

Physico-Mechanical Properties of an Eco-Friendly Compressed Recycled Brick Dust Mortars Based Grog Stabilized Eggshell and Coconut Shell Powder: Effects of Curing Time and Correlations

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Abstract

This work aims to investigate the effect of curing time on the Physico-mechanical Properties of an Eco-friendly Compressed Earth Mortars based Grog stabilized with Eggshell and Coconut shell powder at 28, 56 and 90 days for sustainable construction. Samples were cured at room temperature ($23^{\circ}\text{C} \pm 3^{\circ}\text{C}$) to obtain a mix of percentages of coconut shell and calcined eggshell as 0.13, 0.26 and 0.4 (wt.%), respectively. The mix design of coconut shell and calcined eggshell were incorporated into the grog powder. The physico-mechanical properties (Moisture content, Water absorption, Apparent porosity, Bulk density, Elastic modulus, Compressive strength) were evaluated. Chemical analysis was investigated to establish the effective stability of samples. Results at 28 and 90 days showed an increase in compressive strength with increasing percentages of coconut shell from 1.52 to 3.01, 2.01 to 4.26, 1.34 to 3.42 MPa, respectively, and calcined eggshell, from 1.38 to 1.87, 2.70 to 4.61, 3.88 to 4.14 MPa, respectively. Bulk density decreases with increasing percentages of coconut shell, calcined eggshell and the percentage of grog decrease. A perfect correlation of $R_1^2 = 0.96$ and $R_2^2 = 0.99$ were obtained, which revealed a significant effect at different curing time thus suitable for sustainable eco construction.

Keywords

Coconut Shell, Curing Time, Eggshell, Grog, Linear Correlation, Physico-Mechanical Properties

1. Introduction

The curing regimes are important critical factors that influence cement hydration [1]. The curing regimes have an important influence on the properties of concrete such as compressive strength, flexural strength, bulk density, durability and microstructure [2] and accelerate the strength development of mortars and concrete [3]. Suitable for sustainable construction, recent research has demonstrated the influence of water curing, ambient curing temperature and seal curing methods on the physico-mechanical properties of the geopolymer binder, and to avoid loss of water [1] [3]. Other researchers have demonstrated the strength development of geopolymers which depends on different factors or curing methods including the characteristics of raw materials and alkaline activation, the curing time and the curing temperature [4].

The fired clay brick debris (grog) can be classified as a raw material obtained by the firing of clay bricks, and considered as an artificial pozzolan [5], and commonly used in building construction [6]. The annual production of this industrial manufacturing by-products makes up 6% - 7% approximatively of the total production of clay bricks [7]. This causes a serious environmental problem [8] [9], which is as a result of higher energy demand and consumption of natural resources [10] [11]. Recent studies demonstrate that researchers have study several possibility of using the fired clay bricks waste in the formulation of eco-friendly or environmentally friendly products using other waste alternative [12], which include; increase in sustainability building construction as alternatives to the conventional materials [13], to reduce environmental problems in building sector [14], have good physico-mechanical properties and durability [6] [8], reduction density, fire and strength resistances [15], development of raw materials to improved their performance and reduced costs [16]. Indeed, the fired clay bricks waste presents a good pozzolanic activity [17], more homogenous and porous characteristics [18], a suitable candidate to replace cement in concrete due to the pozzolanic properties [5] and hydration or lime-pozzolan reaction [9] [19]. However, the potential pozzolanic reactivity of fired clay bricks wastes is effective when it is used in fine powder as indicated by [5]. The grog can also affect the porosity and mechanical strength of the final product [20] and can be applied to improve mechanical strength of mortar at later age [5]. Therefore, characterization of the material and definition of the contents that can be incorporated to the clay mass must be carried out so that the requirements of standards are met [21]. In fact, the addition of different industrial wastes to fired clay bricks has shown an increase in apparent porosity and water absorption properties [22]. 15% - 20% of coconut

shell waste is produced [15] and 85% of the total raw material is collected and treated worldwide [23]. This treatment is due to the presence of higher moisture and water absorption properties found in conventional aggregates [24]. The use of coconut shell powder as a sustainable material for building and construction can also be applied as material in preserving the environment [25]. Coconut shell is applicable as coarse aggregate for soil stabilizer [26], fine aggregate [27], pore forming agent in fired clay bricks [15], and lightweight concrete [28].

In order to encourage environmentally friendly and sustainable construction, eggshell is used as a biomaterial [29], with chemical composition similar to that of limestone [30], and as an economical material in building construction [31] and an importance of calcium oxide (CaCO_3) source in the pure, and more stable form of calcite [32], and an excellent substitution of lime in cement production [33]. Indeed, the production of eggs is estimated that 2,367,000 tons is produced annually in Africa [34], and is responsible for serious environmental pollution [30]. Eggshell is applied in different domains such as cement replacement [35], production of biodiesel [36], incorporation of cement with other and easily materials such as fly ash (FA) [37] bagasse ash (BA) [38], rice husk ash (RHA) [39], absorbent materials [40], adsorbent of radioactive metals and corrosion inhibitor [41], soil stabilizer [32], absorbent heavy metals in soil [41], fired bricks [42], unfired compressed bricks [43], to reduce the environmental impact [44], and contribution of the C-S-H gel formation to enhance compressive strength in concrete for cement hydration [45].

