PARTIALLY REPLACED CEMENT BASED PAPER PARTICLES-WOOD SAW DUST-COCONUT FIBER COMPOSITES FOR LOW LOAD BEARING CAPACITY AND LIGHT-WEIGHT CIVIL CONSTRUCTIONS

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Abstract
The increasing demand for cheap and environmentally friendly housing infrastructure for rural and urban populations in developing countries has increased research interests in renewable raw materials in the construction industries. Thus, this research was carried out to reduce the amount of cement in low load bearing capacity components by replacing it with waste paper pulp and reinforcing with coconut fiber and wood sawdust particles. To achieve this, selected raw materials (waste papers, wood saw dust and coconut husk) were sourced and processed to standard. As part of steps to accomplish good results, coconut fiber was treated with alkaline for adequate adhesion. To have a good understanding of bonding tendency, morphological characterization of paper particles and the reinforcements were investigated using scanning electron microscopy. Samples were developed with varying proportions of the compositions and allowed to cure for 7 and 28 days at ambient temperatures, respectively. Cast samples were fabricated into cubic and cylindrical moulds for compressive and tensile tests, respectively while part of the samples were also produced for water absorption characteristics. Microscopy results revealed rough surfaces that will encourage bonding at the interface while alkali treatment of coconut fibers exposed the cellulose surface compared to untreated wood sawdust particles. Results of the mechanical properties revealed that, sample with 50% waste paper particle, 30% cement, 15% wood sawdust and 5% coconut fiber (by weight) exhibited optima tensile and compressive strengths of 0.65 MPa and 2.10 MPa after 21 days of curing, respectively. Water absorption was discovered to reduce with the addition of the reinforcements, hence, the material can be suitable used for ceiling and partitioning in building and construction where strong, light-weight and eco-friendly materials are desirable.

Keywords: partial replacement, paper particles, wood sawdust, coconut fiber, cement-based composites, load bearing capacity

Introduction

Solid waste generation is a continuous occurency globally that requires adequate attention which has led to change of focus by researchers in utilizing them for sustainable applications in recent times (Fadare *et al*., 2021; Okoro *et al*., 2015; Oladele *et al*., 2017). In the modern days, research and development is now been focused on naturally occurring and/or wastes materials for biodegradable components due to the concern on the environments (Oladele *et al*., 2021). These components are usually from composite based materials. In civil constructions, cement-based composite materials, such as mortar and concrete are commonly used in the construction industries. These materials are characterized by high compressive strength which however, suffer from the limitation of low flexural and tensile strengths (Momoh and Osofero, 2019). Hence, for cement-based composites to be useful in building applications, there is the need to improve their tensile and flexural strengths. Reinforcing cement-based composites with other materials is one of the potential strategies aimed at enhancing tensile and flexural strengths. Steel rebar is a widely used as reinforcing material in the building industry nowadays, giving an excellent combination as the properties of cementitious materials are opposite to those of steel in tension (Tarabin *et al.,* 2023). Besides steel rebar, fiber reinforcement using synthetic fibers, such as steel, glass, plastic, etc., have been utilized in cement-based composites to improve tensile and flexural strengths (Wang *et al.,* 2021).

Fiber reinforcements offer some benefits, such as the omission of rebar arrangements at the construction site and inhibit crack expansion, as short fiber reinforcements are usually dispersed evenly within the cement matrix (Futami *et al.,* 2021). Steels that are commonly used as either primary or secondary reinforcement, is the most often utilized reinforcing material amongst synthetic materials in civil contructions in order to compliment the limitation cement. However, environmental unsustainability and frequent corrosion challenges associated with steel fibers limit their use and applications in the construction industries. Although glass and polyvinyl fibers provide the greatest solution to these problems, they are heavy-weight and expensive, and their processing is energy-intensive and environmentally unfriendly due to the release of carbon dioxide into the environment (Momoh and Osofero, 2020). For instance, studies have shown that incorporating 1% steel fiber into the cement matrix increases the carbon footprint and cost of the concrete by at least 50% and 90%, respectively (Chan *et al.,* 2019). High costs and energy demands, and environmental impacts have necessitated a paradigm shift from conventional, environmentally unsustainable, and nonrenewable structural reinforcements, such as steel, to sustainable and renewable alternatives like fibers from vegetative origin in an attempt to protect the environment and achieve low-cost housing.

Natural fibers are mainly subcategorized into animal, plant, and mineral fiber. Plant fibers, also referred to as vegetative or cellulosic fiber, are the most desired natural reinforcing material in cement-based composites (Pickering *et al.,* 2016). The incorporation of plant fibers into the cement matrix is associated with economic, environmental, resource conservation, and energy benefits. Moreover, plant fibers are renewable, recyclable, sustainable, and readily available globally. However, plant fibers are susceptibile to microbial attacks, have lower durability, higher moisture absorption, and higher inconsistencies in mechanical and physical properties (Bichang'a *et al.*, 2022a; Bichang'a *et al.*, 2022b).

