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PERFORMANCE EVALUATION OF COMPRESSED LATERITE BLOCKS REINFORCED WITH COCONUT FIBERS AND STABILIZED WITH GUM ARABIC AS BINDER

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Abstract

This article aims to investigate the viability of Arabic gum as a natural stabilizer for construction materials, focusing on its role in compressed earth blocks (CEB). The study assesses how Arabic gum performs as a natural binding agent in CEB reinforced with coconut fibers, specifically examining compressive strength, dry density, and water absorption. The results emphasize that the simultaneous use of coconut fibers and Arabic gum in stabilizing compressed earth blocks (CEB) did not prove as effective as relying solely on coconut fibers to enhance compression resistance. However, the introduction of Arabic gum addresses the issue of high porosity in CEB reinforced with coconut fibers by improving water absorption and dry density. The experimental procedure includes blending lateritic soil with different ratios of coconut fibers (CF), ranging from 0 to 1% in increments of 0.2% relative to the dry weight of the lateritic soil. The determination of the optimal content of coconut fibers is based on compression strength tests, revealing that the ideal rate is 0.6%. This mixture results in a strength of 4.151 MPa after 28 days of curing, meeting the Kenyan standard (KS 02-1070: 1993). Subsequently, a fixed optimal content of 0.6% CF is established while adjusting the Arabic gum stabilizer (GA) from 0 to 10% with 2% intervals. Compression and water absorption results, in accordance with the Kenyan standard and targeted resistance, reveal that the optimal mixture proportions are 0.6% CF + 2% GA (4.143 MPa at 28 days) and 0.6% CF + 6% GA (10.017% at 28 days), respectively. In summary, the proposed stabilization approach effectively improves the comprehensive mechanical properties of compressed earth blocks (CEB) while addressing the deficiencies observed in CEB exclusively stabilized with coconut fibers.

Keywords: Coconut Fibers, Gum Arabic, Water Absorption, Dry Density, Compressive Strength.

1. INTRODUCTION

Lateritic soils are commonly found in tropical regions with high rainfall and temperatures, which causes the soil to lose its lime and silica content. The distinctive reddish color of lateritic soils, attributed to their elevated iron oxide content, makes them well-suited for the cultivation of cashew nuts and tapioca. These soils are abundant in alumina (Al_2O_3), silica (SiO_2), and iron oxide in the form of hematite (Fe_2O_3). Since the beginning of human civilization, people have relied on earth as their primary building material due to its affordability and adaptability. Throughout history, various earth construction techniques, including cob construction, rammed earth construction, poured earth construction, wattle and

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cob construction, and rammed earth construction [1], have been employed. Surprisingly, even in the technologically advanced 21st century, more than a third of the global population resides in homes made of earth. These structures offer superior adaptability to different climates, environmental friendliness, accessibility, and affordability, all while maintaining a fundamental cultural connection with nature [2].

Despite the widespread use of cement in modern construction, earthen structures persist because not everyone can afford the expense of contemporary cement houses. This has resulted in a renewed focus on employing earth as a construction material, especially in underdeveloped regions like certain African countries. In this context, modern earth construction methods, such as Compressed Stabilized Earth Blocks (CEB), have come to the forefront. CEB, created by compressing damp earth into a mold, represents a modern evolution from Adobe, employing advanced machinery to produce precisely calibrated units. Production adheres to specific quality control standards, with soil clay serving as the primary binder. However, these earthen structures face sustainability challenges, including susceptibility to rain erosion, crumbling, reduced cross-section, low compressive and tensile strength, shrinkage, low strength, and dimensional instability [3, 4]. In order to overcome these challenges and ensure the durability of structures, conventional additives such as lime, fly ash, and cement have been introduced into soils for stabilization purposes [5]. Regrettably, cement, being the most commonly utilized material, plays a role in environmental degradation by emitting greenhouse gases, primarily stemming from the non-renewable nature and restricted accessibility of these materials [2, 5, 6]. Moreover, there is an expense linked to the transportation of these materials [7]. Significantly, the production of cement results in the generation of 1 ton of CO_2 for every ton of cement manufactured [8]. Research shows that compressed stabilized earth blocks (CSEB) yield 22 kg of CO_2 per ton, while concrete blocks produce 143 kg of CO_2 per ton, and clay bricks generate 200 kg of CO_2 per ton [9]. Moreover, in the manufacturing of CSEB, the utilization of 1 kg of cement releases 0.894 kg of CO2. [10, 11]. To alleviate the adverse environmental effects of cement and lime, the utilization of eco-friendly materials, like natural biopolymers, has been proposed as an alternative for soil stabilization. [6], [12, 13].

The incorporation of natural fibers, derived from plant or animal sources, into the construction domain signifies a significant stride towards environmentally friendly practices. These fibers, typically renewable and biodegradable, offer an ecological alternative for various applications in the earth construction sector. In this regard, various modifiers, including binders such as cement and lime, as well as synthetic or natural fibers like coconut fiber, palm oil, sugarcane residue, sheep's wool, and straw, have been extensively employed. Despite the superior mechanical performance and durability of soil blocks reinforced with synthetic fibers compared to those reinforced with natural fibers, the growing interest in the latter arises from environmental considerations [14]. Coconut fiber, listed among the top fifteen plant and animal fibers worldwide, is characterized by its chemical composition, consisting of roughly 90% lignin and cellulose [15]. Coconuts, an agricultural product covering approximately 14.231 million hectares, are extensively cultivated in the tropics and account for over 60% of the volume of global household waste, primarily in the form of coconut husks [16]. Despite its widespread use in products such as ropes, mattresses, brushes, geotextiles, and automobile seats, coir remains underutilized in civil engineering. The increasing popularity of sustainable materials in construction, with their manifold benefits, has spurred studies highlighting the potential applications of natural fibers. These range from their use as a partial replacement for cement and aggregates to their effectiveness as a fiber-reinforcing agent [17]. Further research and investigation are necessary to demonstrate that coir can be a suitable reinforcement in the construction industry. Studies, notably those of [18], indicate variations in density and porosity of the fiber depending on its length, underscoring unique structural properties. Although coconut fiber is not exceptionally strong or rigid, its characteristics, such as its high strain at break, have been identified as assets for increasing the toughness of composites [19]. For a content greater than 1%, they reported an increase in the porosity of the CEB producing destabilization and a reduction in compressive strength, particularly in humid regions. Other researchers support this behavior not only for coconut but also for different types of natural fibers studied as construction materials [20, 21, 22, 23, 24]. However, natural fibers, including coir, face challenges such as poor adhesion to the matrix and high moisture absorption. Various techniques have been developed to overcome these obstacles, as evidenced by the work of [25], presenting physical and chemical methods for treating fibers before their use in composites. Despite the use of coir fibers to reinforce compressed earth blocks, issues remain regarding their physical attributes and durability properties. Thus, in-depth research, particularly using biopolymer materials, is recommended to explore and resolve these issues, thereby fully unlocking the potential of natural fibers in the construction industry.