The reuse of this industrial waste as ecofriendly raw materials by recycling it into producing eco-materials for building and construction is considered an innovative approach to reduce the environmental land pollution [46], to reduce greenhouse gas (GHG) emissions [14], to improve indoor thermal comfort [47] and could provide a solution with economic and environmental benefits [10] [48]. This study aims to investigate the effect of curing time at 28, 56 and 90 days in the physico-mechanical properties of compressed recycled brick dust mortars using grog by reinforcing calcined eggshell and coconut shell powder. Apparent porosity (AP), Water absorption (WA), Bulk density (BD), Moisture content (MC), Elastic modulus (EM) and Compressive strength (CS) were the physico-mechanical properties evaluated. Analyses such as X-ray fluorescence (XRF), X-Ray Diffraction (XRD), Fourier Transformed Infrared spectrometry (FT-IR) were carried out in order to determine the chemical composition, chemical bonds and to determine the amorphous crystallographic phases.

2. Materials and Methods

2.1. Collection and Preparation of Raw Materials and Samples

2.1.1. Collection of Raw Materials

The fired clay brick waste (grog) (RB) was obtained from the Local Materials Promotion Authority (MIPROMALO), Cameroon. The collected grog was oven dried at $105^\circ\text{C} \pm 5^\circ\text{C}$ for 24 h to remove all unwanted substances. It was later ground

and sieve at 2 mm sieve using a standard sieve and package in a plastic bag for further use.

The egg shell was gotten from a bakery in the Etoug-Ebe neighborhood Yaounde, Cameroon. They were washed under a tap flowing water to get rid of contaminants and unwanted particles found on the surface membrane. The washed eggshell was later sun dry at room temperature ($23^{\circ}\text{C} \pm 3^{\circ}\text{C}$) for 5 days then later oven-dried at $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$ for 24 h to eliminate the remaining water moisture from the eggshell. The raw materials were crushed and sieved at $75\text{ }\mu\text{m}$ to obtain fine particles and eliminates the coarse particles. Samples were packaged in hermetically sealed bags for further use. The resulting white eggshell powder was calcined at 900°C (CO) for 2 h in an electric oven.

Coconut shells were obtained from farmers dealing with coconut farming in Yaounde. The fiber was extracted from the coconut using a hammer. The fiber was oven dry at $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$ for 24 h and later crushed and sieved through a $250\text{ }\mu\text{m}$ sieve, packaged and labeled (CN) for further analysis. In order to have water that is free from impurities and contaminants, the water was obtained from the Water Utilities Corporation (Camwater) NC 102-115 [49] which is the Cameroonian standard applied for compressed earth blocks. Water facilitates rapid hydration reaction and paste-bind the matrix's constituent parts together.

2.1.2. Preparation of Mortar Samples

Samples formulated and cured (**Figure 1**) involved combining a 10:2 ratio of earth to water to create a recycled brick dust mortar with dimensions of $2 \times 2 \times 2\text{ cm}$. A total mass of 360 g was used to prepare the samples per formulation as shown by $\text{RB}_{1-x-y}\text{CO}_x\text{CN}_y$, where x represents the weight percentage of calcined eggshells (CO) in total powders, which started between 0 and 0.4 (wt.%), y represents the weight percentage of coconut shells (CN) in total powders, which started between 0 and 0.4 (wt.%), and $1-x-y$ represents the weight of grog (RB). Three (03) samples per formulation were used and the averages taken to calculate mean values and standard deviation.



Figure 1. Samples formulated and cured.

2.2. Methods

2.2.1. X-Ray Fluorescence (XRF)

The X-ray fluorescence is an analysis that allows the chemical composition of the

sample to be determined. The chemical composition of the raw materials (grog, coconut shell and calcined eggshell) was determined using a Zetium PANATICAL apparatus with a power of 1 KW. Before carrying out the analysis, each sample powder was mixed with lithium borate salt and vitrified in a Pt crucible at 1600°C at the Materials Analysis Laboratory of the Artisan Mining Support and Promotion Framework (CAPAM), now SONAMINES, in order to determine the lead content. At each lead content, a peak is determined which indicates the presence energy position at the same intervals as indicated by the markers.

2.2.2. X-Ray Diffraction Analysis (XRD)

In order to qualitatively identify several crystalline compounds and the crystallographic forms of materials, the XRD quantitative method was applied. Ex-situ XRD data were collected on a STOE Stadi-p X-ray powder diffractometer (STOE & Cie GmbH, Darmstadt, Germany) using Cu K α 1 radiation ($\lambda = 1.54056 \text{ \AA}$; Gemonochromator; flat samples) in transmission geometry with a DECTRIS® MYTHEN 1K detector (DECTRIS, Baden-Daettwil, Switzerland).

2.2.3. Fourier Transformed Infrared Spectroscopy (FT-IR)

To measure the impurity and assess the nature of molecules in a material, the FTIR analysis is used which is based on the absorption reaction between infrared radiation that passes through matter. The excitation vibrations of samples are selectively observed and each molecule or group of molecules make up vibrational levels which corresponds to precise energies. The measurements of infrared spectroscopy are measured in transmittance using a spectrometer. A Bruker Vertex 80v with KBr was used by mixing 1 g of each sample with 200 mg of KBr and pressing at 100 kN using a hydraulic press (ENERPAC P392, USA) to obtain each pellet. The infrared spectrum of each pellet was recorded in the range of 400 - 4000 cm^{-1} with a resolution of 2 cm^{-1} and 32 scans. The samples were recorded using OPUS Spectroscopy software.

