0.54	181	838.4	1076.957
10CHA	304.49	26.05	0.55	181	838.4	1076.957
15CHA	287.57	39.08	0.55	181	838.4	1076.957
20CHA	270.65	52.1	0.56	181	838.4	1076.957
25CHA	253.74	65.13	0.57	181	838.4	1076.957

The casting of concrete for compressive, split tensile and flexural strength of concrete is prepared by using ASTM C 39(ASTM Committee, 2001), ASTM C 496(ASTM Committee, 1996), and ASTM C 78(ASTM Committee, 2000) respectively. Curing of concrete was conducted for 7, 14, and 28 days. Durability tests like Water absorption and Sulfate attack were conducted based on ASTM C642-97 (ASTM Committee, 1997) and ASTM C1012(ASTM Committee, 2002) respectively. The sulfate attack was determined by the emersion of 28days cured concrete in Na2So4 solution for 28day and the weight change and loss of strength of the specimen can be calculated.

4. Results and Discussions

4.1 Physiochemical Characterization of OPC and CHA Modified Cement

4.1.1 X-ray Diffraction (XRD)

X-ray diffraction is used to determine the mineralogical composition and to examine amorphous and crystalline structures of OPC and CHA replacement in powder form. As shown in the figure below, the main mineralogical constituent for OPC are- alite or Calcium Silicate (Ca3 Si O5), Aluminum Iron, belite or Larnite (Ca2 Si O4) and Zeolite (Ca49.1 (Al96 Si96 O384)).

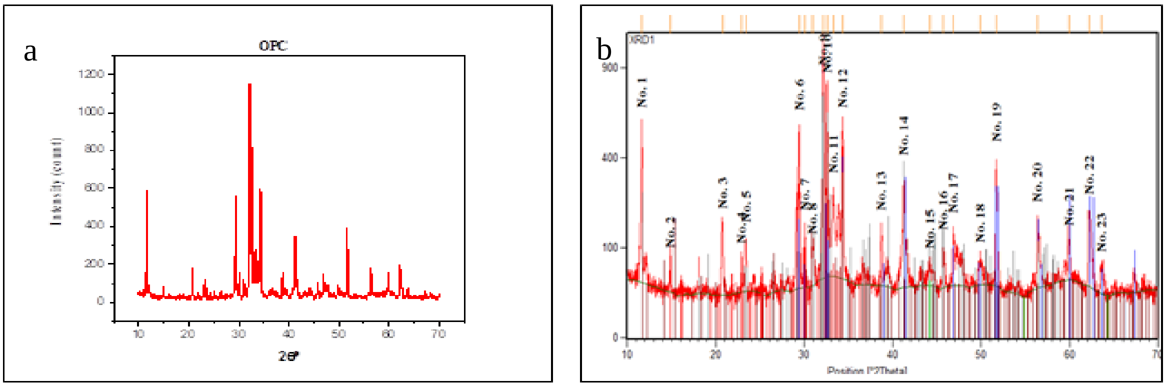


Fig. 2 – (a) XRD graph of OPC; (b) mineralogical composition of OPC

The main mineralogical constituent for 5% CHA is: alite or Calcium Silicate Oxide (Ca_3SiO_5), tricalcium magnesium orthosilicate ($Ca_3Mg(SiO_4)_2$), Periclase (MgO), Sodium Aluminum Iron Oxide ($Na_2Al_{0.5}Fe_{9.5}O_{15}$), belite or Calcium Silicate (Ca_2SiO_4), Tridymite (SiO_2), and Calcium Sodium Aluminum Oxide ($Ca_{8.688}Na_{0.625}(Al_6O_{18})$).

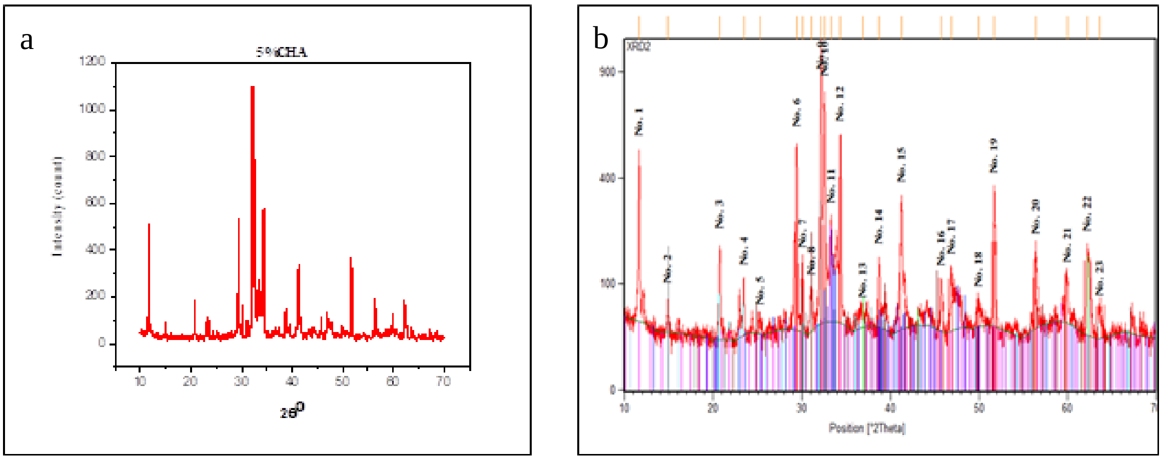


Fig. 3 - (a) XRD graph of 5% CHA; (b) mineralogical composition of 5% CHA

The main mineralogical constituent for 10% CHA are: alite or Calcium Silicate Oxide ($Ca_3(SiO_4)O$), Sodium Magnesium Silicate ($Na_{1.8}Mg_{0.9}Si_{1.1}O_4$), Calcium Silicide ($CaSi$), Zeolite or Ca-exchanged, dehydrated ($Ca_{46}(Al_{92}Si_{100}O_{384})$).

