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Characterisation and Utilisation of Coir Fibre as Reinforcement for Geopolymer Composite

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Abstract. **Geopolymers are sustainable alternatives to Ordinary Portland Cement (OPC) and have been in existence for some decades. The usage of coir fiber as reinforcement for metakaolin-based geopolymer binders is examined in this work. Here, process optimization study was carried out to develop a consistent method producing the geopolymer binder. NaOH and Na_2SiO_3 were used as alkaline activators for the binders while fibre volume fractions of 0.03, 0.05, 0.07, 0.1 and 0.12 were used for the mix design. Elemental and mineralogical characterisation was carried out on the kaolin and coir fibres with the aid of an x-ray fluorescence analyser and x-ray diffractometer. Compressive tests on all samples at 28 days showed an optimum of 14.91MPa for the 0.1 fibre volume fraction while an optimum flexural strength of 3.53 was achieved for the 0.07 fibre volume fraction. A good interfacial adhesion between the fibers and the matrix was also revealed by Scanning Electron Microscope (SEM) analysis. The present study investigated the potential for developing a sustainable geopolymer technology by utilizing locally available coir fibre. Utilizing coir fiber has benefits including affordability and sustainability. The geopolymer binders produced showed comparable strengths to OPC and would be suitable as construction materials for less critical applications. The optimization of fiber composition and long-term durability can be studied further.**

Keywords *— Geopolymer, Coir fibre, Metakaolin, Alkaline activators*

I. INTRODUCTION

The usage of fibre-reinforced composites presents multiple advantages over conventional materials and has gained popularity in variety of sectors [1]. These composites add fibers to prevent cracking and increase ductility, which improves mechanical qualities including fracture toughness [2].

Geopolymers are generally made by mixing alkaline activator(s) with aluminosilicates source(s). The activators used are mostly obtained from silicates and hydroxides of alkali metals, though sulphates, aluminates and carbonates are sparingly reported [3]. The aluminosilicate sources on the other hand are gotten from either industrial by products or geological sources and the conventional ones used are clay, slag and fly ash [4]. Though the environmental impact of using clay compared to other industrial waste is lower, the availability of the industrial waste may not meet up with the demand especially in a large scale, thus the need to utilise the geological sources [5].

Geopolymers are known for their good mechanical qualities, robustness, and thermal stability, and have attracted a lot of attention. Their products have a lower calcium content than Portland cement-based materials, making them more acid-resistant and environmentally benign [6]. Natural or synthetic fibers are often added to geopolymers to further increase their strength. Particularly short fibers successfully enhance the mechanical and physical characteristics of geopolymer composites [2]. Although inorganic fibers like carbon or glass are often employed, natural fiber reinforcements are gaining popularity because of their repeatability, low density, high specific strength, and environmental friendliness [1].

In comparison to Portland cement, geopolymers have more complicated reactions, and factors such as the kind of raw material used, source of raw materials, the amount of activator used, the activator ratio, the curing environment and many others have a big impact on the microstructural characteristics of the finished product [7]. There is also not set acceptable standard since it is still an emerging technology, thus consistent research in

this field will increase understanding of the alkali-precursor interactions in geopolymers.

Characterising and using natural coir fibers as reinforcement for reinforcing metakaolin-based geopolymer binders is the goal of the study.

II. MATERIALS AND METHODS

A. *Materials Selection and Preparation*

Kaolinite clay was chosen as the aluminosilicate precursor based on their availability in Nigeria as well as their reportedly consistent performance. The kaolin samples were manually obtained from Markafi area of Kaduna State and prepared as reported in [8].

Coir fibres were manually collected from a farm in Cross River State. The matured coconut fruit were plucked and the fibres dehusked from the coconut fruit manually (Figure 1). The fibres were then ground and washed with sodium hydroxide (NaOH) solution to remove surface impurities in order to improve interfacial bonding before being stored in sealable bags.