2.2.4. Characterization Methods of Physico-Mechanical Properties

The prepared samples were tested on 28, 56 and 90 days of ambient temperature ($23^\circ\text{C} \pm 3^\circ\text{C}$). curing. These properties include: water absorption, apparent porosity, bulk density, moisture content, compressive strength and elastic modulus.

1) Bulk density and Moisture content. The weight of each sample was registered.

Three samples each of $2 \times 2 \times 2 \text{ cm}$ clay mortar were used for each formulation to determine the average density according to BS EN 14617-1 [50]. This calculation was done using the formula in Equation (1) below.

With BD: bulk density in $\text{g}\cdot\text{cm}^{-3}$; M_i = initial mass of sample after 28 and 56 days of curing in g; V: volume of sample in cm^3 . Moisture content was measured at 28 and 56 days. Samples were introduced into the electric oven at $105^\circ\text{C} \pm 5^\circ\text{C}$ for 24 h to obtain the dry mass. Three (03) samples from each formulation were used to obtain their mean values and later calculated their standard deviations.

The formula for moisture content is shown in Equation (2):

Whereby M_1 = initial mass of sample after 28 and 56 days of curing in g;

M_2 = dry mass of sample after 24 h in an oven in g.

2) Water absorption and Apparent porosity

According to ASTM C373-88 standard [51] water absorption determines the quantity of water retained by the material for 24 h, and also it gives information on the stability of the material in water. It is shown in Equation (3) below and was determined using an average of 3 samples: Whereby M_2 = dry mass of sample after 24 h in an oven in g; M_3 = wet mass of sample after 24 h in water in g. Apparent porosity reveals the porous nature of the material and gives information on voids within the material. The averages of three (03) samples were used following Equation (4) such that MC, WA, AP (%); ρ_e = density of water ($1 \text{ g}\cdot\text{cm}^{-3}$); V = volume of sample in cm^3 ; M_1 = initial mass of sample after 28 and 56 days of curing in g; M_2 = dry mass of sample after 24 h in an oven in g; M_3 = wet mass of sample after 24 h in water in g.

3) Compressive strength and elastic modulus

This corresponds to the maximum load per unit area, subjected to stress under the specific conditions at ambient temperature which can resist before breaking. It was measured at 28 and 90 days. While the Elastic modulus gives information on the elasticity and degree of deformation of a material. As concerns compression strength, this was determined at 28 and 90 days using an average of 3 samples. It is linked to compressive strength by Hooke's law, and is shown on Equation (5)

$$BD = \frac{M_1}{V} \quad (1)$$

$$MC = \frac{M_1 - M_2}{M_2} \times 100 \quad (2)$$

$$WA = \frac{M_3 - M_2}{M_2} \times 100 \quad (3)$$

$$AP = \frac{M_3 - M_2}{\rho_e \times V} \times 100 \quad (4)$$

$$CS = \varepsilon EM \quad (5)$$

With CS = compressive strength in MPa; EM = elastic modulus in MPa; ε = stretching or displacement.

3. Results and Discussion

3.1. X-Ray Fluorescence (XRF) of Raw Materials

The chemical composition of grog, coconut shell and calcined eggshell is shown in **Table 1**. The results from grog revealed important contents such as silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) as follows: 51.47%, 21.16% and 10.71%, respectively, with a silica ratio of $\left(\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} \right) = 1.61$. The coconut shell powder contained 58.44% of SiO_2 , 24.54% of Al_2O_3 and 13.39% of Fe_2O_3 , with silica ratio

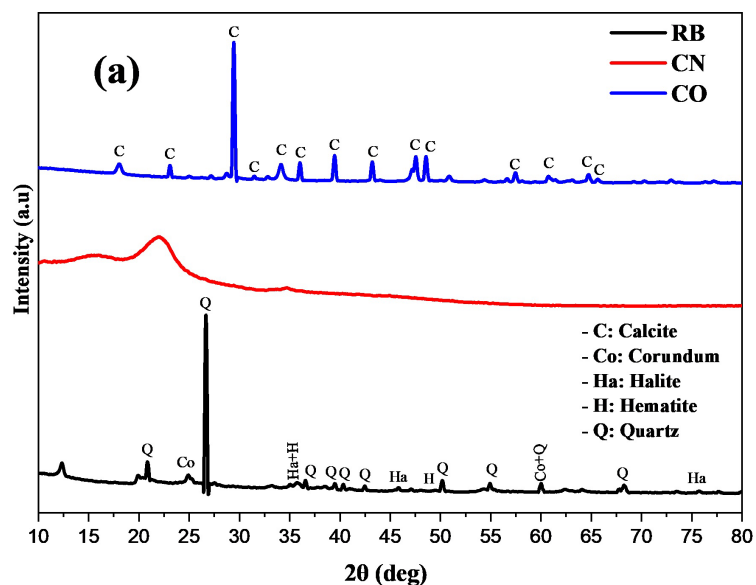
$\left(\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} \right) = 1.54$. The calcined eggshell contained 4.24% of (SiO₂), 0.76% of Al₂O₃, 0.08% of Fe₂O₃ with silica ratio $\left(\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3} \right) = 5.04$, and the high content of calcium oxide (CaO) of 53.75% was the result of decomposition of calcium carbonate (CaCO₃) at 900°C. The results of grog and coconut shell show the presence of three major oxides: silica, alumina and iron oxide. The sums of the major oxides (SiO₂ + Al₂O₃ + Fe₂O₃ = 83.34%) for grog and (SiO₂ + Al₂O₃ + Fe₂O₃ = 96.37%) for coconut shell, respectively, which more than 70% revealed the pozzolanic nature of raw materials by ASTM C618 standard [52].