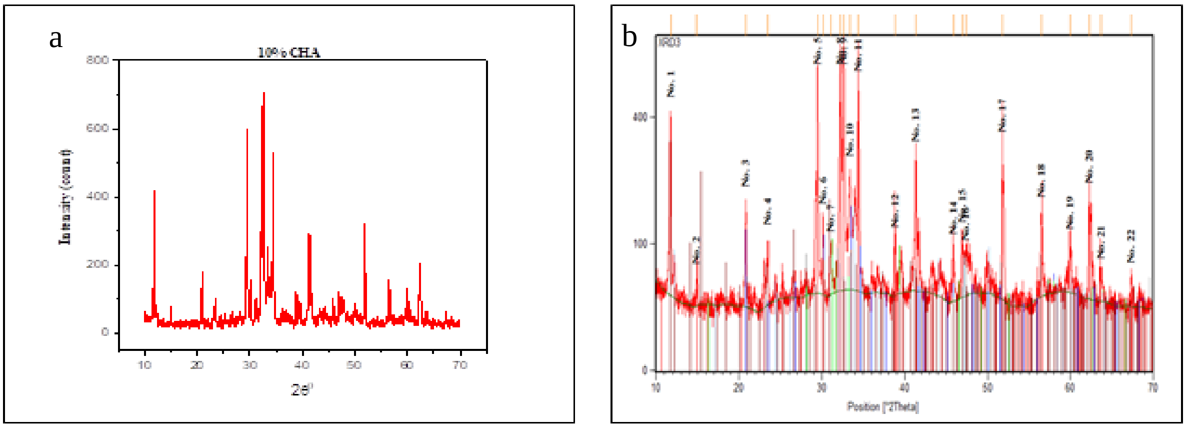


Fig. 4 - (a) XRD graph of 10% CHA; (b) mineralogical composition of 10% CHA

The main mineralogical constituent for 15% CHA are: alite or Calcium Silicate Oxide (Ca3 (SiO4) O), Sodium Oxide (Na2 O2), Tridymite (Si O2) and Zeolite or Ca-exchanged, dehydrated (Ca46 (Al92 Si100 O384).

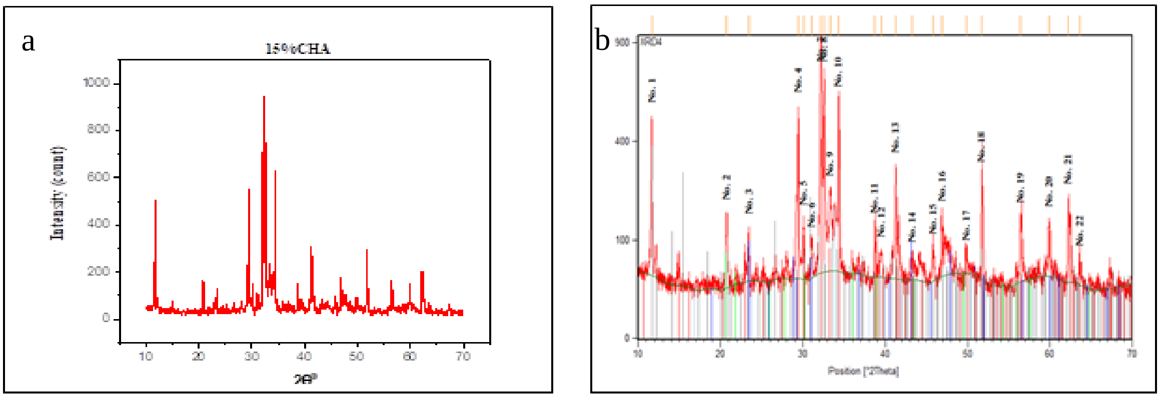


Fig. 5 - (a) XRD graph of 15% CHA and; (b) mineralogical composition of 15% CHA

The main mineralogical constituent for 20% CHA are: alite or Calcium Silicate Oxide (Ca3 Si O5), Aluminum Oxide (Al2 O3), Sodium Calcium Silicate (Na4 Ca Si3 O9), Periclase (Mg O), Silicon Oxid (Si O2), Quartz (Si O2), Clinoenstatite (Mg Si O3) and Zeolite or Ca-exchanged, dehydrated (Ca46 (Al92 Si100 O384).

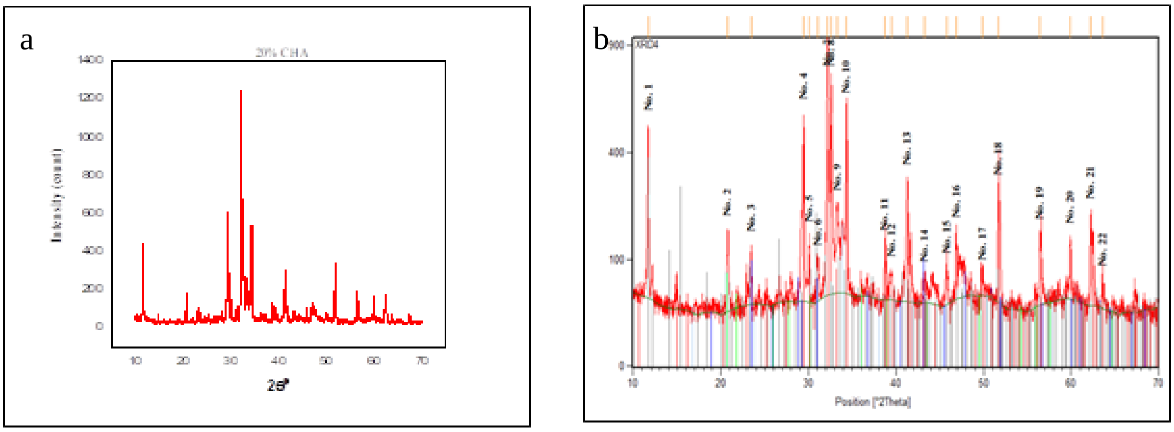


Fig. 6 - (a) XRD graph of 20% CHA; (b) mineralogical composition of 20% CHA

The main mineralogical constituent for 25% CHA are: alite or Calcium Silicate Oxide (Ca3 Si O5), Aluminum Oxide (Al2 O3), Periclase (Mg O), tricalcium magnesium orthosilicate (Ca3 Mg (Si O4)2), Sodium Oxide (Na2 O2), Sodium Magnesium Silicate (Na1.8 Mg0.9 Si1.1 O4) and Zeolite or Ca-exchanged, dehydrated (Ca46 (Al92 Si100 O384).