Furthermore, investigations have been carried out on specific gums for soil stabilization, notably xanthan gum, gellan gum, agar gum, polyacrylamide, and guar gum [5, 26], as discussed in the review titled "Natural additives and biopolymers for raw earth construction stabilization" from 2021.It is acknowledged that limited research has been documented in the area of stabilizing earth blocks with gum Arabic (GA). However, research conducted by [27] has shown a particular interest in the use of GA in the stabilization of earth blocks. By adjusting the content of GA in the soil from 0 to 10%, researchers [27] observed that the compressive strength of blocks stabilized with GA increased as the GA content rose. Following the interesting results obtained by [27], it was recommended to continue research on the stabilization of earth blocks with GA but in combination with other binders such as cement, lime, as well as synthetic or natural fibers, etc. It has also been recommended to evaluate the effects of water on blocks stabilized with GA.

While existing studies have demonstrated the effectiveness of Gum Arabic in stabilizing soil blocks, there is limited information on studies providing experimental evidence of the combination of coconut fibers and Gum Arabic to stabilize soil blocks, specifically CEBs. This ongoing research effort represents a novel approach to stabilize CEBs by combining coconut fibers with Arabic gum to address the limitations of CEBs stabilized solely with coconut fibers and enhance the overall mechanical properties of such blocks. This article aims to explore the potential of Arabic gum as a natural stabilizer in construction materials. The study assesses the performance of Arabic gum as a natural stabilizing agent in laterite

The Seybold REPORT

ISSN 1533-9211

blocks reinforced with coconut fibers. The structural efficiency of the compressed earth block (CEB), reinforced with coconut fibers and stabilized with Arabic gum, is evaluated in terms of compressive strength, dry density, and water absorption. Test results revealed that the combination of coconut fibers and Arabic gum for CEB stabilization was not as effective as the exclusive use of coconut fibers in enhancing compressive strength. However, the introduction of Arabic gum addressed the issue of high porosity in coconut fiber-reinforced CEB by improving water absorption and dry density. Lateritic soil is combined with different proportions of coconut fibers (CF), varying from 0 to 1% at intervals of 0.2% based on the dry weight of the lateritic soil. The compressive strength test is conducted to identify the ideal coconut fiber content, determined to be 0.6%, yielding 4.151 MPa after 28 days of curing and complying with the Kenyan standard KS 02-1070:1993. Consequently, an optimal CF content of 0.6% is established, while simultaneously adjusting the Arabic gum stabilizer (GA) from 0 to 10% in increments of 2%. The compression and water absorption results indicate that, considering the Kenyan standard and the targeted strength, the optimal mixture proportions are 0.6% CF + 2% GA (4.143 MPa at 28 days) and 0.6% CF + 6% GA (10.017% at 28 days), respectively. Therefore, the proposed innovative stabilization approach effectively enhances the overall mechanical properties of CEB and corrects the observed flaws in CEB reinforced with coconut fiber.

2. LITERATURE REVIEW

Throughout history, various types of earthen structures have been in existence. Traditional methods of earthen construction encompass cob construction, adobe construction, poured earth construction, wattle and daub, and rammed earth construction [1]. Nowadays, the predominant approach to earthen construction is through compressed earth blocks (CEBs).

This technique represents a modern advancement of Adobe construction, employing advanced machinery to manufacture perfectly calibrated components. The production of CEBs adheres to specific standards for quality control. The main binding agent for CEBs is clay found in the soil [28]. However, in their natural state, CEBs are susceptible to the whims of nature, particularly during rainfall. To enhance their performance, an additional binder is commonly introduced through a process known as stabilization. This section delves into literature reviews on the stabilization of soils and compressed earth blocks in general, as well as the suitability of gum Arabic and coconut fiber biopolymers for stabilizing both the soil and compressed earth blocks. Walker proposed fundamental guidelines for cement stabilization and recommended a cement stabilization of 5 to 10% for manual pressing to achieve a saturated compressive strength between 1 and 3 N/mm^2 [29]. Over the past decades, the use of fibers as additives, either to complement or replace wood, has experienced exponential growth for economic, environmental, and political reasons. The utilization of coconut fibers as additives in soil-cement blocks has demonstrated a reduction in thermal conductivity and block weight, albeit with a decreased compressive strength [30]. Earlier research examining the incorporation of coconut and sisal fibers into soil blocks, featuring a fiber content of 4% by weight, indicated a reduction in the occurrence of visible cracks and yielded blocks with enhanced ductility [31]. The performance of composite soil reinforced with barley straw has been positive, showing a reduction in shrinkage with straw inclusion, improved compressive strength, and reduced curing time [32]. Reinforcing mud blocks with plastic, polystyrene, and barley straw in a specific geometric configuration has shown an improvement in compressive strength ranging from 17 to 21% [33]. Existing literature reviews suggest that there have been limited studies focused on optimizing the utilization of coconut fiber waste as reinforcement in soil-cement blocks concerning strength and durability characteristics. The coconut industry, the largest cottage industry in the state of Kerala, India, employs over a million people. However, waste from this industry adds serious health risks to the public and the environment due to the slow process of biological degradation. This research therefore focused on the sustainable disposal of coconut fiber waste as reinforcing elements in earthen building blocks. Recent studies have highlighted that gum Arabic (GA) is a natural plant product primarily found in West Africa, especially in Sudan. GA possesses numerous attractive physical and rheological properties, making it highly sought after, particularly due to its cost-effectiveness. GA applications can be categorized into three main groups: food, pharmaceutical, and technical.

In the food industry, GA serves as an additive, playing various roles such as a stabilizer, emulsifier, and thickener [34]. Additionally, GA is widely used as a binder, emulsifier, and viscosity-enhancing agent [35]. In the realm of technical applications, GA has both traditional and modern uses. Traditionally, it is employed as a binder in mud-based paints and coatings, offering protection against heavy rains for residential structures [36]. On the other hand, modern use of GA primarily focuses on its application as an admixture in concrete [37]. Therefore, studying the impact of GA properties on the performance of construction materials when used as an additive is of significant interest [38]. The compressive strengths of concrete incorporating GA rise proportionally with the GA dosage, and a dosage range of 0.50% to 0.75% is deemed appropriate for application. [39].