Various techniques, such as chemical and physical pre-treatments, have proven effective in negating these limitations, thus, improving the properties of the resultant cement-based composites for building applications (Oladele *et al.,* 2010; Yan *et al.,* 2016). Literature survey shows that the use of cellulosic fibers in cement composites can reduce the overall weight, production energy requirement, and cost by 10, 80, and 5%, respectively, compared to synthetic fiber reinforcements (Balasubramanian and Selvan, 2015). Other natural fibers investigated as reinforcing materials in cement-based composites include piassava, razor grass, coconut, sisal, pineapple, flax, curaua, sugarcane bagasse, rattan, etc. (Rocha *et al.,* 2022; Okoro *et al*., 2015).

Coconut fibers offer advantages such as durability and toughness, high resistance to rotting and fungi attack, resilience, excellent insulation against sound and temperature, lowest water absorption capacity, and enhanced impact energy absorption characteristics compared with other natural fibers (Oladele *et al.*, 2022; Althoey *et al.,* 2023). With increasing demand for cheap housing infrastructure for rural and urban populations in developing countries, several strategies aimed at reducing the cost of traditional building materials have been proposed. One of the innovative strategies that has attracted research interests is to find, develop, and use an alternative, non-traditional local building ingredient, such as industrial and agricultural wastes (wastes), as reinforcing elements for traditional building materials. Due to limitations in technological advancement for waste management in many developing countries, industrial incineration waste management practices are conducted in an uncontrolled manner, leading to environmental air pollution. Therefore, there is a need for research studies to develop value-added products from these wastes. Using these wastes as reinforcing elements in cement matrix to develop building materials in a sustainable approach to the elimination of wastes and their associated environmental hazards. The current study investigates the potential of incorporating coconut fiber, waste paper pulp, and wood sawdust particles in a cement-based matrix with the aim of reducing the required cement proportion, thus developing strong, cheap, sustainable, and environmentally friendly building material.

Materials and Methods

Materials

Coconut fiber, wood sawdust, white waste paper, cement, and tap water were used in the present study to fabricate samples for characterization. Coconut fibers were collected from some fruit vendors while white waste papers were collected from Metallurgical and Materials Engineering department both at the Federal University of Technology Akure. Wood sawdust was obtained from a furniture workshop in Akure. Cement was procured from a hardware store in Akure, all in Ondo State, Nigeria.

Preparation of Reinforcement
Preparation of coconut fiber

The collected coconut husk was soaked in water for 24 hours to soften the husk and extract the fibers after which they were washed in running water to remove dirt and sand particles and sun-dried to remove moisture. The fibers were treated with 0.5 M NaOH solution for 24 hours at ambient temperature followed by washing with tap water and rinsed with distil water till a pH of 7 was attained. The alkali-treated coconut fibers were oven-dried at 105°C for 3 hours to remove moisture and left to cool to ambient temperature in a desiccator. The alkali-treated coconut fibers were chopped into 60 mm length for composite fabrication.

Preparation of Paper Pulp

Waste paper was soaked in water for 7 days to soften it and pulped on a paper pulping machine to form paper slurry. The paper slurry was sun-dried for 7 days to reduce the moisture content and pulverized using a grinding machine to obtain fine particles.

Sieve Analysis of Sawdust

The sieve size analysis of sawdust was conducted in accordance with ASTM C136 – 12 Standard procedures (ASTM C136-12, 2012). First, the sawdust was dried at 105°C for 12 h in a convection oven (Gallenkamp Plus Oven). The dried sawdust was sieved using Fragtech Standard Laboratory Sieves of apertures 150 µm on a sieve shaker machine to obtain <150 µm.

Preparation of the cement-based composite samples

Cubic and cylindrical molds measuring 50 mm × 50 mm (compressive test samples) and 50 mm diameter × 100 mm length (tensile test samples) were used to fabricate the composites. Spent engine oil was coated on the inner surfaces of the molds to facilitate easy removal and prevent delamination of the developed samples. Using the percentage weight proportions presented in Table 1, paper pulp, wood sawdust, coconut fiber, and cement mixture were mixed thoroughly and then poured into the molds. After 24 hours, the composite samples were removed from the molds and then allowed to cure at ambient temperature for 7 and 28 days, resectively before testing. T

Table 1: Sample ID and Percentage weight proportion of the Developed Cement-based Composites

Samples	Waste paper (%)	Coconut fiber (%)	Wood sawdust (%)	Cement (%)
80WP	80	-	-	20
70WP	70	-	-	30
70WP/5CF/5WS	70	5	5	20
65WP/5CF/10WS	65	5	10	20
60WP/5CF/15WS	60	5	15	20
65WP/10CF/5WS	65	10	5	20
60WP/15CF/5WS	60	15	5	20
60WP/5CF/5WS	60	5	5	30
55WP/5CF/10WS	55	5	10	30
50WP/5CF/15WS	50	5	15	30

Property Evaluation

The tensile strength of the composite samples was determined in accordance with ASTM D3038M – 08 standard (ASTM D3038M – 08, 2008) on the Digital Compression Testing Machine, Series 3369, with a capacity of 10 – 300 ton.