Sodium Silicate (Na_2SiO_3) and NaOH were used as the synthetic alkaline activators. The activators were purchased from Ibrahadad Chemicals, a reputable distributor in Nigeria. The silicate was purchased in liquid form with an SiO2 to Na2O ratio of about 2.5 and chemical composition of 30%, 12% and 58% by weight of SiO2, Na2O and H2O respectively. The NaOH a 98% purity were purchased in pellet form and a measured quantity of the pellets were dissolved in the right amount of distilled water to prepare 8M and 10M concentrated solution.

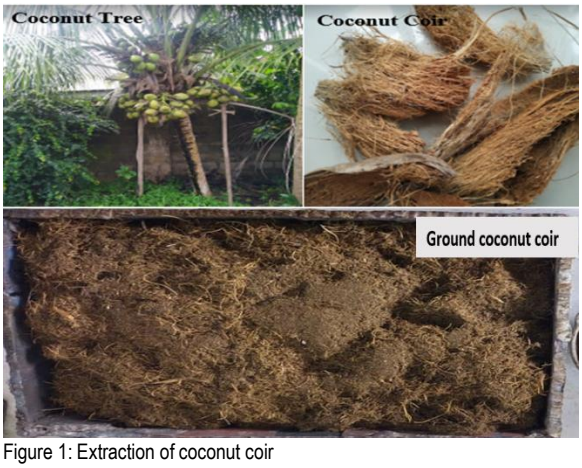

Figure 1: Extraction of coconut coir

B. ***Characterisation of Raw Materials***

The particle size distribution of the kaolin and metakaolin were performed using sieve analysis. Sieve sizes between 5μm and 150μm were used for this purpose. Weight loss of kaolin after calcination was also noted. Chemical composition of the kaolin and coir fibres were investigated using the X-ray fluorescence naysayer while the mineralogical composition of the clay was investigated with the X-ray diffractometer.

C. ***Mix Design***

Different geopolymer binders were produced using different fibre ratio in order to determine their physical and mechanical properties. The fibre volume fraction, Vf used was 0.03, 0.05, 0.07, 0.10 and 0.12. These fibre volume fractions were obtained using equation 1

$$V_f = \frac{M_f \rho_m}{M_f \rho_m + M_m \rho_f} \quad (1)$$

Here, Vf is the fibre volume fraction, Mf and ρf are the mass and density of the fibres while Mm and ρm are the mass and density of the matrix.

Factorial design of experiments was used to analyse two factors, the hydroxide concentration at two levels and the fibre volume fraction at five levels. The mix design was completely randomised and 10 samples prepared.

For the preparation of the GP composite, the dry component of the mixture was first mixed that is, the metakaolin and the coir fibre at the varying fibre volume fraction. The activators (Na_2SiO_3 and NaOH) were mixed together in a container with a ratio of 1:1 before incorporating properly in the dry mixture. After proper stirring and mixing, the GP was poured into a 50 mm x 50 mm x 50 mm and 20 x 20 x 100 mm silicone mould and vibrated to remove any air bubble formed as a result of the mixing process. The samples were then left undisturbed for 24 hours before the removal from their mould. After removal, they were sealed in bags and allowed there to cure for 7, 14 and 28 days. Data for control samples were used as

D. ***Test Methods***

Physical properties such as density and water absorption were measured. XRD and XRF analysis were carried out on the kaolin and coir to determine their mineralogical and elemental composition. The compressive and flexural tests were carried out on three replicates for each mix design using the ASTM C109 and ASTM C293 respectively. The cubic samples were used for compressive test while prismatic samples were used for flexural tests. The ASTM C642 was used to conduct the water absorption tests. Samples were weighed before submerging in water for an hour, drying and weighing again.