In the field of soil, research has explored the use of natural ingredients for earth construction, drawing on oral traditions passed down through generations [40]. Among these natural ingredients is GA. Laboratory tests have been conducted to underscore the importance of using these natural materials in earth constructions. Although limited to erosion and abrasion tests, these studies recommend further research into the performance of these natural ingredients in earth constructions [40]. It has also been reported that GA is widely used in mud coatings in Africa as a stabilizer and acts as a waterproofing agent [41]. In Africa, GA is abundantly available as organic matter (a biopolymer), making the African continent the world's largest exporter of GA [42]. It has been reported that GA contributes to improving the durability properties of concrete and paint [40, 38]. The properties of GA, including durability, binding, stabilization, and waterproofing, may result from the presence of three mineral elements: sepiolite, palygorskite, and mordenite [43, 44]. Sepiolite (Si12Mg8O30(OH)4(H2O))4) is a hydrated magnesium silicate characterized by a micro fibrous morphology and a unique texture, offering a high specific surface area [45]. Their physico-chemical properties result from high specific surface area, porosity, and thermal resistance, making them attractive as adsorbents. Palygorskite is a crystalline hydrated aluminum and magnesium silicate that naturally occurs as a fibrous mineral with a large specific surface area, excellent chemical stability, and strong adsorption properties [46].

Therefore, it is recommended to delve deeper into research concerning the utilization of gum Arabic (GA) in the stabilization of earth blocks. Identifying methods to improve the performance of Compressed Earth Blocks (CEB) strengthened with coconut fibers would offer significant advantages from environmental and economic perspectives. With this objective, the study reinforced CEB with diverse proportions of coconut fibers, spanning from 0.2% to 1% at 0.2% intervals. Stabilization was achieved by adjusting the GA content from 2% to 10% at 2% intervals. The aim was to evaluate the performance of the various types of CEB obtained through these adjustments.

3. MATERIALS AND METHODS

3.1 Materials

The research was conducted at the Civil Engineering Laboratory of Jomo Kenyatta University of Agriculture and Technology (JKUAT), situated in Kenya at coordinates 1°5'25"S latitude and 37°0'31"E longitude. The materials employed in this study included gum Arabic, lateritic soil, coconut fibers, and water. Gum Arabic was locally sourced from Isiolo, a county in central Kenya. The lateritic soil, obtained from Jomo Kenyatta University of Agriculture and Technology Primary School, underwent air-drying before utilization. The coconut fibers used originated from Mombasa, Kenya. For the mixing of various materials (lateritic soil, coconut fibers, gum Arabic), curing, and conducting tests, drinking water without impurities provided by the university system (JKUAT) was utilized. This water source adhered to Kenyan water regulations (KS EAS 12, 2014).

3.1.1 Methods

3.1.2 Preparation of materials

The chemical composition of both laterite soil and gum Arabic was determined using the X-ray fluorescence technique.

- **Coconut Fibers:**

In this study, coconut fibers were cut to a length of 4 cm and soaked in water for 24 hours to aid in separating the fibers. The treatment applied to these coconut fibers involved a physical process, specifically boiling them for a duration of 2 hours.

Figure 1: Treatment of Coconut fiber

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- **Gum Arabic:**

Upon procurement of Arabic gum, it was processed into powder since it was already dry and sieved with a mesh size of 0.6 mm. After measuring various proportions of Arabic gum, ranging from 0 to 10% with a 2% interval, using a scale relative to the dry weight of the lateritic soil for block manufacturing, the powdered Arabic gum was immersed for 24 hours in a predetermined quantity of water during the compaction test. This was done to achieve an optimal moisture content (MOC) for maximum dry density (MDD) (Figure 1), ensuring complete dissolution of the Arabic gum. To prevent confusion regarding the different percentages of Arabic gum, each container of Arabic gum was labeled with its percentage using a marker, as shown in Figure 1.

Figure 2: Preparation of the solution of GA

3.1.3 Blocks Production

The manufacturing procedure for blocks measuring 290x120x140mm, composed of laterite soil, coconut fiber, and gum Arabic, was executed following two distinct scenarios.

Scenario 1: The initial step involved soil preparation, where the designated earth for block manufacturing underwent screening using a 5 mm sieve, followed by bagging and transportation to the laboratory. In the second step, the lateritic soil was mixed with varying proportions of coconut fibers, ranging from 0 to 1% with a 0.2% interval. Table 1 details the various stages of mixing in block fabrication.

Scenario 2: In this setup, the lateritic soil was mixed using the optimal proportions of fibers obtained in Scenario 1, while adjusting Arabic gum proportions from 0 to 10%, with a 2% interval, in the third step. The fourth step involved the addition of water under different scenarios. The required water quantity was determined based on the optimal moisture content obtained during the compaction test for various proportions of coconut fibers and Arabic gum. The entire mixture was then thoroughly homogenized. Table 1 details the various stages of mixing in block fabrication.

The fifth step involved block production using a manually operated press, pre-lubricated with drain oil. The homogeneous mixture was compressed in the mold to produce the blocks. Finally, the sixth step involved the curing of CEBs. After production, the blocks were covered with polystyrene for 24 hours and left to air-dry before undergo undergoing tests. Figure 3 visually illustrates the compressed earth block production process.

The Seybold REPORT

ISSN 1533-9211

Table 1: Mix proportion of compressed stabilized laterite blocks

Production of blocks to determine the optimum of coconut fiber varying from 0 to 1%				
Stabiliser				
Coconut fiber	Gum Arabic	Laterite soil	Water	Designation
0%CF	0%	Constant	OMC	0%CF
0.2%CF	0%	Constant	OMC	0.2%CF
0.4%CF	0%	Constant	OMC	0.4%CF
0.6%CF	0%	Constant	OMC	0.6%CF
0.8%CF	0%	Constant	OMC	0.8%CF
1%CF	0%	Constant	OMC	1%CF

Production of blocks by fixing the optimum of coconut fiber (0.6%CF) and varying GA from 0 to 10%				
Stabiliser				
Coconut fiber	Gum Arabic	Laterite soil	Water	Designation
0.6%CF	0%	Constant	OMC	0.6%CF+0%GA
0.6%CF	2%	Constant	OMC	0.6%CF+2%GA
0.6%CF	4%	Constant	OMC	0.6%CF+4%GA
0.6%CF	6%	Constant	OMC	0.6%CF+6%GA
0.6%CF	8%	Constant	OMC	0.6%CF+8%GA
0.6%CF	10%	Constant	OMC	0.6%CF+10%GA