The compressive test was carried out in accordance with ASTM C873 standard (ASTM C873, 2008) on the Digital Compression Testing Machine, Series 3369, with a capacity of 10 – 300 ton. The specimen was placed between the compressive plates parallel to the surface and then compressed at a uniform rate. The stress-strain data was recorded. For repeatability and reproducibility, three identical tensile and compressive test samples were tested for each weight fraction, and the average values were reported.

Water absorption tests were carried out in accordance with ASTM D570-18 standard (ASTM D570-18, 2018). First, the initial weight of dry composite samples (W_d) was measured. Thereafter, the samples were fully submerged in distilled water for 7 and 28 days, respectively. At the end of the immersion time, the samples were removed from the water and wiped with a dry water-absorbent cloth to remove any water from the sample surface, and their weight was measured as final weight (W_t). The collected data was used to compute the water absorption as a percentage of the samples using Equation 1.

$$Water\ absorption, \% = \frac{W_t - W_d}{W_d} \times 100 \qquad (1)$$

where; W_t and W_d are dry sample weight after time t (in days)

Results and Discussion

Reinforcements Characterization

The study of the reinforcement surface morphology is critical in outlining their mechanical and physical properties in understanding their role in cement-based composite materials. Figure 1 shows the surface of the materials. The reinforcements have a rough surface characterized by the presence of protrusions for wood sawdust particles, serrations for waste paper pulp particles, and fibrils for coconut fiber. The fibrils observed on the surface of coconut fiber represent fibril clusters bonded with lignin forming a single fiber filament. The presence of rough surfaces increases the appropriateness of fibers for reinforcement with the cement-based matrix as the surfaces easily adhere to the matrix, forming a good bonding strength. The presence of white surfaces and spots on the surface of wood sawdust and coconut fiber depicts the presence of non-cellulosic/amorphous constituents, mainly lignin, wax, hemicellulose, pectin, and other impurities and contaminants. Similar results have been observed in raw dombeya buettneri fiber (Bichang'a *et al.,* 2023) and pineapple crown fiber (Bernardes *et al.,* 2023).