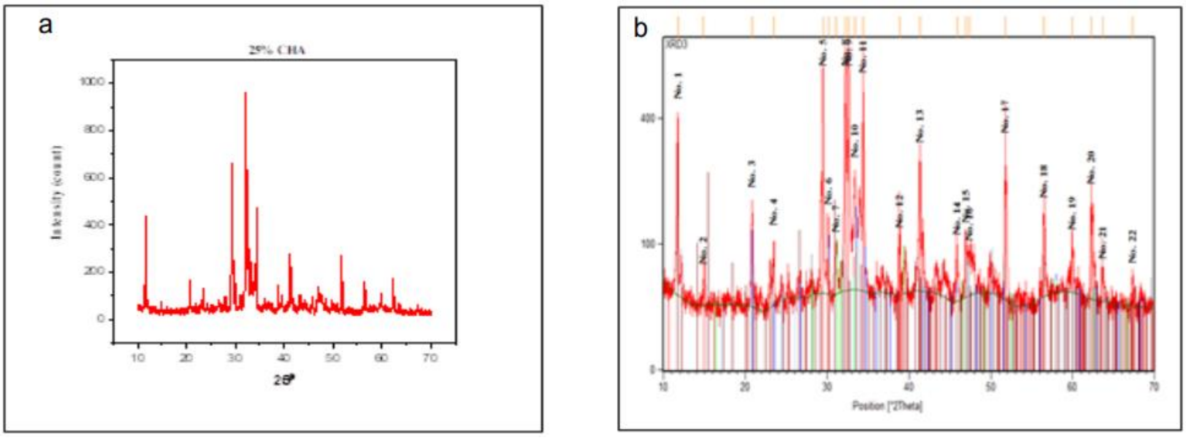


Fig. 7 - (a) XRD graph of 25% CHA; (b) mineralogical composition of 25% CHA

The highest pick values for all replacement are around 2Ɵ and as the percentage replacement increases the value of the pick decreases due to non-crystalline material, however, it further increases the percentage replacement of coffee husk ash in the cement the peak intensity again increases, this is due to the formation of crystalline silica. . Further, the presence of these crystalline phases reduces the reactivity of silica in the synthesis of other industrial products. And also *Byung Wan Jo et.al., (2017)* showed that less Alite peak at 2Ɵ value in the XRD peaks indicates that a greater degree of hydration. Therefore, as it can be seen from the above graphs, the amount of crystalline silica increases with further increasing percentage replacement of CHA.

4.1.2 Scanning Electron Microscope (SEM)/ Micro Graph Analysis

The Scanning electron microscope (SEM) analysis is used to find the size and shape of the material. The next figures show the Scanning electron microscope image and the average diameter/size of partial replacement of cement in coffee husk ash.