III. RESULTS AND DISCUSSIONS

The mean particle size of the calcined clay was 19.3μm. A weight loss of the calcined clay of about 9.3% was recorded. The chemical composition from the XRF analysis of the kaolin and coir fibres are recorded in

Table I. The kaolin had a combined SiO_2 and Al_2O_3 content of 83.5% while XRD analysis showed that the kaolin is crystalline in nature but upon calcination a more amorphous structure is obtained as shown in Figure 1. The minerals present in the kaolin and metakaolin are depicted in Table II.

A. Physical Characterisation of Geopolymer Paste

The Table 3 depicts the different mix designs generated and the densities of the binders which varied from 1.53 – 1.71 g/cm^3. Binders with more fibre volume fraction had lower densities. The first number in the mix codes represents the NaOH molarity, the next letter C signifies coir fibres and the numbers after that represents the fibre volume fraction. The control sample is made activating metakaolin with a mixture of NaOH and Na_2SiO_3 activators

TABLE III
MIX DESIGN OF GEOPOLYMER PASTES

Mix code	NaOH Molarity	Coir content (g)	Density (g/cm^3)
8C03	8	0.03	1.70
8C05	8	0.05	1.70
8C07	8	0.07	1.68
8C1	8	0.10	1.67
8C12	8	0.12	1.65
10C03	10	0.03	1.75
10C05	10	0.05	1.73
10C07	10	0.07	1.73
10C1	10	0.10	1.70
10C12	10	0.12	1.71
Control			1.80

TABLE I
XRF OF KAOLIN AND COIR FIBRES

Source	Chemical composition													
	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	Cl	CaO	MgO	Na_2O	K_2O	MnO	Cr_2O_3	CuO	Other	LOI
Kaolin	51.18	32.35	0.88	0.34	0.80	0.02	0.001	0.01	1.87	0.02	0.03	0.25	7.93	11.32
Coir	32.12	2.53	0.30	7.11	1.78	34.51	14.56	1.09	3.50	0.18	0.42	0.32	1.34	