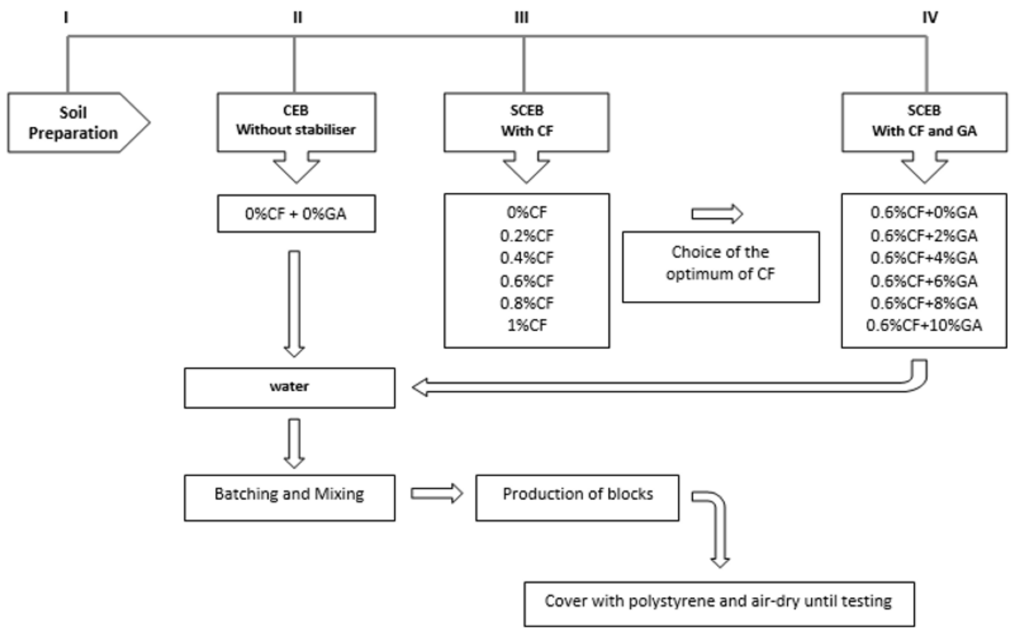


Figure 3: Blocks production process

ISSN 1533-9211

3.1.4 Compressive Strength

The study focused on the mechanical characteristics of compressed earth blocks (CEBs) reinforced with coconut fibers and stabilized with gum Arabic, taking into account factors such as compressive strength, density dry and water absorption. Block testing occurred at intervals of 7, 14, and 28 days. Compressive strength assessments were in accordance with specifications outlined in the British Standard (BS EN 772-1, 2011) and were carried out using the Universal Testing Machine (UTM). The formula employed to calculate compressive strength is as follows:

$$\sigma = \frac{F}{S} \qquad (1)$$

In this context, σ represented the maximum stress, F denoted the maximum load, and S referred to the loaded area. Figure 4 illustrates the compressive strength test of the blocks.

(a) Block sandwiched between the trays of the UTM for compression test

(b) Block after compression test

Figure 4: Compressive strength test procedure

3.1.5 Dry density

The assessment of dry density for Compressed Earth Blocks (CEBs) followed the guidelines set forth in the Nigerian Industrial Standard (NIS 87, 2004). The determination of the dry density of the blocks was carried out using the following procedure:

$$\gamma_d = \frac{w_d}{V} \qquad (2)$$

In this context, w_d represented the weight of the dry sample (kg), V stood for the volume of the blocks(m^3), and γ_d denoted the dry density of the blocks(kg/m^3). The process for determining the dry density is visually presented in Figure 5.

(a) Drying in oven

(b) Dry weight

Figure 5: Determination of the dry density of SCEB

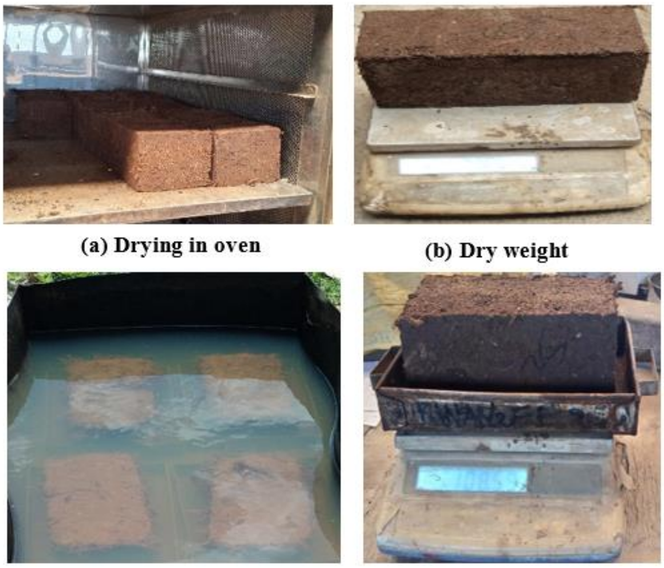
The Seybold Report
ISSN 1533-9211

3.1.6 Water Absorption

The water absorption of Compressed Earth Blocks (CEBs) was assessed following the British Standard 1377 (1967). Figure 6 depicts the steps involved in the water absorption test. The calculation of water absorption utilized the following formula:

$$M_c = \frac{(w_a - w_b)}{w_b} x100 \quad (3)$$

In this context, w_a the mass of the block after absorption, w_b denotes the mass of the block before absorption, and M_c represents the percentage moisture absorption on a dry basis (%).



(a) Drying in oven

(b) Dry weight

(c) Immersion in water for 24hours

(d) Weight after immersion in water

Figure 6: Water absorption test procedure

4. RESULTS AND DISCUSSION

4.1 Chemical Characteristics of Basic Materials

- **Laterite soil**

The XRF analysis conducted on the laterite soil revealed its predominant components as SiO_2 (61.54%), Fe_2O_3 (16.29%), and Al_2O_3 (15.89%). To meet the classification criteria for lateritic soil, the silica-sesquioxide ratio ($SiO_2/(Fe_2O_3+Al_2O_3)$) should fall within the range of 1.33 to 2 [1]. In this study, the silica-sesquioxide ratio of the soil was determined to be 1.54, confirming that the soil utilized in the production of Compressed Earth Blocks (CEBs) was indeed lateritic soil. The chemical composition of the laterite soil is presented in Table 2.

ISSN 1533-9211

Table 2: The chemical composition of laterite soil

Element Name	Percentage (%)
SiO2	15.89
Al2O3	61.54
Fe2O3	16.29
Ci	0.14
K2O	1.01
CaO	0.43
Mn	2.50

- **Gum Arabic**

The chemical properties of the Arabic gum utilized in this investigation are outlined in Table 3.

Table 3: The chemical composition of the Arabic gum

Element Name	Percentage (%)
SiO2	14.78
P2O5	0.68
K2O	26.30
CaO	55.31
Ti	0.59
Mn	0.06
Fe2O3	1.82
Cu	0.06
Zn	0.01
Zr	0.01
Sr	0.18

4.2 Mechanical Properties of CEB Stabilized by Combining CF with GA

4.3 Compressive Strength

The evaluation of the mechanical properties of Compressed Earth Blocks (CEBs) places significant emphasis on compressive strength, a key parameter.

The Kenya Standard (KS 02-1070:1993) prescribes a minimum compressive strength of 2.5 MPa for earth blocks.

Figure 7 illustrates the results of the compressive strength tests. It's important to note that the compressive strength of all CEBs exhibits an upward trend as the curing period prolongs.