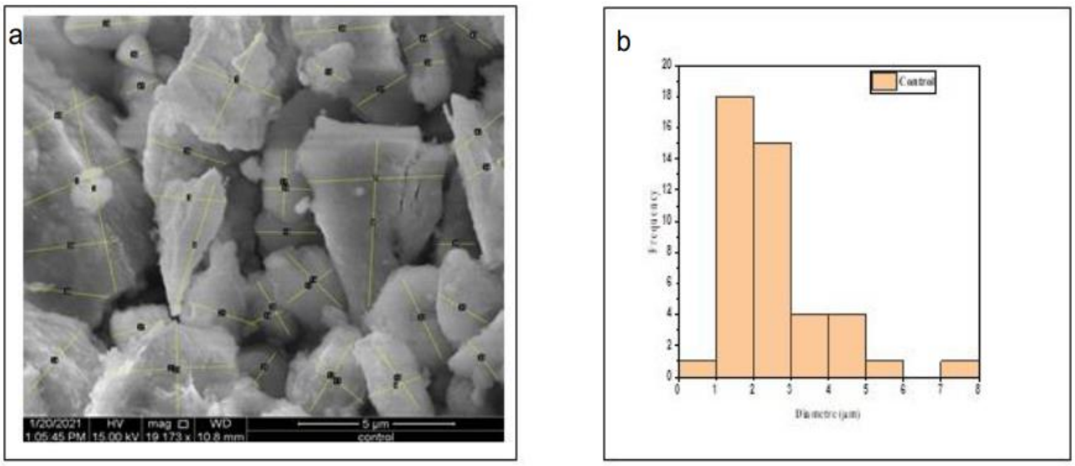


Fig.5 - (a) SEM micrograph of OPC; (b) average diameter=2.516µm

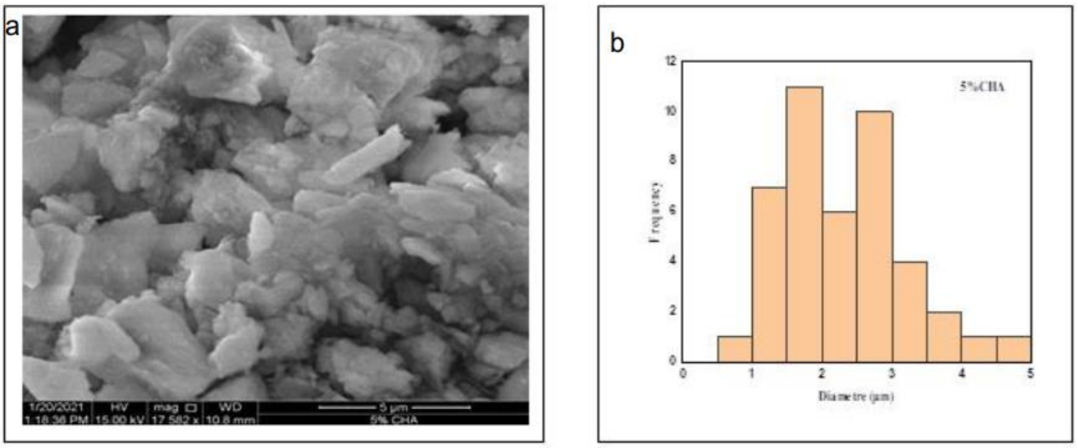


Fig. 9 - (a) SEM micrograph of 5% CHA; (b) average diameter=2.261µm

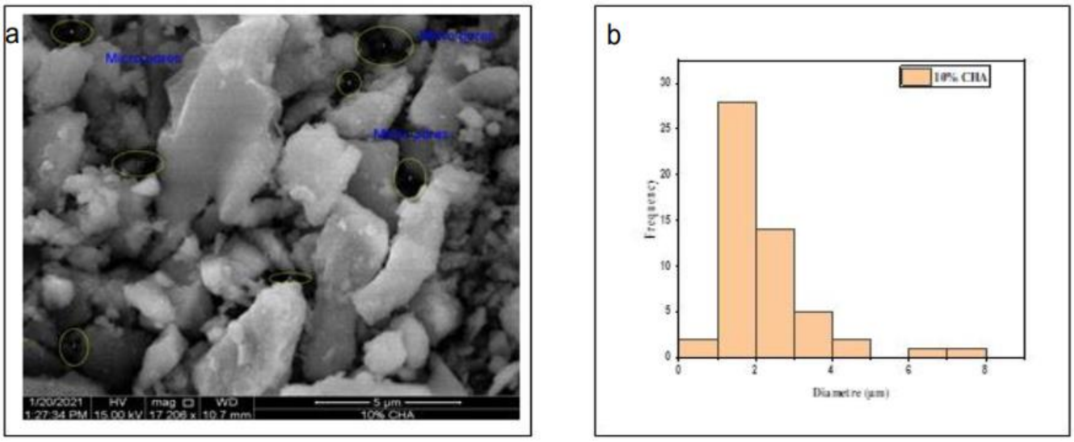


Fig. 10 - (a) SEM micrograph of 15% CHA and; (b) average diameter=2.219µm

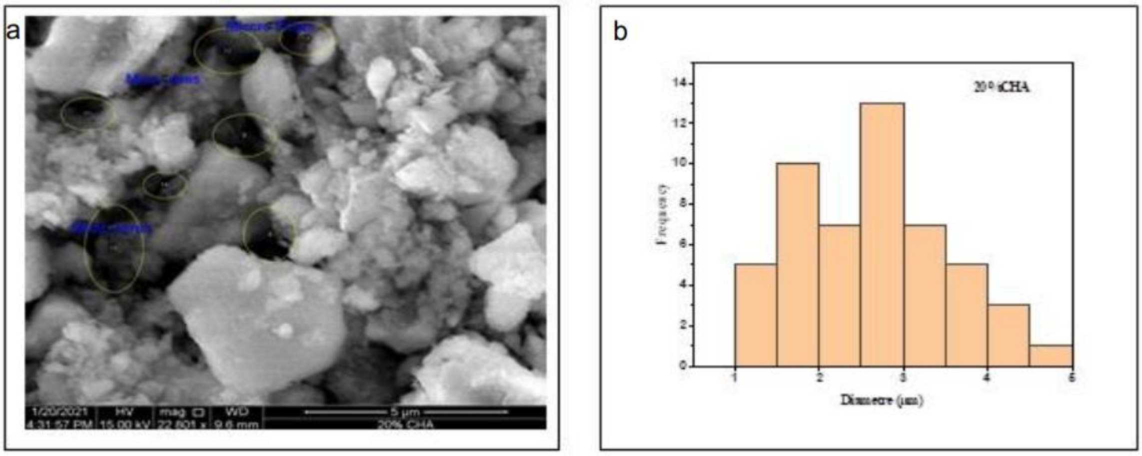


Fig. 11 - (a) SEM micrograph of 20CHA; (b) average diameter=2.261µm

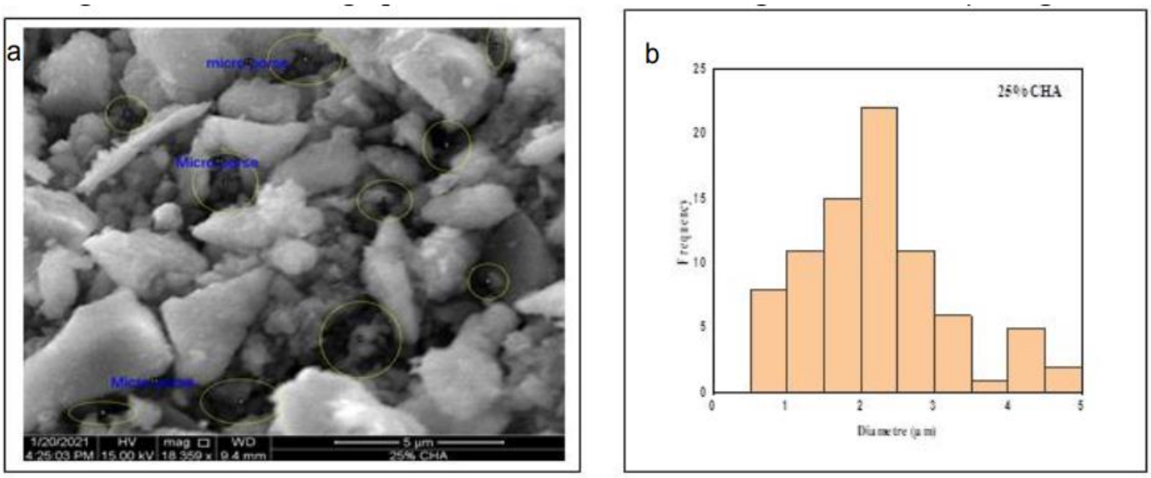


Fig. 6 - (a) SEM micrograph of 25CHA; (b) average diameter=2.221µm

From the above figures, the scanning electron microscope shows that the shapes of the material are flakey or spherical and some are irregular in shape. The flaky or spherical and irregular type morphology of the material in the image indicates that the surfaces are more loosely bound which makes them highly amorphous and reactive as indicated by Selamawit W, (2020). The average diameter of the material is less than 5µm. Additionally, as we can see from the SEM image, as the replacement percent increases, the micropores or air void (as shown in the dark image) are also increases. The reason is the ability of low electron back-scattering, epoxy resin-filled pores to appear darker than other materials in the composition *(*Tanvir Imtiaz et al., 2020), which is less dense and compact it leads to a decrease in the strength of concrete.

4.1.3 Fourier Transforms Infrared Spectroscopy (FTIR)

Fourier transforms infrared spectroscopy for determinations of the functional group of all partial replacement of cement are discussed below. The sample was scanned in the region of 4000cm^{-1} 400cm^{-1}, but for this case, the analysis is done in the region of 2000cm^{-1} -400cm^{-1}.