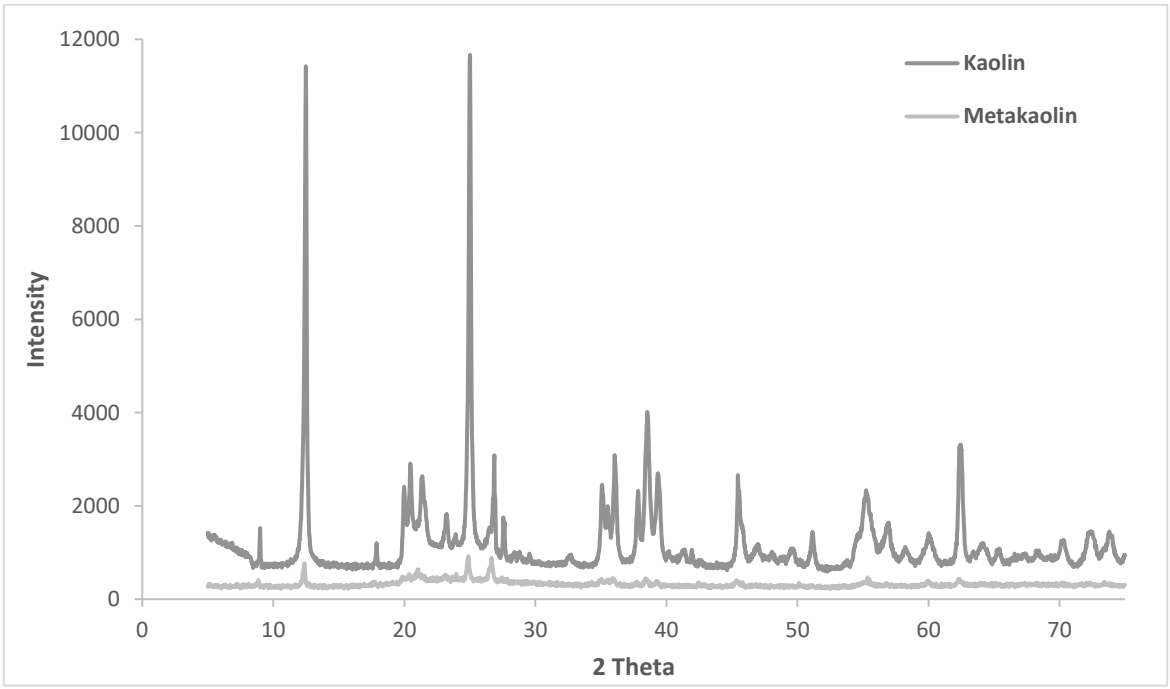

Figure 2: XRF of kaolin and metakaolin samples

TABLE II
MINERALS PRESENT IN THE KAOLIN AND METAKAOLIN

	Kaolinite ($Al_2Si_2O_9$) (%)	Muscovite ($K_{2.4}Na_{1.48}Al_{11}$)(%	Rutile (Ti_2O_4)(%)	Biotite ($K_6Mg_{18}Si_{18}$)
Kaolin	78.0	12.1	9.3	
Metakaolin	74			23

B. Mechanical and Physical Tests of Geopolymer Binders

The water absorption tests shown in Figure 3 shows a higher water absorption rate when compared with the control sample. This is most likely due to the presence of fibres in the binders because coir fibres are hydrophilic in nature. Further treatment of the fibres before use may have the ability to lower the water absorption rate.

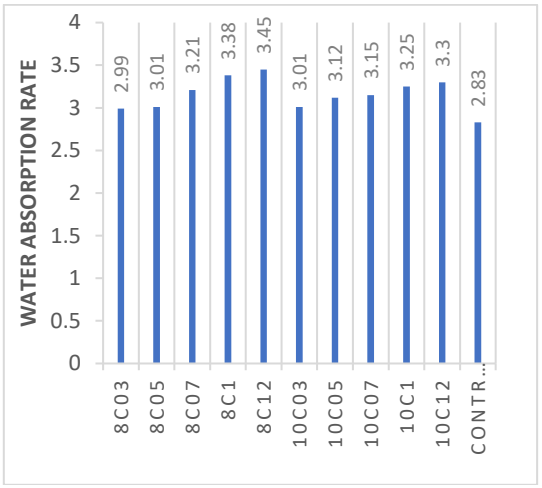

Figure 3: Water absorption rate

The flexural and compressive strength of the binders were analysed after curing at room temperature for 7, 14 and 28 days. Maximum strength of 14.91 MPa was gotten from the 8C1 binders as shown in Figure 4 which is about 18% higher than the control. An early strength development was also recorded for the geopolymer binders when compared with the control which aligns with previous researches [9]. In general, compressive strength for those prepared with 8M NaOH increased with increase in coir fibre content but reduced after 0.1 fibre volume fraction.

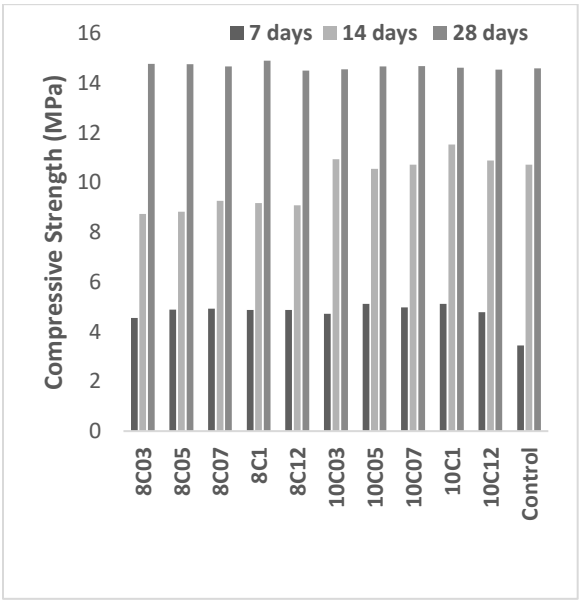

Figure 4: Compressive Strength of Geopolymer Binders

The maximum flexural strength obtained from the mix design was 3.52 MPa which was gotten from the 10C07 binders. The binders incorporated with the coir fibres, generally had a higher flexural strength than those without the fibres as depicted in Figure 5 and also recorded a higher early strength than the control binder. This was expected because the introduction of fibres reportedly increases the tensile properties of the composites as well as its flexural strength [1][2].