The highest compressive strength value for unstabilized CEBs was achieved at 2.817 MPa after a curing period of 28 days.

The Seybold REPORT
ISSN 1533-9211

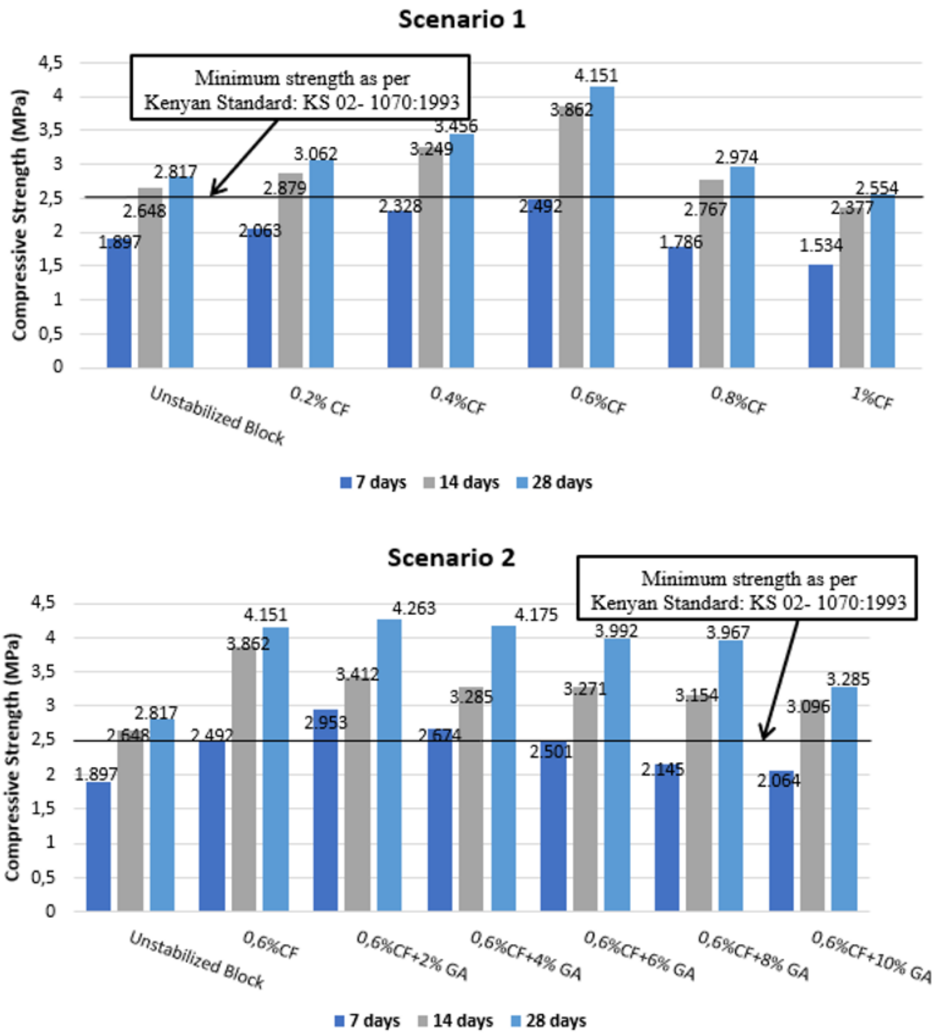


Figure 7

In Stabilization Scenario 1, the outcomes of the 28-day compression tests for Compressed Earth Blocks (CEBs) reinforced with varying proportions of coconut fibers (ranging from 0 to 1% with a 0.2% increment) are depicted in Figure 7. As illustrated, CEBs fortified with coconut fibers exhibit a progressive increase in compressive strength over time; all average values surpass the specifications outlined in the Kenyan standard: KS 02-1070:1993, set at 2.5 MPa. At 0% coir, the average compressive strength of the formulated material is 2.817 MPa, surpassing the Kenyan standard value of 12.68%. From 0.2% to 0.8% coconut fiber, the 28-day compressive strength of the composite material rises by 8.71%, 22.68%, 47.36%, 5.57%, compared to the control CEB, with respective coconut fiber contents of 0.2%, 0.4%, 0.6%, and 0.8% (3.062, 3.456, 4.151, and 2.974 MPa). This increase can be attributed to the robust cohesion of connections between coconut fibers and the CEB matrix, generating internal stresses that enhance material resistance. Additionally, Figure 7 reveals an optimal

ISSN 1533-9211

strength for CEBs reinforced with coconut fiber at a content of 0.6%. It's noteworthy that the inclusion of 1% coconut fibers results in a 9.34% reduction in compressive strength at 28 days, equating to 2.554 MPa compared to the control CEB. However, this value exceeds the minimum recommended threshold of 2.5 MPa set by the Kenyan standard. The decline in compressive strength can be attributed to increased porosity, leading to a lower rate of internal bonding between fibers and the CEB matrix, and an intensification of bonding between fibers. These findings align with the conclusions of [47]. In stabilization scenario 2, the results of the 28-day compression tests for CEB blocks reinforced with 0.6% coconut fibers and various proportions of Arabic gum ranging from 0 to 10% at intervals of 2%, are presented in Figure 7. As depicted in the figure, CEBs reinforced with 0.6% coconut fibers and different proportions of Arabic gum show a cumulative increase in compressive strength with age; all average values surpass those prescribed by the Kenyan standard: KS 02-1070:1993[39], set at 2.5 MPa. The addition of 2 to 4% Arabic gum in CEBs reinforced with 0.6% coconut fibers results in an increase in compressive strength at 28 days for the composite materials by 2.71% and 0.58%, respectively, compared to the control CEB reinforced with 0.6% coconut fibers, with Arabic gum contents of 2% and 4% (4.263 and 4.175 MPa).

This enhancement can be attributed to the adhesive properties of the very fine particles in Arabic gum, capable of filling voids and improving cohesion between coconut fibers and the lateritic matrix due to its high viscosity [48]. In other words, Arabic gum, as a cementitious material rich in calcium oxide (CaO), when in contact with water (H2O), generates a gel called calcium hydroxide ($Ca(OH)_2$). This gel, combined with lateritic soil rich in silica (SiO2), triggers a pozzolanic reaction forming calcium silicate hydrate ($Ca(OH)_2$), a hydrogel with finer particles than those in the soil, penetrating pores to firmly bind particles together [5].

Furthermore, the study of Arabic gum as an admixture in concrete has reported that the reaction between cement and Arabic gum forms denser and higher quantities of calcium silicate hydrate ($Ca(OH)_2$) than in cement alone, enhancing concrete properties and leading to better performance. However, in the case of lime soil stabilization, it has been reported that it is the formation of C-S-H that is responsible for soil stabilization [9, 49]. These findings align with the research of (Mohammed et al, 2021), demonstrating that biopolymers, particularly xanthan gum, improve compressive strength of blocks and contribute to better performance.