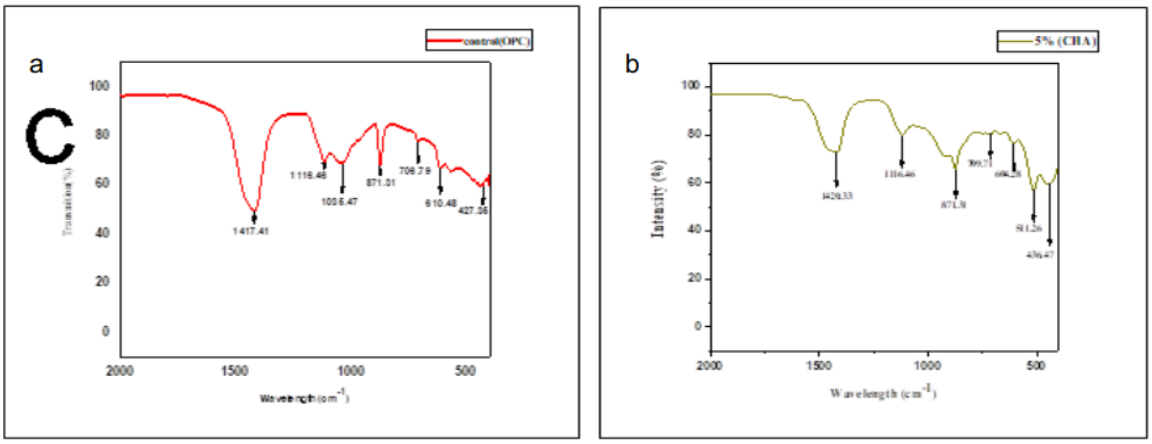


Fig. 7 - (a) FTIR graph of Control (OPC); (b) FTIR graph of 5% CHA

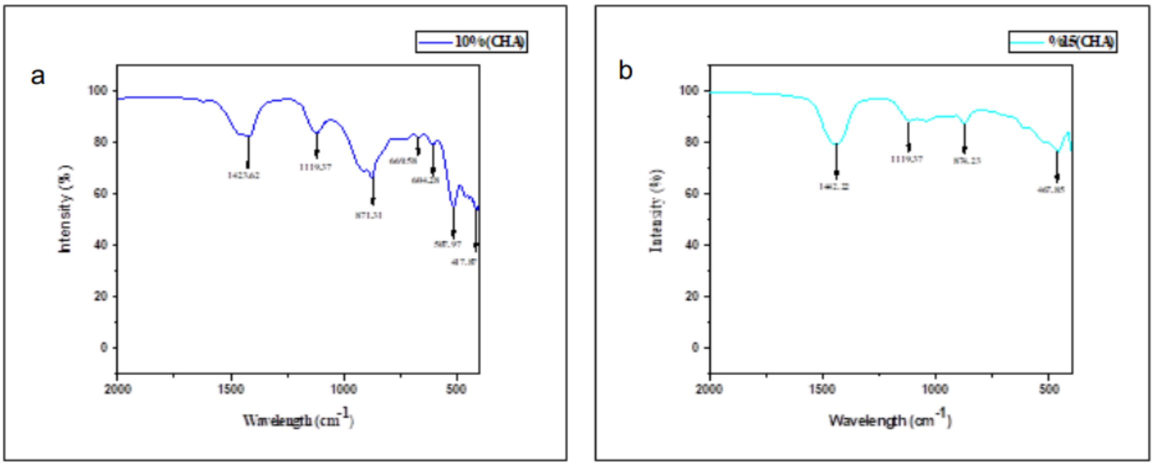


Fig. 14 - (a) FTIR graph of 10% CHA; (b) FTIR graph of 15% CHA

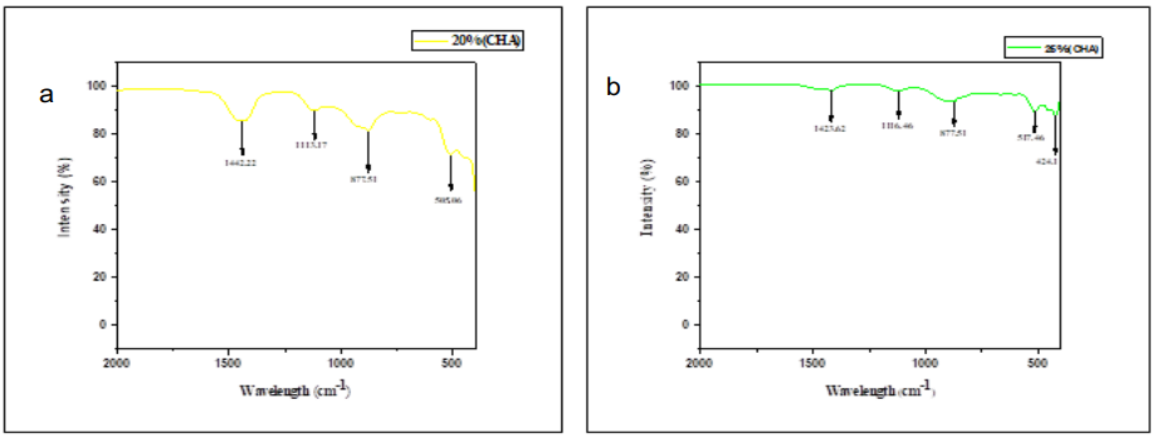


Fig. 15 - (a) FTIR graph of 20% CHA; (b) FTIR graph of 25% CHA

From figures 13-15, the following points are discussed

The peak found near 520cm-1 is due to Si-O out of plane bending vibration, and Si-O in plain bending due to vibration near to in the region of around 425cm^{-1}. The band found near to 600-650cm^{-1} are due to bending vibration of S-O linkage in the SO_4^{2-} group *(*Singh et al., 2009*)*, further increasing the replacement level the peak disappeared.

The FTIR spectra of OPC and CHA up to 10% replacement, there is a sharp band found in the region of around 871 cm-1 due to antisymmetrical stretching vibration of SiO4. But further increasing percentage replacements are decreasing the concentration of SiO4 in the material. This causes, the connection of SiO4 groups to form a ring of tetrahedral that occurs in the crystal of alite (C3S) or belite (C2S) bond are disappeared (Morales & Martínez-ramírez, 2008). In another word, the strength formation by C3S and C2S are decreased. C_3S percentage reduction in cementitious materials is also another factor attributed to the delay of setting time (Shumet Getahun , 2020).

A similar band found in the range of 1110-1120cm-1 is associated with a group of gypsum and anhydrite due to S–O stretching vibration (ν3) of (SO4) for all replacement percent.