Table 1. XRF of raw materials.

Raw materials	Chemical composition of Oxides (%)														Silica ratio
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	SO ₃	Na ₂ O	K ₂ O	MgO	TiO ₂	Mn ₂ O ₃	P ₂ O ₅	LOI	Others	Total	
Grog	51.47	21.16	10.71	2.79	0.24	0.13	0.55	0.47	0.01	0.01	0.12	6.36	5.98	100	1.61
Coconut shell	58.44	24.54	13.39	/	0.35	0.48	0.55	0.45	0.71	0.10	0.32	0.66	0.01	100	1.54
Calcined eggshell	4.24	0.76	0.08	53.75	0.55	0.14	0.05	0.60	0.02	0.01	0.27	39.33	0.2	100	5.04

3.2. X-Ray Diffraction of Raw Materials and Mortar Samples

Figure 2 indicates the X-Ray Diffraction of grog (waste brick), eggshell powder calcined at 900°C, coconut shell, and mortar samples. However, **Figure 2(a)** indicates the raw materials while **Figure 2(b)** indicates the mortar samples. From **Figure 2** below, the following abbreviations are represented on the diagram as: D = RB_{0.74}CO_{0.26}CN₀; E = RB_{0.74}CO_{0.13}CN_{0.13}; I = RB_{0.6}CO_{0.13}CN_{0.27}; G = RB_{0.6}CO_{0.4}CN₀; F = RB_{0.74}CO₀CN_{0.26}.



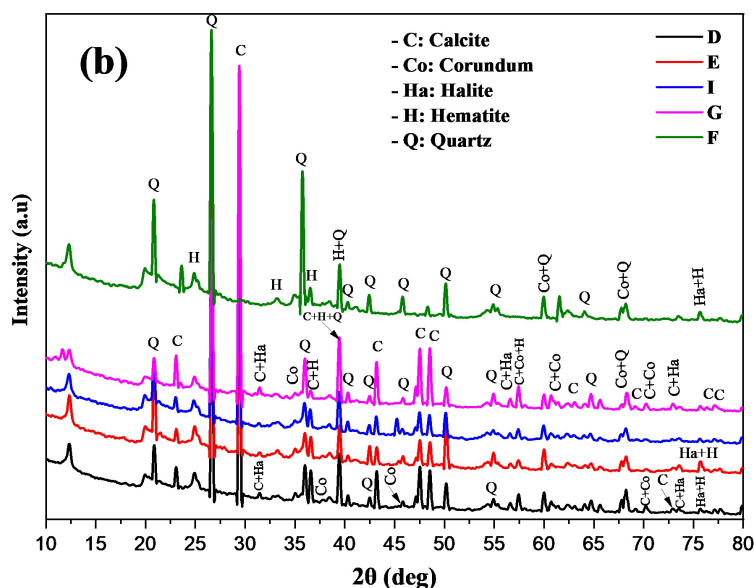
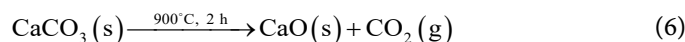


Figure 2. XRD pattern of: (a) raw materials, (b) mortar samples.

As indicated in **Figure 2(a)**, the peak characteristic of grog is Quartz (SiO_2) and minor peaks consist of Hematite (Fe_2O_3), Corundum (Al_2O_3) (crystalline pure nature) [14], and unreactive phase nature Halite (NaCl) [53]. This is due to the presence of chloride element contained in the others fraction in XRF analysis, and the presence of sodium in SEM-EDX analysis [54]. Coconut shell shows no peak and presents an amorphous texture [55] which is almost completely amorphous with a broad peak or hump shown between 20° and 30° (2θ) [56]. The calcined eggshell powder is chemically composed of Calcite (CaCO_3) indicates that during decomposition, calcination was not yet complete and that organic matter was still present in the final product. One more phase is observed as Calcite in the form of CaO [57] (Equation (6)), which is important for a pozzolanic reaction to affect the properties of clay bricks [58]. While coconut shell and calcined eggshell can be good candidates as additives to create pores [59]. From **Figure 2(b)** the samples D, E, I, G and F are identical and present all phases into raw materials, that presented the crystalline phases of calcite and quartz adding to calcium silicate hydrate (C-S-H) gel [5]. In this study, no significant differences were observed due to the different formulations [60], while no formation of intermediates in any of the five samples was observed. The decomposition of calcium carbonate is shown in Equation (6) below.



3.3. Fourier Transform Infrared Spectroscopy (FT-IR) of Raw Materials and Mortar Samples

Figure 3 shows the FT-IR spectra of the raw materials (grog, calcined eggshell powder and coconut shell powder) and mortar samples (D, E, I, G and F) mentioned in **Figure 3** below.