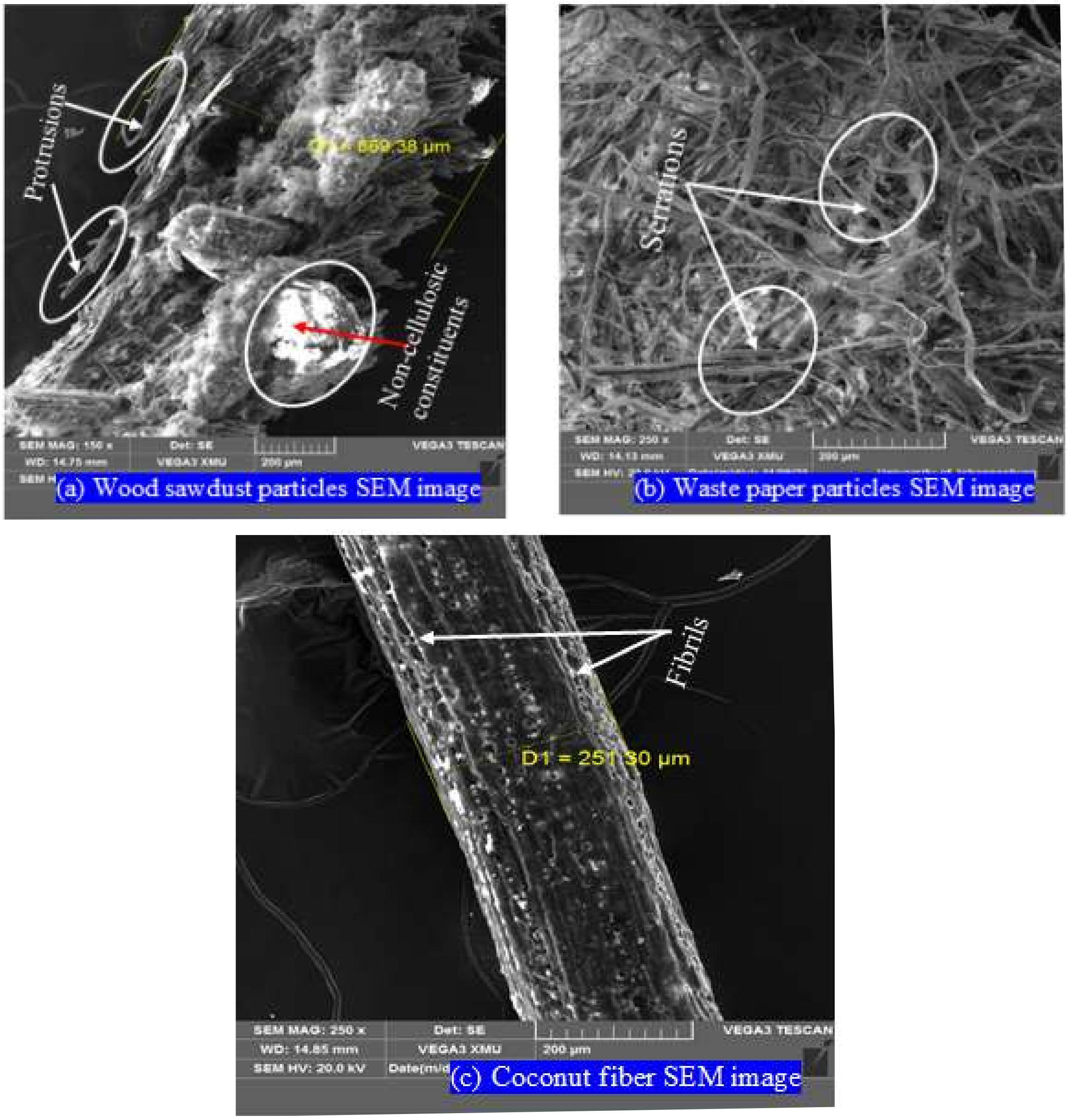


Figure 1: SEM Images of (a) wood sawdust particles, (b) waste paper pulp particles, and (c) treated coconut fiber

The presence of non-cellulosic constituents hinders the bonding between the reinforcement and the matrix, thus adversely affecting the properties of the developed composite material. Therefore, to enhance the properties of the composites, the amorphous constituents should be removed through chemical pre-treatments, such as alkali treatment.

Figure 2 depicts the surface characterization of wood sawdust particles, waste paper pulp particles, and coconut fiber using energy-dispersive X-ray spectroscopy.