4.2 Normal Consistency of Blended Pastes

Normal consistency of the material increased when replacement percentage increases, this shows that it needs much amount of water to satisfy the requirement (26% up to 33%).

Table 6 - Normal consistency of blended pastes

Code	W/C (400gm of cement)	Amount of water required	Penetration depth
0CHA	0.535	214gm	11
5CHA	0.5413	216.5gm	11
10CHA	0.5477	219.1gm	10
15CHA	0.5543	221.7gm	10
20CHA	0.561	224.4gm	9
25CHA	0.5679	237.2gm	9

The above table 4 demonstrated that percentage replacement increases the amount of water requirement also increases. The increment in water requirement is because of as shown from the SEM image, increasing the percentage replacement, the porosity also increases. For all replacements, Plunger penetration is within the accepted range (10±1).

4.3 Initial and Final Setting Time of Coffee Husk Ash to Cement Mix Pastes

Table 5 below demonstrated that, the initial, as well as the final setting time of CHA and cement mix pastes, the result shows an increment in time when percentage replacement increases, which means when CHA percentage replacement increases which retard the setting time, this is because, as shown from the XRD graph the reactivity of silicate were decreased and also the probable reason of its lower specific gravity/density of the material. However, the results are within the specified limit in ASTM C 191 standard (185min to 600min).

Table 7 - Initial and final setting time of CHA to OPC mix

No	Mix code	Initial setting time (min)	Final setting time (min)
1	0CHA	71	385
2	5CHA	83	405
3	10CHA	105	420
4	15CHA	117	435
5	20CHA	126	450
6	25CHA	135	465

4.4 Properties of Concrete Using Different Percentage Replacement

4.4.1 Properties of Fresh Concrete

4.4.1.1 Workability Test

The slump values were conducted in each concrete by different percentage replacement of CHA to OPC in 0%, 5%, 10%, 15%, 20% and 25% percentage.

Table 8 - Slump value of different mixes

No	Mix code	Slump value (mm)	w/c
1	0CHA	75	0.54
2	5CHA	75	0.54
3	10CHA	73	0.55
4	15CHA	72	0.55
5	20CHA	70	0.56
6	25CHA	65	0.57

Table 5 above showed that target slumps values were 75mm-100mm, so to achieve this range, the water to cement ratio was changed. The probable reason is to be, the higher specific surface area of the coffee husk ash and its lower density giving it a higher porosity leads to higher water demand. To get a similar slump for the control and CHA /OPC concrete, the water content can be increased as the coffee husk ash content increases.

4.4.2 Properties of Harden Concrete

4.4.2.1 Compressive Strength Test

The specimen used for compression testing is 150mmx150mmx150mm size of concrete prepared with partial replacement by varying CHA dosage at the percentage of 0%, 5%, 10%, 15%, 20%, and 25%. The laboratory test was conducted based on ASTM C 39.

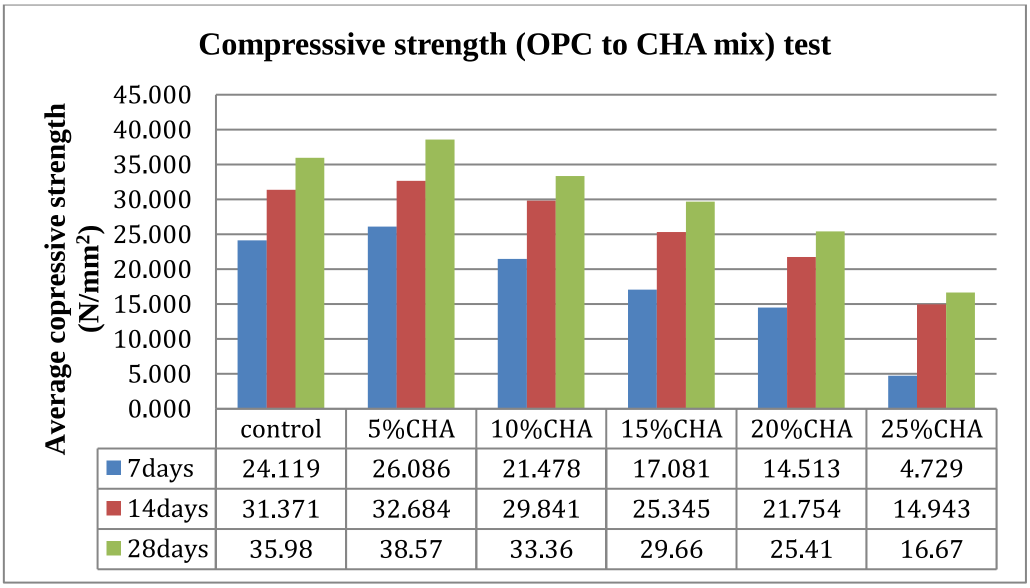


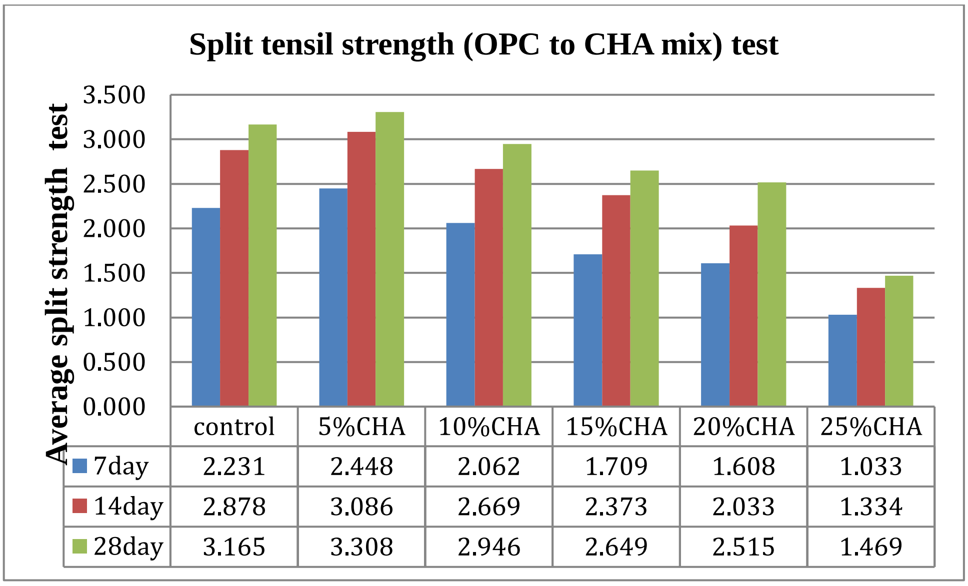
Fig. 16 - Compressive strength of concrete

Figure 17 demonstrated that the compressive strength values are increased from 36.98Mpa (0%) to 38.57Mpa (5% CHA replacement) this is because the reactivity of the silicate is increased. Further increasing the percentage replacement, the compressive value decreases. The probable reason for this is reducing the cement content of the mixture which in turn causes a reduction in the hydration reaction.