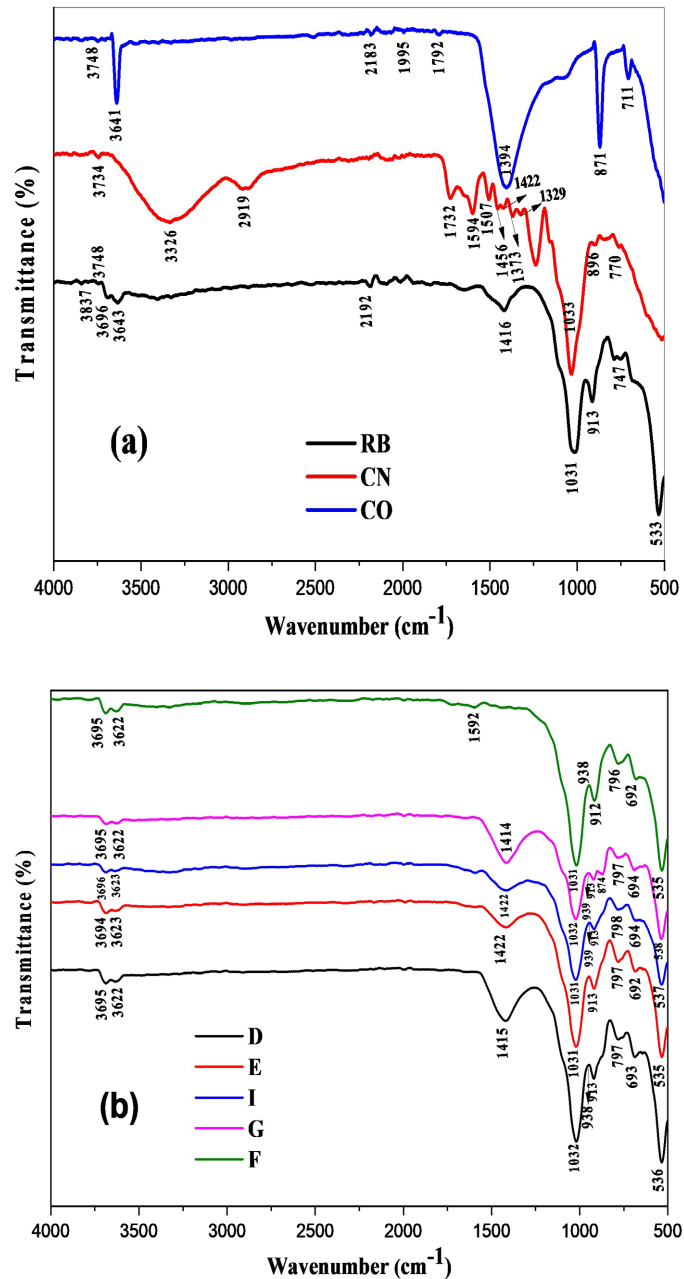


Figure 3. Infrared spectrum of: (a) raw materials, (b) mortar samples.

The Fourier Transformed Infrared Spectrum (FT-IR) of the RB (grog) (**Figure 3(a)**) is measured within the range limit of 3837 - 3643 cm^{-1} attributing to the stretching vibration of O-H and H-O-H bonds [61], indicating that the partial hydration after calcination, is as a results of the moisture present in the environment. While the peak at 2192 cm^{-1} reveals the stretching vibration of C = C. The peak at 1416 cm^{-1} correspond to the stretching vibration of C-O bond [62], indicating the carbonation of CO_2 from ambient air. The peaks at 1031 cm^{-1} and 533 cm^{-1} correspond to the deformation vibration of Si-O and Si-O-Si bonds respectively [61], which indicating the presence of amorphous quartz in the material

[61]. The peaks at 913 cm^{-1} and 747 cm^{-1} indicate the deformation vibration of Al-O-H and Si-O-Al bonds respectively [59] [61].

The FT-IR spectrum of CO (calcined eggshell) (**Figure 3(a)**) shows the range of $3748 - 3641\text{ cm}^{-1}$ which attributes the stretching vibration of O-H and H-O-H bonds [63], and indicating the presence of moisture in the environment [58]. The range of $2183 - 1792\text{ cm}^{-1}$ indicates the stretching vibration of C = O carbonyl bonds, originating from calcination eggshells at 900°C [58]. The peaks at 1394 cm^{-1} , 871 cm^{-1} and 711 cm^{-1} revealing the presence of C-O bond (this is due to partial carbonation of CaO) [64], and the organic matter [58].

Concerning the FT-IR spectrum of CN (coconut shell) (**Figure 3(a)**), within the range of $3734 - 3326\text{ cm}^{-1}$ attributes the stretching vibration of O-H and H-O-H bonds [59] [65]. The peaks at 2919 cm^{-1} and 1507 cm^{-1} revealing the presence of stretching vibration of C-H and C=C bonds [15] [65]. The different peaks at 1456 cm^{-1} , 1422 cm^{-1} , 1373 cm^{-1} , 1329 cm^{-1} , 1239 cm^{-1} and 770 cm^{-1} correspond the stretching vibration of C-O bond [65], while the peaks at 1033 cm^{-1} and 896 cm^{-1} correspond to Si-O bonds indicating the presence of amorphous silica present in the material [15] [55]. The peak at 1732 cm^{-1} reveals unconjugated carbonyl C = O [55] [65]. The FT-IR spectra of samples D, E, I, G and F (**Figure 3(b)**) show similar identity for peaks characteristics from obtained results. Results from XRD and FT-IR analysis show no compositional and chemical differences between the mortar samples [66], and show the formation of identically phases of samples after curing time [67]. Due to the addition of raw materials, the possibility of chemical properties of the crystallinity is revealed [68]. Results from XRD and FT-IR analysis revealed that after curing time, the crystalline phases initially present in the raw materials were also found in the chemical properties of mortar samples, which justify their partial formation into the process mixture [69].

3.4. Physico-Mechanical Properties of Earth Mortars

The physico-mechanical properties of samples are represented on **Table 2** below. The physico-mechanical properties of earth mortars (moisture content, water absorption, apparent porosity, bulk density, compressive strength and elastic modulus) were determined and shown in **Figure 4** below.