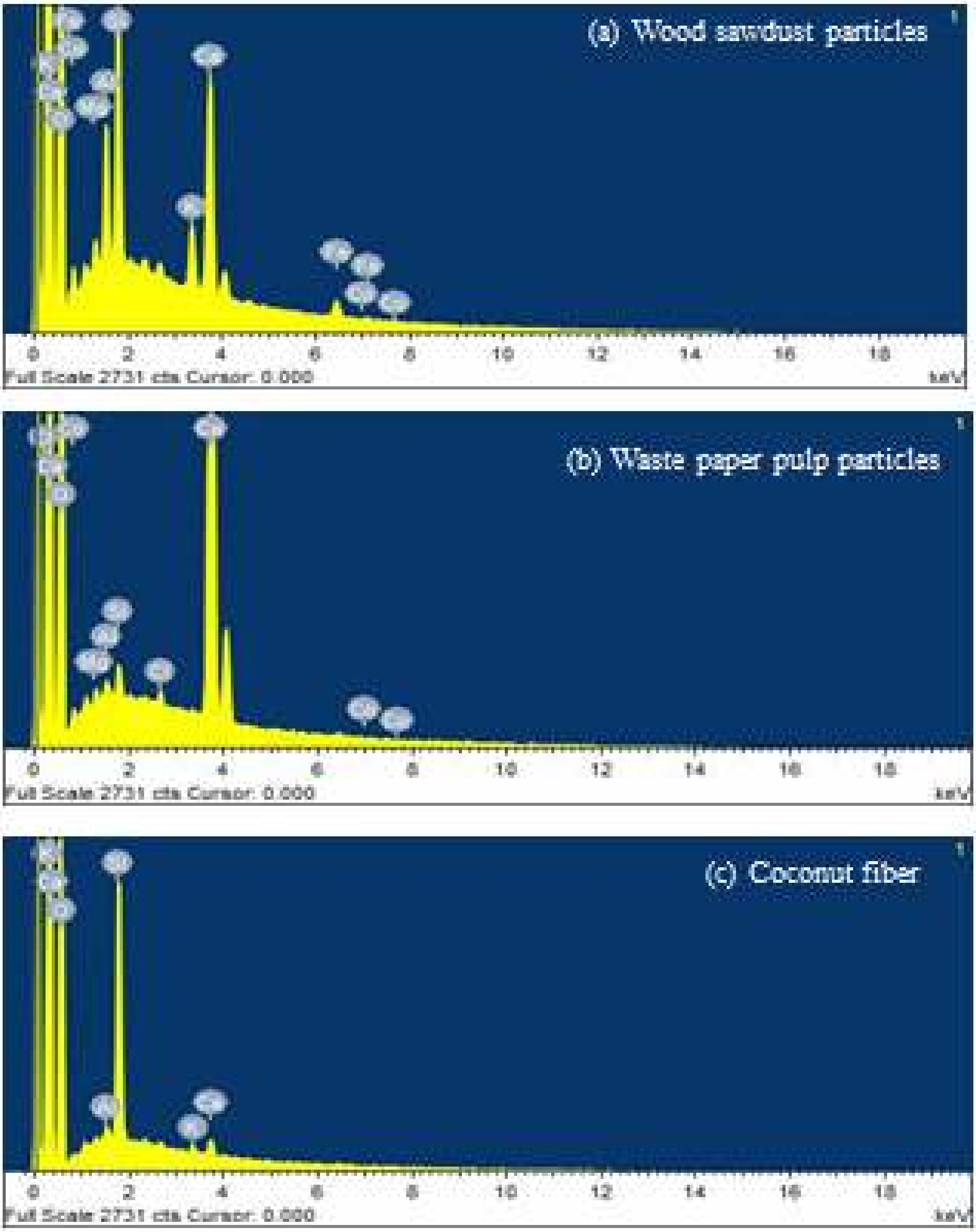


Figure 2: EDX Spectrum of (a) wood sawdust particles, (b) waste paper pulp particles, and (c) coconut fiber

The basic elements in wood sawdust particles and waste paper pulp particles are calcium (Ca) and oxygen (O), which are the major elements of the surface of the reinforcements. On the other hand, oxygen (O) and silicon (Si) are the major elements on the surface of coconut fiber. The weight and atomic percentages of oxygen are 39.53 and 57.99 for wood sawdust particles, 29.58 and 50.60 for waste paper pulp particles, and 50.42 and 65.05 for coconut fiber. Besides oxygen, calcium, and silicon, which were observed as major elements, the reinforcements had other elements such as iron (Fe), magnesium (Mg), aluminum (Al), among other elements with varying weight and atomic percentages, as summarized in Table 2.

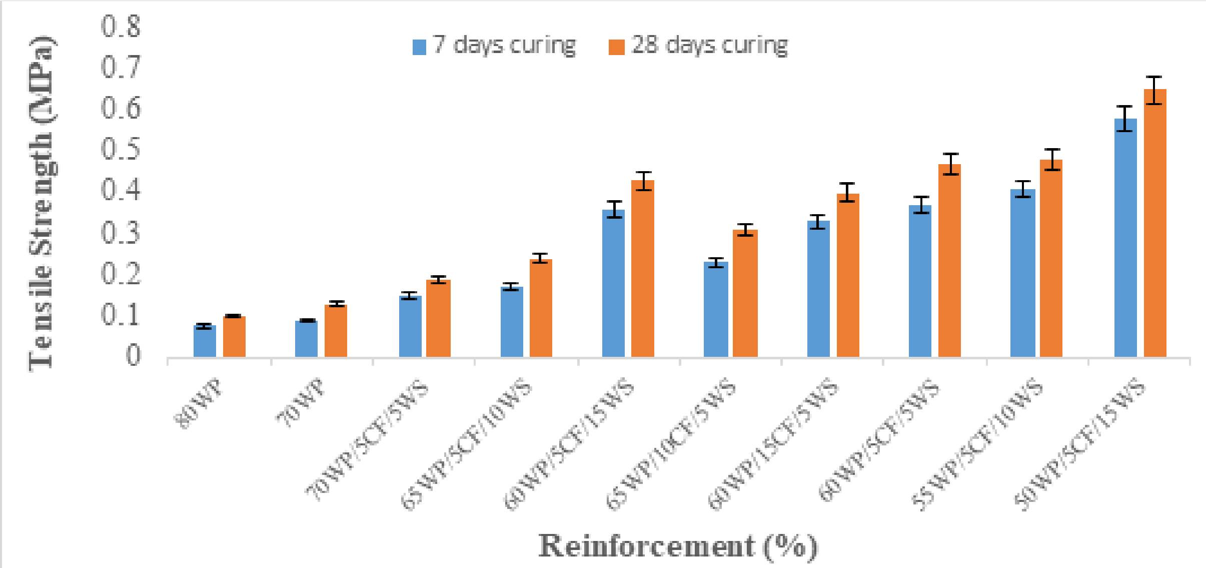
Table 2: Elemental composition of wood sawdust particles, waste paper pulp particles, and coconut fiber

Reinforcement	Element	Al K	Si K	K K	Ca K	O	Mg K	Fe K	Cl K	Co K
wood sawdust	Weight	8.02	17.02	5.5	22.9	39.53	2.1	4.77	-	-0.05
	Atomic	6.98	14.22	3.48	13.41	57.99	1.94	2.01	-	-0.02
Waste paper	Weight	0.81	1.61	-	66.23	29.58	0.99	-	1.01	-0.24
	Atomic	0.82	1.57	-	45.22	50.6	1.12	-	0.78	-0.11
Coconut	Weight	1.7	40.78	1.96	5.14	50.42	-	-	-	-
	Atomic	1.3	29.97	1.03	2.65	65.05	-	-	-	-