4.4.2.2 Tensile Strength Test

Tensile strength test was conducted by varying CHA dosage of 0%, 5%, 10%, 15%, 20%, and 25% percentage replacement for three consecutive days (7,14 and 28 days). The laboratory test was conducted based on ASTM C 496. The spacemen can be calculated by the following equation;-

$$T = \frac{2P}{\pi l d} \tag{3}$$



	control	5%CHA	10%CHA	15%CHA	20%CHA	25%CHA
7day	2.231	2.448	2.062	1.709	1.608	1.033
14day	2.878	3.086	2.669	2.373	2.033	1.334
28day	3.165	3.308	2.946	2.649	2.515	1.469

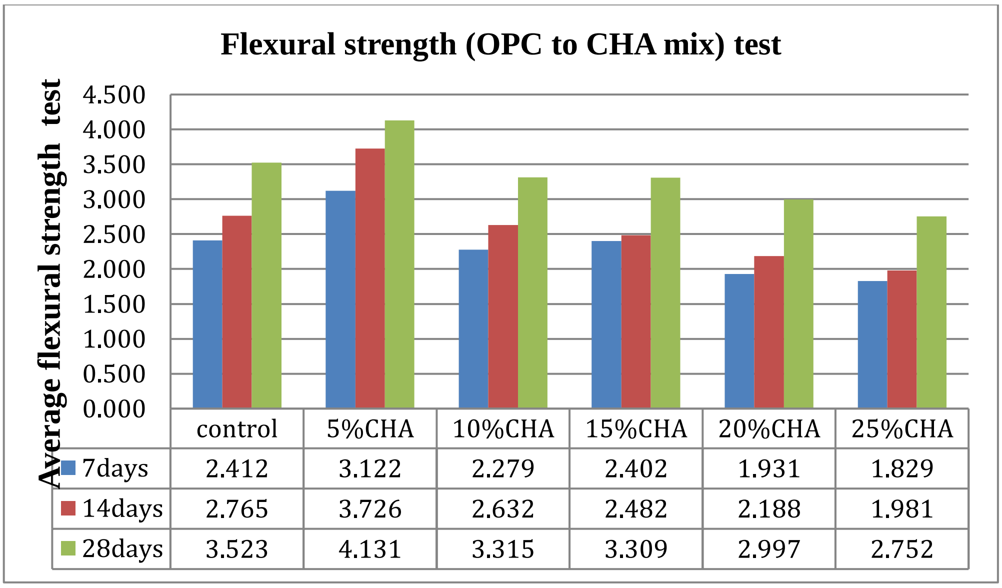
Fig. 8 - Split tensile strength of concrete

Figure 18 demonstrated that 5%CHA (3.308Mpa) replacements were given a higher split tensile strength value than the control ones (0% 3.165Mpa). For 10% CHA replacement, the value decreased only by 6.92%. The total value 15%, 20% and 25% CHA replacement are declined in respect to the control values are 16.3%, 19.6% and 53.6% respectively. The probable reason for this is due to the high percentage replacement of cement by coffee husk ash, thus reducing the cement content of the mixture which in turn causes a reduction in the hydration reaction and the reactivity of silicate.

4.4.2.3 Flexural Strength Test of Concrete

Flexural strength test was conducted by varying CHA dosage of 0%, 5%, 10%, 15%, 20%, and 25% percentage replacement for three consecutive days (7,14 and 28 days). The laboratory test was conducted based on ASTM C 76. The spacemen can be calculated by the following equation;

$$R = \frac{PL}{bd2} \tag{4}$$



	control	5%CHA	10%CHA	15%CHA	20%CHA	25%CHA
7days	2.412	3.122	2.279	2.402	1.931	1.829
14days	2.765	3.726	2.632	2.482	2.188	1.981
28days	3.523	4.131	3.315	3.309	2.997	2.752

Fig. 9 - Flexural strength of concrete

Figure 19 demonstrated that 5% CHA replacement was a higher value than that of the control mix by 8.1%. For 10% CHA replacement, the value decreased only by 12.31% from the control value. The total value 15%, 20% and 25% CHA replacement are declined in respect to the control values 12.51%, 28.2% and 35.67% respectively.
Similar to the compressive and flexural strength of concrete, the split tensile strength of the concrete also shows the same property. Generally, the probable reason for this is due to the high percentage replacement of cement by coffee husk ash, thus reducing cement content of the mixture which in turn causes a reduction in the hydration reaction and the reduction of reactivity of silicate.

4.4.3 Durability of Concrete Spacemen

4.4.3.1 Sulfate Resistance of Concrete

The spacemen were prepared by casting 150x150x150mm size concrete cubes. Coffee husk was replaced by 0%, 5%, 10%, 15%, 20%, and 25%, and the weight change and loss of strength of the specimen were calculated.

Table 9 - Weight and strength loss due to Na2So4 solution

Mix code	Before immersion		After immersion		% loss in weight	% loss in compressive strength
	Average weight	compressive strength	Average weight	compressive strength		
0CHA	8.627	35.98	8.4332	34.1	2.298	5.513
5CHA	8.421	38.57	8.2698	36.5	1.828	5.671
10CHA	8.435	33.36	8.321	32.58	1.370	2.394
15CHA	8.621	29.66	8.4295	28.5	2.272	4.070
20CHA	8.631	25.41	8.3535	22.3	3.322	13.946
25CHA	8.5775	16.67	8.2765	14.41	3.637	15.684

From the above table, it can be seen that after immersion of the spacemen in Na2So4 solution, the percentage loss in weight and strength are observed. However, when comparing partially replaced cement with that of control concrete, a positive result of up to 15% CHA was gained, this is because, the volume batching may improve the properties of concrete and also the microstructure of the spacemen are dens, but further increasing the replacement level, the microstructure of the spacemen are decreased.