For Arabic gum proportions ranging from 6 to 10% at intervals of 2%, the compressive strength at 28 days of the composite material decreases by 3.830%, 4.433%, and 20.862% compared to the control CEB reinforced with coconut fibers, with Arabic gum contents of 6%, 8%, and 10% (3,992, 3,967, and 3,285 MPa). This decrease is explained by the higher Arabic gum percentages in coconut fiber-reinforced CEBs, which become too high to ensure good strength due to the water generated by the sugar in Arabic gum during block curing, increasing humidity in coconut fiber-reinforced CEBs and causing insufficient solidification, leading to poor cohesion between coconut fibers and the CEB matrix. This phenomenon results in the creation of internal stresses aiming to improve the material's resistance to higher

ISSN 1533-9211

compression compared to the control CEB. A combination of 6%, 8%, and 10% Arabic gum with 0.6% coconut fibers is not suitable for achieving good results in the compression test [50]. It's noteworthy to emphasize that, at 28 days, the compressive strength of all the Compressed Earth Blocks (CEBs) exceeded the minimum value recommended for CEBs (2.5 MPa) according to the Kenyan standard. Consequently, these Stabilized Compressed Earth Blocks (SCEBs) are suitable and can be recommended for construction purposes.

4.4 Water Absorption

The results of the water absorption test are depicted in Figure 8. For earth blocks to be considered suitable for construction, their water absorption must not exceed 15% (African Standard WD-ARS 1333-2018). These findings indicate that unstabilized compressed earth blocks (CEBs) lacked stability in water, making their water absorption incalculable.

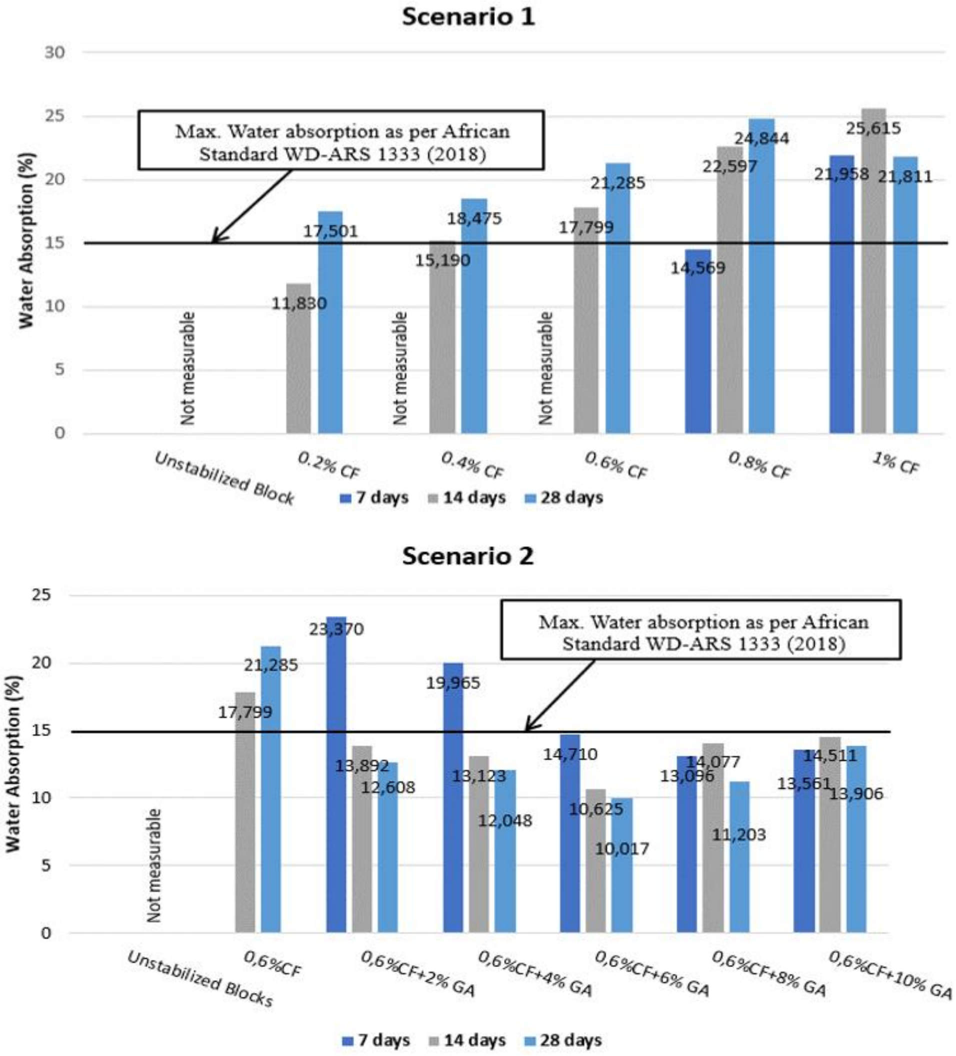


Figure 8: Water absorption of SCEBs

The Seybold Report
ISSN 1533-9211

Concerning stabilization scenario 1, the results of the water absorption test, illustrated in Figure 8, indicate that Compressed Earth Blocks (CEB) reinforced with different percentages of coconut fibers (ranging from 0.2% to 1% at 0.2% intervals) underwent a 24-hour immersion in water at different ages of 7, 14, and 28 days.

These results are compared against the maximum limit set by the African Standard WD-ARS1333-2018, which is established at 15%. As illustrated in Figure 8, CEBs reinforced with coconut fibers in the range of 0.2% to 0.6% failed to withstand a 24-hour water immersion after 7 days of curing. Only CEBs reinforced with 0.8% to 1% of coconut fibers demonstrated resilience in water after 24 hours.

Additionally, only the CEB reinforced with 0.8% of coconut fibers exhibited a value of 14.56%, which is below the limit set by the African Standard WD-ARS1333-2018.Nevertheless, for CEBs reinforced with various proportions of coconut fibers from 0.2% to 1%, it is observed that they resisted a 24-hour water immersion, and only those reinforced with 0.2% and 0.4% of coconut fibers had values below or equal to the limit set by the African Standard WD-ARS1333 -2018 at 14 and 28 days.

The increase in coconut fibers in CEBs leads to higher water absorption rates, a phenomenon explained by the hydrophilic nature of the fibers. This augmentation may also result in the disruption of a homogeneous matrix, causing the formation of void spaces and a reduction in block density. This outcome, in connection with the porosity of CEBs stabilized with coconut fibers, aligns with the study conducted by [51].