Characterization of the Developed Cement-based Composites

Tensile Strength

Figure 3 shows the influence of curing time, reinforcements, and weight fractions on the ultimate tensile strength of developed cement-based composites with and without coconut fiber and wood sawdust reinforcements. Samples 80 WP and 70 WP containing 80% waste paper pulp/20% cement matrix and 70% waste paper pulp/30% cement matrix (by weight), respectively, without coconut fiber and wood sawdust reinforcements, were taken as control samples. From the results, it was noticed that as the cement content increases, the tensile strength increases from 0.1 to 0.13 MPa for 7 and 28 days cured samples respectively. This showed that higher cement content enhances the tensile strength within these range. With the addition of wood saw dust and coconut fiber, it was observed that the tensile strength increases with curing time, with 28-days cured samples reporting higher tensile strength than 7-days cured counterparts. This is because the fiber-matrix bonding strength increases with curing conditions in agreement with previous researchers (Akçaözoğlu and Kıllı, 2021). Also, tensile strengths increases with increase in wood saw dust when coconut fiber was fixed. Hence, sample designated as 50WP/5CF/15WS has the optima tensile strengths of 0.58 and 0.65 MPa for 7 and 28 days curing time, respectively. This showed that the optimum coconut fiber is 5 wt.%. Similar to the control samples, coconut fiber and wood sawdust particles based composite samples with 30 wt.% cement matrix had higher tensile strength compared to samples with 20 wt.% cement matrix. Therefore, the composition with the optimum tensile strength is 50WP/5CF/15WS/30CM. The observed results can be attributed to the presence of sufficient cement matrix to wet and bind the reinforcements within the composite structure in the higher cement content samples compared to the one with low cement content. The addition of coconut fiber and wood sawdust particles into waste paper pulp/cement structure significantly enhanced the tensile strength of the resultant composites. The increase in tensile strength with coconut fiber addition and increasing wood sawdust particle loading indicates that reinforcements enhance the tensile capacity of cement-based composites. Additionally, this observation can be attributed to reduction in initial crack opening and fracture propagation as a result of tensile loading similar to what has been reported with the incorporation of plant fibers in cement-based composites (Oladele *et al.*, 2022; Katman *et al.,* 2022).



Compressive strength

Figure 4 presents the variations of compressive strength for control and developed cement-based composites where similar trends to tensile strengths results in Figure 3 was observed, indicating that there is agreement in the sample's response to the mechanical properties. The enhancement of compressive strength with coconut fiber and increasing wood sawdust particles can be attributed to the filling of pores and voids and proper wetting of the constituents by the cement. The wood sawdust microparticles have a large contact surface area and high aspect ratio, enabling them to flow and fill internal voids and pores, thus, ensuring adequate bonding within the composite structure. From the results, it was observed that sample denoted as 50WP/5CF/15WS/30 CM has the highest compressive strength with values of 1.83 and 2.1 MPa for 7 and 28 days, respectively. Similar to the results in Figure 3, sample designated as 80 WP, containing 20 wt.% cement exhibited the least compressive strength values of 0.21 and 0.31 MPa for 7 and 28 days, respectively. Literature survey shows that the addition of açai fiber to the cementitious matrix fills internal pores and absorbs and distributes internal stresses, thus, enhancing the compressive strength of the developed cement-based composites (de Azevedo *et al.,* 2021). Further, the findings reported in the current study are congruent and consistent with previous studies for aggregate/coir fiber/cement-based hybrid composites (Oladele *et al.*, 2022; Katman *et al.,* 2022).