Results obtained for physico-mechanical properties at 28 and 56 days (bulk density, moisture content, water absorption and apparent porosity), and at 28 and 90 days for (compressive strength and elastic modulus) are presented in **Figure 4** below.

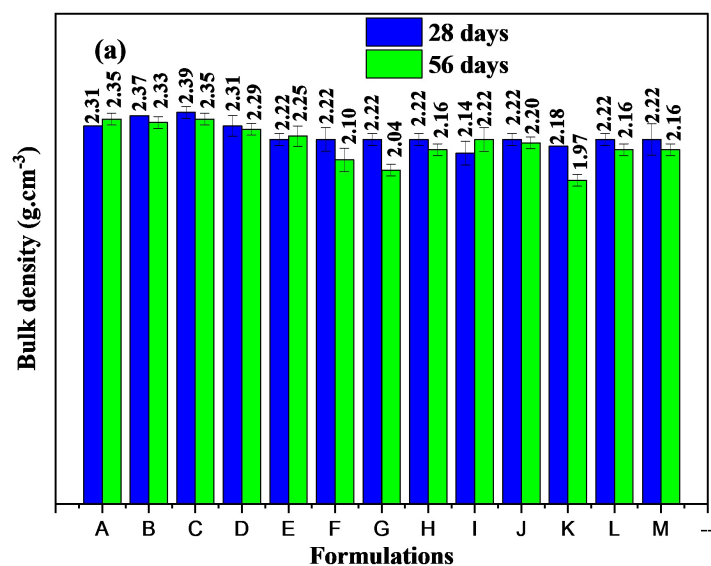
Figure 4(a) shows bulk density. The bulk density of samples shows a slight decrease in strength values. For $\text{RB}_{0.87}\text{CO}_{0.13}\text{CN}_0$, $\text{RB}_{0.74}\text{CO}_{0.26}\text{CN}_0$ and $\text{RB}_{0.6}\text{CO}_{0.4}\text{CN}_0$, their densities between 28 and 56 days of curing decreases with an increase in the percentage of calcined eggshell from: 2.37 to 2.33, 2.31 to 2.29 and 2.22 to $2.04\text{ g}\cdot\text{cm}^{-3}$, respectively. The bulk density values decrease from 28 to 56 days in ambient curing condition as 1.68%, 0.86%, and 8.82%, respectively. These results are similar to those found by [70], who obtained less density concretes based on calcined eggshell. While for $\text{RB}_{0.87}\text{CO}_0\text{CN}_{0.13}$, $\text{RB}_{0.74}\text{CO}_0\text{CN}_{0.26}$ and $\text{RB}_{0.6}\text{CO}_0\text{CN}_{0.4}$, the bulk density between 28 and 56 days of curing decreases with an increase in the

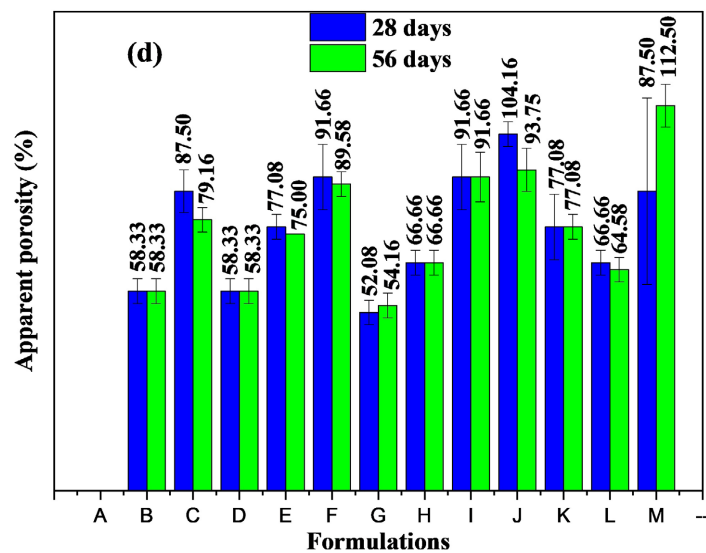
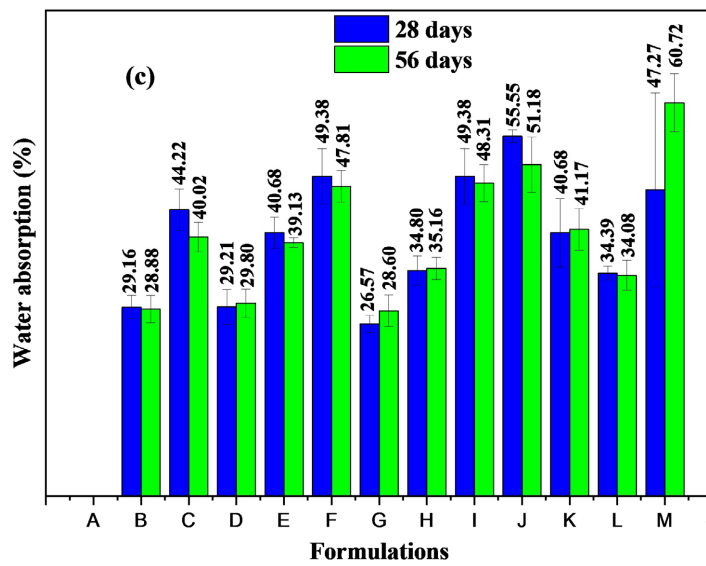
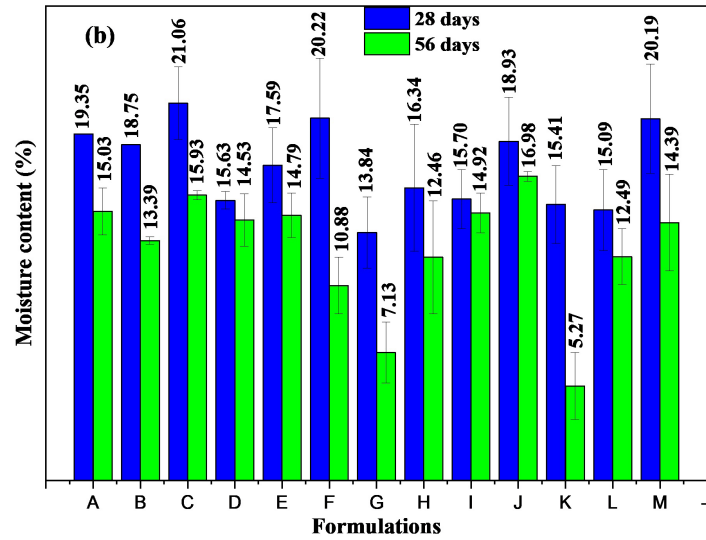
percentage of coconut shell from: 2.39 to 2.35, 2.22 to 2.10 and 2.22 to 2.20 g·cm⁻³, respectively. The decrease in bulk density value at ambient curing temperature was 1.27%, 5.71%, and 0.90% at 28 to 56 days, respectively. These results were compared with that obtained by [71], indicating that the density of types of concretes decreases with an increase in the percentage replacement of granite with coconut shell powder. Since the coconut shell powder are lightweight and occupy substantial amount of space during formulation, the particles were not closely bonded to each other as a result of the mould casting method. However, it can be attributed to the decrease in values of bulk density [72].