Table 4: Water absorption of CEB reinforced with CF (scenario 1)

Days	Percentage of binder (%)	Water Absorption (%)	Observation	
7	0%CF	Not Measurable	Blocks crumbled before 24h	
	0.2%CF	Not Measurable	Blocks crumbled before 24h	
	0.4%CF	Not Measurable	Blocks crumbled before 24h	
	0.6%CF	Not Measurable	Blocks crumbled before 24h	
	0.8%CF	14.57	Good Condition	
	1%CF	21.96	Good Condition	
14	0%CF	Not Measurable	Blocks crumbled before 24h	
	0.2%CF	11.83	Good Condition	
	0.4%CF	15.19	Good Condition	
	0.6%CF	17.80	Good Condition	
	0.8%CF	22.60	Good Condition	
	1%CF	25.62	Good Condition	

The Seybold REPORT

ISSN 1533-9211

28	0%CF	Not Measurable	Blocks crumbled before 24h	
	0.2%CF	17.50	Good Condition	
	0.4%CF	18.48	Good Condition	
	0.6%CF	21.29	Good Condition	
	0.8%CF	24.84	Good Condition	
	1%CF	21.81	Good Condition	

In the context of stabilization scenario 2, the water absorption test results, depicted in Figure 8, reveal that Compressed Earth Blocks (CEB) reinforced with 0.6% coconut fibers (CF) and varying proportions of Gum Arabic (GA), ranging from 2% to 10% with a 2% interval, were immersed in water for 24 hours at maturity stages of 7, 14, and 28 days.

These results are compared against the maximum limit established by the African Standard WD-ARS1333-2018, set at 15%. According to Figure 8, CEBs reinforced with 0.6% coconut fibers and different proportions of Gum Arabic, from 2% to 10%, all withstood water immersion after 24 hours, whether they had been cured for 7, 14, or 28 days.

CEBs reinforced with 0.6% coconut fibers and stabilized with Gum Arabic proportions from 2% to 10% exhibit water absorption values below the limit set by the African Standard WD-ARS1333-2018, except for 2% and 4% at 7 days, which exceed this standard.

The decrease in water absorption percentage noted in the stabilization of Compressed Earth Blocks (CEBs) reinforced with different amounts of Gum Arabic, ranging from 2% to 10%, can be attributed to the adhesive characteristics of this finely particulate material.

These properties allow it to fill voids and increase the material density while creating bonds between coconut fibers and the lateritic matrix, resulting in reduced voids [5, 52, 53, 54]. Moreover, Gum Arabic is traditionally used as a stabilizing agent to waterproof mud coatings and protect homes from the adverse effects of heavy rainfall [36, 41].

Given that the durability of blocks is closely linked to their water absorption rate [55, 4], it can be inferred from these results that blocks exhibiting good water absorption performance, such as those reinforced with 0.6% coconut fibers and 6% Gum Arabic, could be suitable for construction.

Previous research using guar and xanthan gums as stabilizers in earth blocks has also demonstrated their positive impact on block performance against water [50].

ISSN 1533-9211

Table 5: Water absorption of CEB reinforced with CF and stabilized with GA (scenario 2)

Days	Percentage of binder (%)	Water Absorption (%)	Observation	
7	**0%CF**	**Not Measurable**	**Blocks crumbled before 24h**	
	0.6%CF+2%GA	23.37	Good Condition	
	0.6%CF+4%GA	19.97	Good Condition	
	0.6%CF+6%GA	14.71	Good Condition	
	0.6%CF+8%GA	13.11	Good Condition	
	0.6%CF+10%GA	13.56	Good Condition	
14	**0%CF**	**17.80**	**Good Condition**	
	0.6%CF+2%GA	13.89	Good Condition	
	0.6%CF+4%GA	13.12	Good Condition	
	0.6%CF+6%GA	10.63	Good Condition	
	0.6%CF+8%GA	14.08	Good Condition	
	0.6%CF+10%GA	14.51	Good Condition	
28	**0%CF**	**21.29**	**Good Condition**	
	0.6%CF+2%GA	12.61	Good Condition	
	0.6%CF+4%GA	12.05	Good Condition	
	0.6%CF+6%GA	10.08	Good Condition	
	0.6%CF+8%GA	11.20	Good Condition	
	0.6%CF+10%GA	13.91	Good Condition	

In summary, it is essential to highlight that the utilization of Coconut Fibers (CFs) in conjunction with Gum Arabic (GA) for the stabilization of Compressed Earth Blocks (CEBs) successfully addresses the porosity issues observed in CEBs stabilized solely with CFs. Consequently, CEBs stabilized through the combined use of CF and GA exhibit enhanced water stability, making them a viable recommendation for constructing exterior walls in regions characterized by high humidity and frequent rainfall.

4.5 Dry density

The dry density results for blocks stabilized with various proportions of fibers and gum Arabic are displayed in Figure 9. These results reveal that the blocks exhibit a dry density ranging from 1550 kg/m3 to 1762 kg/m^3. Importantly, all recorded dry density values fall within the recommended dry density range specified by the African standard, which is 1500 kg/m^3 to 2000 kg/m^3. The dry density is intricately linked to compressive strength and inversely related to the water absorption of CEBs [56, 57].