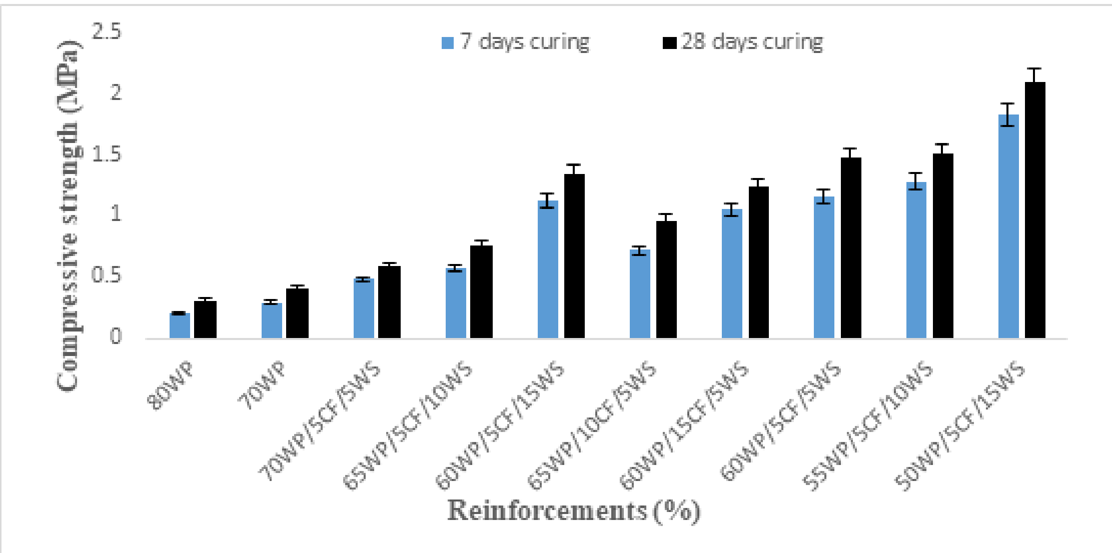
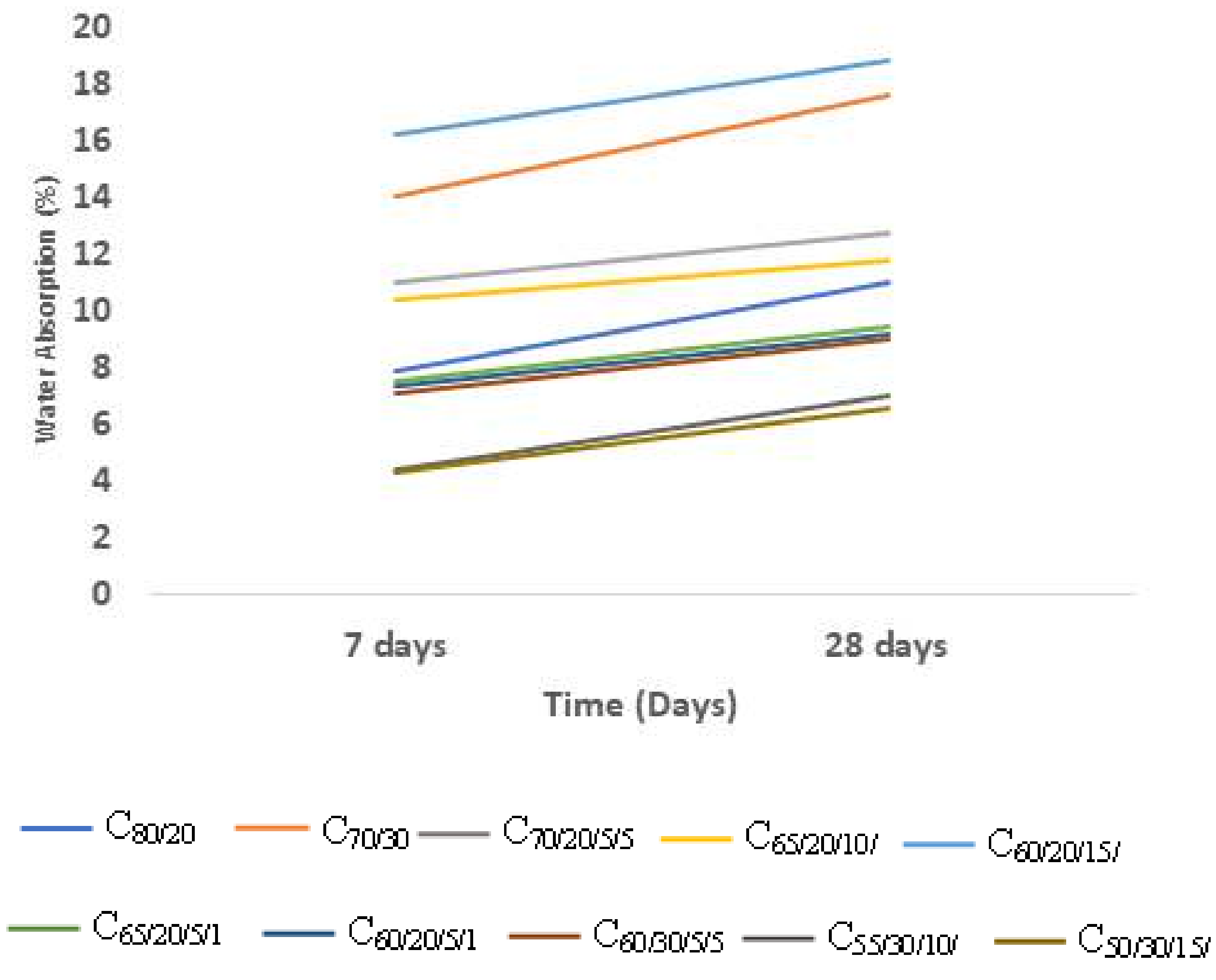


Figure 4: Variation of Compressive Strength of the Developed Cement-based Composites