Table 2. Physical and mechanical properties of mortar samples at 28, 56 and 90 days.

Formulations	Moisture content (%)		Water absorption (%)		Apparent porosity (%)		Bulk density (g·cm ⁻³)		Compressive strength (MPa)		Elastic modulus (MPa)	
	28 d	56 d	28 d	56 d	28 d	56 d	28 d	56 d	28 d	90 d	28 d	90 d
A	19.35	15.03 ± 1.31	0	0	0	0	2.31	2.35 ± 0.03	1.54 ± 0.51	2.39 ± 0.45	10.89 ± 1.07	8.78 ± 2.05
B	18.75	13.39 ± 0.20	29.16 ± 1.80	28.88 ± 2.09	58.33 ± 3.60	58.33 ± 3.60	2.37	2.33 ± 0.03	1.38 ± 0.38	1.87 ± 0.62	8.41 ± 1.32	10.79 ± 1.55
C	21.06 ± 2.03	15.93 ± 0.24	44.22 ± 3.22	40.02 ± 2.27	87.50 ± 6.25	79.16 ± 3.60	2.39 ± 0.03	2.35 ± 0.03	1.52 ± 0.26	3.01 ± 0.51	9.46 ± 1.49	10.36 ± 1.25
D	15.63 ± 0.48	14.53 ± 1.46	29.21 ± 2.66	29.80 ± 2.17	58.33 ± 3.60	58.33 ± 3.60	2.31 ± 0.06	2.29 ± 0.03	2.70 ± 0.90	4.61 ± 0.92	9.74 ± 2.93	9.51 ± 2.72
E	17.59 ± 2.09	14.79 ± 1.24	40.68 ± 2.38	39.13 ± 0.74	77.08 ± 3.60	75.00	2.22 ± 0.03	2.25 ± 0.06	1.30 ± 0.18	1.89 ± 0.46	9.74 ± 0.83	10.32 ± 2.47
F	20.22 ± 3.35	10.88 ± 1.58	49.38 ± 4.28	47.81 ± 2.45	91.66 ± 9.54	89.56 ± 3.60	2.22 ± 0.07	2.10 ± 0.07	2.01 ± 0.43	4.26 ± 0.53	8.46 ± 1.08	13.25 ± 0.94
G	13.84 ± 1.98	7.13 ± 1.69	26.57 ± 1.33	28.60 ± 2.42	52.08 ± 3.60	54.16 ± 3.60	2.22 ± 0.03	2.04 ± 0.03	3.88 ± 0.77	4.14 ± 1.29	5.85 ± 1.35	12.00 ± 1.29
H	16.34 ± 3.55	12.46 ± 3.15	34.80 ± 2.28	35.16 ± 1.68	66.66 ± 3.60	66.66 ± 3.60	2.22 ± 0.03	2.16 ± 0.03	0.73 ± 0.20	1.40 ± 0.27	4.95 ± 2.62	10.06 ± 2.94
I	15.70 ± 1.65	14.92 ± 1.11	49.38 ± 4.28	48.31 ± 2.85	91.66 ± 9.54	91.66 ± 7.21	2.14 ± 0.07	2.22 ± 0.07	1.34 ± 0.32	2.22 ± 0.44	9.05 ± 1.41	12.60 ± 1.02
J	18.93 ± 2.45	16.98 ± 0.27	55.55 ± 0.97	51.18 ± 4.27	104.16 ± 3.60	93.75 ± 6.25	2.22 ± 0.03	2.20 ± 0.03	1.34 ± 0.44	3.42 ± 0.70	5.72 ± 2.28	12.53 ± 1.08
K	15.41 ± 2.17	5.27 ± 1.86	40.68 ± 5.28	41.17 ± 3.22	77.08 ± 9.54	77.08 ± 3.60	2.18	1.97 ± 0.03	1.16 ± 0.10	0.85 ± 0.15	7.11 ± 2.42	9.92 ± 1.12
L	15.09 ± 2.26	12.49 ± 1.56	34.39 ± 1.07	34.08 ± 2.29	66.66 ± 3.60	64.58 ± 3.60	2.22 ± 0.03	2.16 ± 0.03	0.74 ± 0.09	0.57 ± 0.14	4.39 ± 1.54	8.20 ± 1.11
M	20.19 ± 3.05	14.39 ± 2.69	47.27 ± 14.28	60.72 ± 4.46	87.50 ± 27.24	112.50 ± 6.25	2.22 ± 0.09	2.16 ± 0.03	0.29 ± 0.13	0.58 ± 0.24	3.25 ± 0.78	8.21 ± 1.59