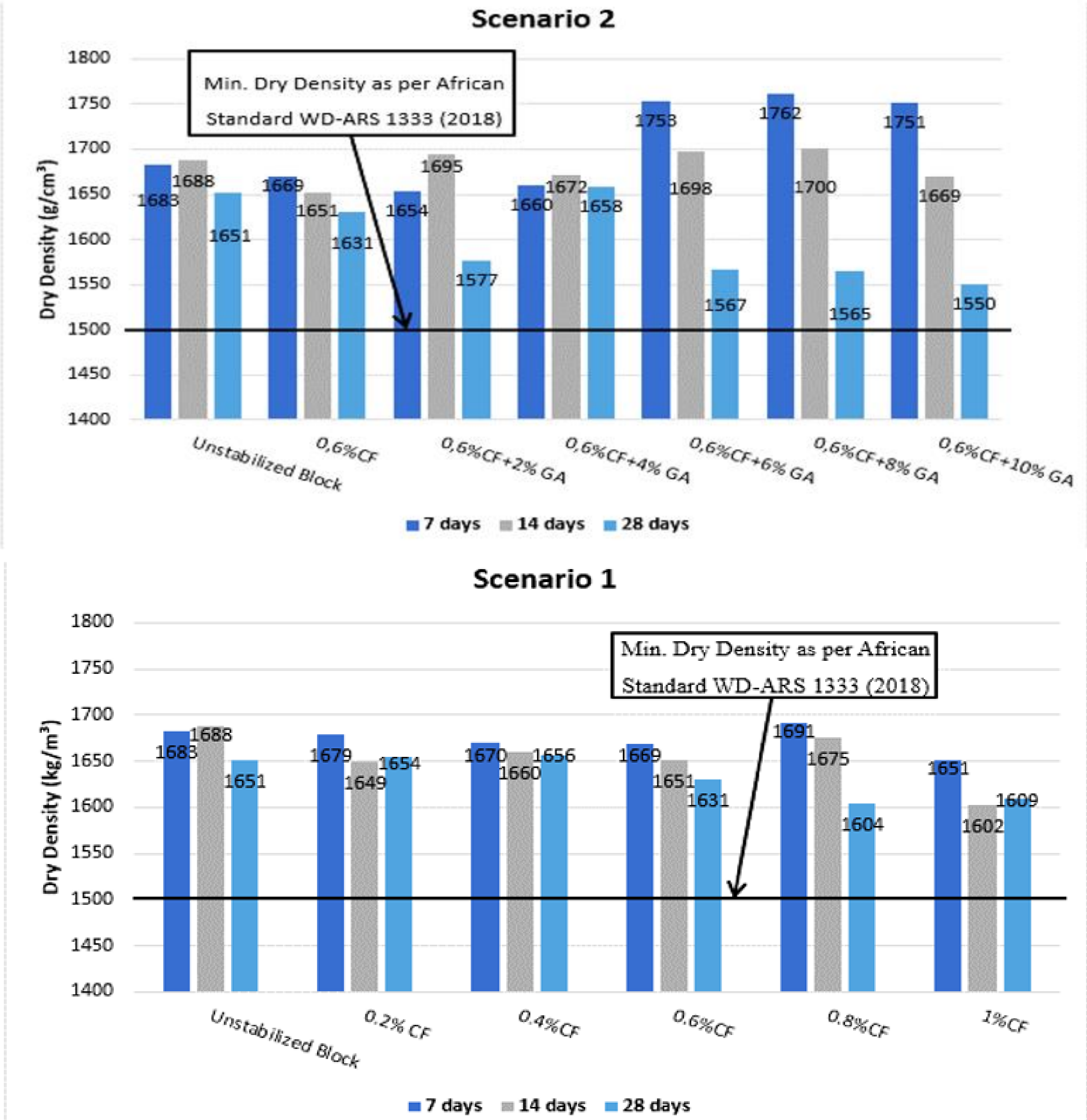


Figure 9: Dry density of SCEBs

The dry density results of Compressed Earth Blocks (CEB) are presented in Figure 9. Notably, in scenario 1, CEBs reinforced with varying proportions of coconut fibers (CF), ranging from 0.2% to 1% at 0.2% intervals, exhibit dry densities between 1602 kg/m^3 and 1691 kg/m^3. As depicted in Figure 9, after 7 days of curing, only CEBs reinforced with 0.8%

CF showcase a higher dry density, unlike those with 0.2%, 0.4%, 0.6%, and 1% CF, which display a lower dry density than the lateritic matrix.

At 14 days of curing, the dry densities of blocks reinforced with different CF proportions, ranging from 0.2% to 1%, indicate values lower than those of the lateritic matrix. Conversely, at 28 days of curing, only CEBs reinforced with 0.2% and 0.4% CF exhibit a higher dry density, while those with 0.6%, 0.8%, and 1% CF demonstrate a lower dry density than the lateritic matrix. The evolution of the dry density for each CEB type throughout the curing period does not reveal a specific trend. Achieving 100% homogeneity in the mix is practically unattainable during CEB production. Dry density decreases as the percentage of CF increases. The substitution of the soil-cement matrix (dense material) with coconut fiber waste (light material) has resulted in an increase in the total volume of the mix. This increase in the compacted mix's volume has led to a decrease in the weight and density of the samples, as observed by [51]. The dry density results of Compressed Earth Blocks (CEB) are presented in Figure 9.

In scenario 2, CEBs reinforced with 0.6% coconut fibers (CF) and stabilized with varying proportions of gum Arabic (GA), ranging from 2% to 10% at 2% intervals, exhibit dry densities between 1550 kg/m3 and 1762 kg/m3. As shown in Figure 9, after 7 days of curing, only CEBs reinforced with 0.6% CF + 8% GA and 0.6% CF + 10% GA demonstrate a higher dry density, contrary to those with 0.6% CF + 2% GA, 0.6% CF + 4% GA, and 0.6% CF + 6% GA, which display a lower dry density than the lateritic matrix reinforced with 0.6% CF. Additionally, at 14 days of curing, all CEBs exhibit higher dry densities than the CEB reinforced with 0.6% CF, whereas at 28 days of curing, the results are opposite to those found at 14 days.

The evolution of the dry density for each type of CEB throughout the curing period shows a distinct trend. This finding has also been observed in the case of soil stabilization with other types of gums [52, 58]. Overall, the increase in the dry density of CEBs stabilized by combining CF and GA compared to those stabilized with CF alone can be attributed to the adhesive properties of GA, enhancing electrochemical attraction and binding aggregated soil particles together [5, 52]. Therefore, it can be inferred that the combination of CF with GA effectively addresses the high porosity of CEBs stabilized with CF alone, making them more compact and denser.

5. CONCLUSION

Based on the aforementioned experimental work, it was observed that blocks stabilized with 0.2%, 0.4%, and 0.6% coconut fibers (CF) did not withstand a 24-hour water immersion at 7 days.

Conversely, blocks containing 0.6% CF and 6% gum Arabic (GA) demonstrated the best results in terms of water absorption rates, reaching 10.02%. Regarding the dry density of the blocks, the dry density values of all Compressed Earth Blocks (CEB) reinforced with CF and stabilized with GA were within the recommended range.

The Seybold Report
ISSN 1533-9211

At 28 days, blocks containing 0.6% CF and 4% GA exhibited the highest dry density value, reaching 1658 kg/m^3. By reinforcing lateritic CEBs with 0.6% CF and 2% GA compared to CEBs reinforced with 0.6% CF, the compressive strength increased from 4.151 MPa to 4.263 MPa, representing a 2.70% increase and identified as optimal for achieving the best performance of blocks stabilized with GA. Consequently, it can be concluded that blocks containing 0.6% CF and 2% GA could be recommended for construction purposes, as they exhibit compressive strength exceeding 2.5 MPa, a dry density ranging from 1,500 to 2,000 kg/m3, and water absorption below 15% at 28 days.

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5.2 Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5.3 Credit author statement

Grace loic Tresor MAMONO: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Visualization. Isaac Fundi Sanewu: Writing – Review & editing, Supervision. Kepha Abongo: Writing – Review & editing, Supervision.

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Appendix

No	Abbreviation	Description
1	CO_2	Carbon Dioxide
2	CEB	Compressed Earth Block
3	CEBS	Compressed Earth Block Stabilized
4	CF	Coconut Fibers
5	C-S-H	Calcium Silicate Hydrate
6	GA	Gum Arabic
7	JKUAT	Jomo Kenyatta University of Agriculture and Technology
8	PAU	Pan African University
9	UTM	Universal Testing Machine
10	SA	Setting Accelerator
11	Wr	Water Reducer