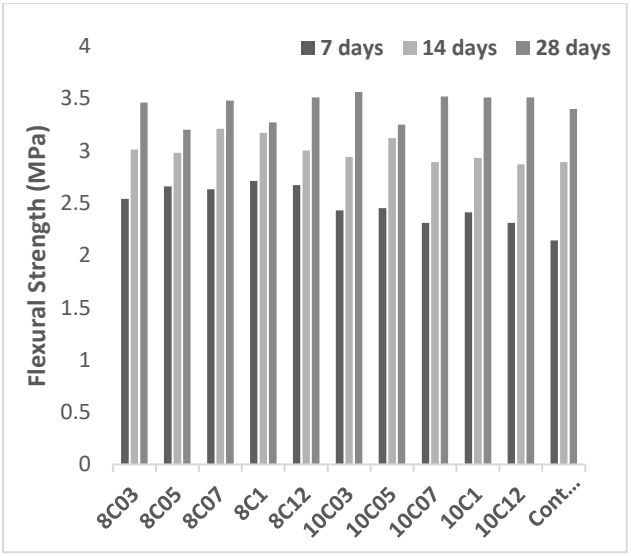

Figure 5: Flexural strength of geopolymer binders

C. SEM Morphology

The 8C1 binder was analysed with SEM because it had the best mechanical properties. The SEM morphology of 8C1 binder is shown in Figure 6. The particulate fibres were hardly visible from the SEM with no clustering which suggests good distribution of the fibres. Also, few voids were noticeable from the image which makes the binders possess good strength.

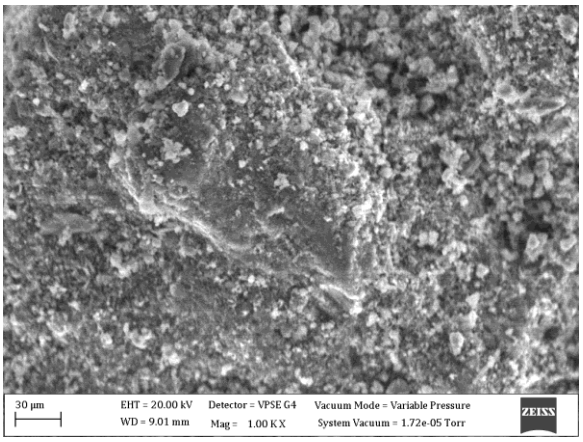

Figure 6: SEM of 8C1 fibres

IV. CONCLUSION

This study investigated the properties of metakaolin-based geopolymers reinforced with coir fibres at five different fibre volume fractions. The density of the samples reduced with increase in the fibre volume fraction. Also, the composites possessed a higher water absorption ratio when compared with the control sample probably due to the presence of the fibres. The compressive and flexural strength showed better performance of 14.91 MPa and 3.53 MPa when compared with the control sample which depicts a positive impact due to the introduction of the fibres. SEM morphology of the sample with the best compressive strength showed a good distribution of fibres in the mix and few voids present.

Geopolymer binders' compressive and flexural strength were all improved by the addition of coir fiber. The experimental design using coconut husk, calcined clay, and activators produced encouraging outcomes. Because it is renewable and biodegradable, coir fiber acts as reinforcement and encourages sustainability. Overall, coir fiber presents a practical and eco-friendly alternative for creating durable and eco-friendly building materials.

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