4.4.3.2 Water Absorption of Concrete

Table 7 below demonstrated that up to 15%CHA replacement amount of water absorbed by concrete are decreased. This implies that the pores are minimized and the arrangement is compact. Further increasing percentage replacement, led to increasing the water absorption level, this is because of the loss of the microstructure of the spacemen as shown in the SEM image.

Table 10 - Percentage water absorption of concrete

Mix code	Oven dray sample (kg)	Surface dry sample (kg)	Difference	Water absorption (%)
0CHA	8.348	8.528	0.180	2.156
5CHA	8.337	8.472	0.135	1.619
10CHA	8.324	8.413	0.089	1.069
15CHA	8.304	8.389	0.085	1.024
20CHA	8.134	8.358	0.224	2.754
25CHA	8.054	8.321	0.267	3.315

5. Conclusion

1. The XRD result confirmed that increasing percentage replacement of CHA, increases crystalline silica amount. The presence of these crystalline phases reduces the reactivity of silica. The SEM result showed that the flaky or

spherical and irregular type morphology of the material in the image indicates that the surfaces are more loosely bound which makes them highly amorphous and reactive, and the average diameter of the particle is below 5µm. FTIR spectra of OPC and CHA replacement showed a similar band in different percentage replacement. However, further increasing the percentage replacement, a sharp band found in the region of around 871cm^{-1} and 600-650cm^{-1} are decreased, this is due to of SiO_4 groups to form a ring of tetrahedral occurs in the crystal of alite (C_3S) or belite (C_2S) bond are disappeared.

2. The workability of concrete containing coffee husk ash decreases with the coffee husk ash content increases due to the higher water demand of coffee husk ash.

3. The investigation of this study has conducted that coffee husk ash to cement mix proportion for 5% replacement shows that, 7.17% increment from the control value and 15.1% increment form the target strength, whereas, 10% percent CHA replacement satisfy 99.6% of target compressive strength and 92.14% the control value. Further increasing the replacement level u to 20% CHA replacement is important for normal strength concrete.

4. Similarly to the compressive strength of concrete, the percentage increased for flexural strength and split tensile strength of the concrete has been increased at 5% percentage, however, up to 15% and 20% replacement levels which satisfy the criteria. Finally, water absorption and sulfate attack of partially replaced concrete are shown as an improvement in the durability of concrete.

6. Recommendation

Depends on the above study and other similar studies that were particularly conducted in this area, the following recommendation is forwarded:-

For academic community

1. The effects of fineness of coffee husk ash on strength of concrete should be studied.
2. The additional test will be conducted regarding durability strength tests like - carbonation, water permeability, and the like.
3. Economical study on machinery cost and initial investments shall be investigated.

For different stakeholders

1. Based on current combustion equipment and technology it is difficult to produce a high quantity of coffee husk ash at a time. Thus, the respected stakeholders' have to enrich the technology.

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Table 11 - Physical property of aggregate

Test Description	Fine Aggregate	Course Aggregate	Remark
Maximum size	4.75mm	37.5mm	
Moisture content	0.47	0.98%	
Unit weight of aggregate	-	1572.2kg/m3	
Absorption capacity	0.36 %	1.04 %	
Bulk Specific Gravity (SSD)	2.73	2.84	
Bulk Specific Gravity	2.71	2.8	
Apparent Specific Gravity	2.78	2.91	

Fineness modulus	2.65	3.26

Table 12 - Properties of CHA

Particulars	Properties	Remark
Color	Gray	
Shape texture	Irregular	
Mineralogy	Non-crystalline	
Particle size	< 75μm	
Oder	Odorless	
Specific gravity	2.42	
Appearance	Very fine	

Table 13 - Replacement Matric

Matrix	Description	Remark
0CHA	0 % Coffee husk ash and 100 %Dangote Grade 42.5	Control mix
5CHA	5 % Coffee husk ash and 95 % Dangote Grade 42.5	Mix-one
10CHA	10% Coffee husk ash and 90 % Dangote Grade 42.5	Mix-two
15CHA	15% Coffee husk ash and 85 % Dangote Grade 42.5	Mix-three
20CHA	20% Coffee husk ash and 80 % Dangote Grade 42.5	Mix-four
25CHA	25% Coffee husk ash and 75 % Dangote Grade 42.5	Mix-five

Table 14 - Weight equivalency of CHA

Percentage by volume	5%CHA	10%CHA	15%CHA	20%CHA	25%CHA
F_W (Percentage by weight)	3.85%	7.70%	11.60%	15.40%	19.30%

Table 15 - Mix proportion for 1m^3 concrete mix

Mix code	Cement quantity (kg/m3)	CHA ash (kg/m3)	W/B	Water (kg/m3)	FA (kg/m3)	CA (kg/m3)
0CHA	338.32	0	0.54	181	838.4	1076.957
5CHA	321.4	13.03	0.54	181	838.4	1076.957
10CHA	304.49	26.05	0.55	181	838.4	1076.957
15CHA	287.57	39.08	0.55	181	838.4	1076.957
20CHA	270.65	52.1	0.56	181	838.4	1076.957
25CHA	253.74	65.13	0.57	181	838.4	1076.957

Table 16 - Normal consistency of blended pastes

Code	W/C (400gm of cement)	Amount of water required	Penetration depth
0CHA	0.535	214gm	11
5CHA	0.5413	216.5gm	11
10CHA	0.5477	219.1gm	10
15CHA	0.5543	221.7gm	10

20CHA	0.561	224.4gm	9
25CHA	0.5679	237.2gm	9

Table 17 - Initial and final setting time of CHA to OPC mix

No	Mix code	Initial setting time (min)	Final setting time (min)
1	0CHA	71	385
2	5CHA	83	405
3	10CHA	105	420
4	15CHA	117	435
5	20CHA	126	450
6	25CHA	135	465

Table 18 - Slump value of different mixes

No	Mix code	Slump value (mm)	w/c
1	0CHA	75	0.54
2	5CHA	75	0.54
3	10CHA	73	0.55
4	15CHA	72	0.55
5	20CHA	70	0.56
6	25CHA	65	0.57

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	Average weight	compressive strength	Average weight	compressive strength		
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