Water Absorption

Figure 5 (a-b) showed the variation in the percentage of water absorption for the cube (compressive) and cylindrical (tensile) samples. From the plots, the control samples exhibited the maximum water absorption properties for both cubic and cylindrical samples after 7 and 28 days curing time. For both samples, there was a drastic reduction in water absorption characteristics with the addition of coconut fiber and wood sawdust particles. This is because wood sawdust microparticles, due to their large surface area and high aspect ratio flow and fill internal micropores responsible for water absorption. Similarly, the presence of coconut fibers in the cementitious matrix enhances the stiffness of the resultant composite, thus, preventing water penetration. This is congruent and consistent with literature survey, which has reported that the inclusion of coir fibers in cement matrix caused a reduction in water penetration (Oladele *et al.*, 2022; Katman *et al.,* 2022). On the contrary, an investigation to enhance the performance of cement-based mortar reported an increase in the composites' ability to absorb water as the proportion of coconut fiber increased from 3 – 15 wt.% (Nawab *et al.,* 2023). This is because the surface of plant fiber has lumens, acting as void, responsible for water absorption from the environment (Saha, *et al.,* 2021). Therefore, as the cellulosic fiber weight weight fraction increases, the proportions of lumens increases. This makes the developed composite to freely absorb water molecules, causing a rise in the water uptake rate. Hence, as discovered in this work, an optimum value of 5 wt.% is good for the enhancement of both mechanical and physical properties of cement-paper particles-coconut fiber-wood saw dust based composites.



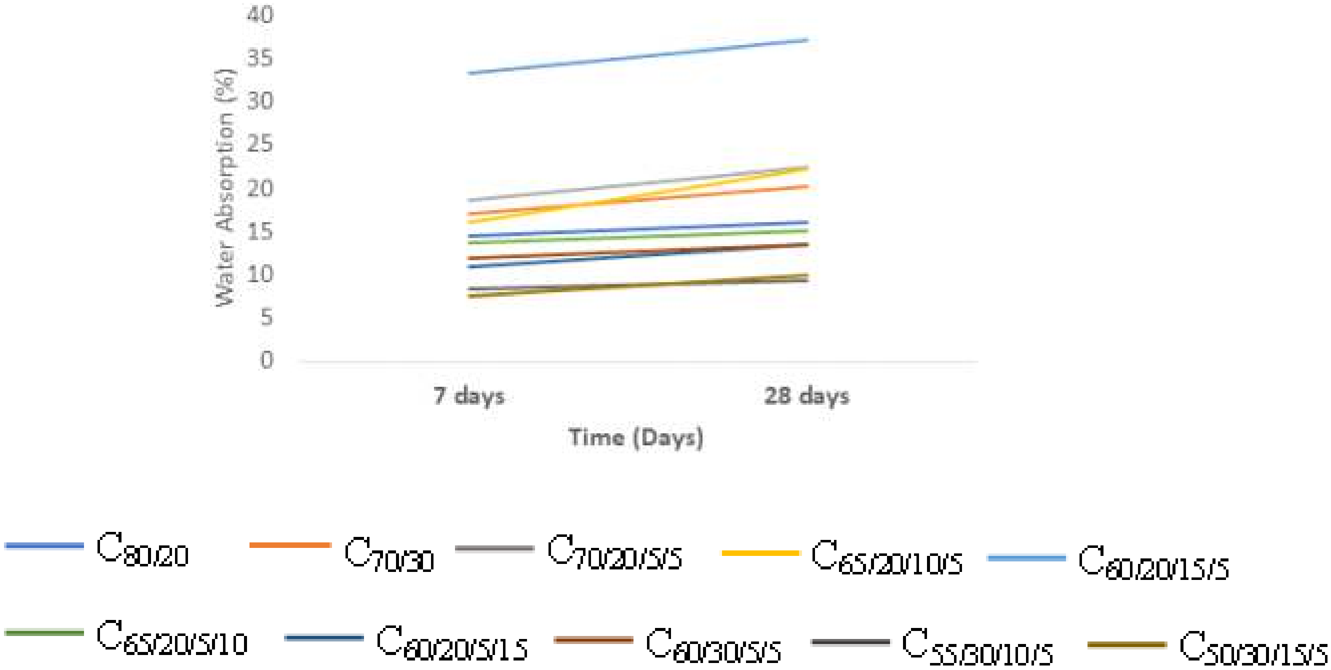


Figure 5b. Water absorption of the tensile composite samples

Conclusion

The study investigate the possibility of using waste paper in partial replacement for cement in civil contructions for low load bearing componenet where light-weight is desirable and discovered the following conclusions.

(a) Particulate waste paper can be suitable used in combine with wood saw dust and coconut fiber in partial form to reduced the amount of cement to be used. Hence, 50WP/30CM/15WD/5CF representing 50 wt.% paper particles, 30 wt.% cement, 15 wt.% wood saw dust and 5 wt.% treated coconut fiber is the optimum composition for enhance properties.

(b) Tensile, compressive and water repellant properties of the developed composites increases as the curing time increases from 7 to 28 days with optima strengths been 0.65 and 2.1.MPa for tensile and compressive, respecrively. The addition of wood saw dust and cocnut fiber actually aid the reduction in water absorption for the cement-paper particles based composites which can be adopted when water repellant is essential. Hence, this material can be suitable adopted for use in low load bearing capacity applications where strong and light-weight materials are desirable.

(c) The material is recommended for use based on its potentials in meeting the interest of researcher globally for sustainable eco-friendly materials.

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