Whereby A = RB₁CO₀CN₀; B = RB_{0.87}CO_{0.13}CN₀; C = RB_{0.87}CO₀CN_{0.13}; D = RB_{0.74}CO_{0.26}CN₀; E = RB_{0.74}CO_{0.13}CN_{0.13}; F = RB_{0.74}CO₀CN_{0.26}; G = RB_{0.6}CO_{0.4}CN₀; H = RB_{0.6}CO_{0.27}CN_{0.13}; I = RB_{0.6}CO_{0.13}CN_{0.27}; J = RB_{0.6}CO₀CN_{0.4}; K = RB_{0.87}CO_{0.065}CN_{0.065}; L = RB_{0.67}CO_{0.26}CN_{0.07}; M = CH_{0.67}CO_{0.07}CN_{0.26}.





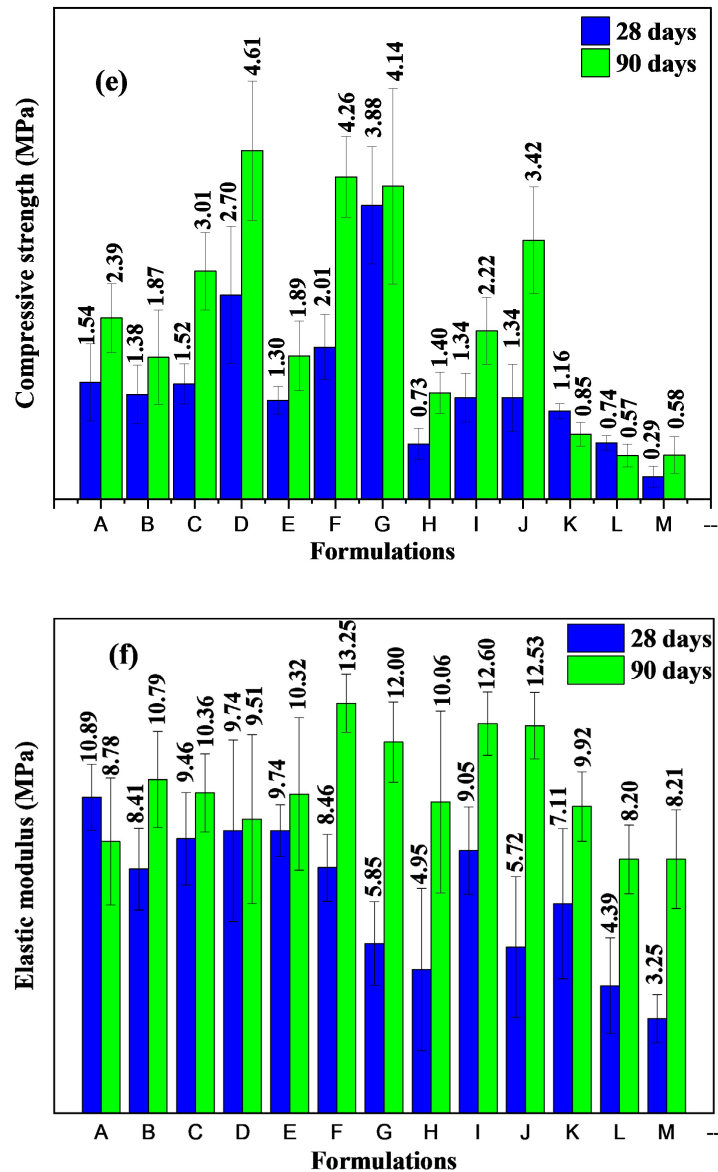


Figure 4. Average curves at 28 and 56 days of: (a) bulk density, (b) moisture content, (c) water absorption, (d) apparent porosity, at 28 and 90 days of: (e) compressive strength, (f) elastic modulus.

However, for $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$, $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$, $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$ and $\text{RB}_1\text{CO}_0\text{CN}_0$, their bulk density at 28 and 56 days of curing increases and decreases from: 2.22 to 2.25, 2.22 to 2.16, 2.14 to 2.22, 2.18 to 1.97, 2.22 to 2.16, 2.22 to 2.16 and 2.31 to 2.35 $\text{g}\cdot\text{cm}^{-3}$, respectively. The increase in the bulk density value in ambient curing temperature at 28 and 56 days of curing was 1.35, 3.73, and 1.73% for $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$ and $\text{RB}_1\text{CO}_0\text{CN}_0$, respectively. On the other hand, the decrease in the bulk density value in ambient curing condition at 28 and 56 days was 2.70%, 9.63%, 2.70%, 2.70% for $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$ and $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$, respectively. However, these values are greater than 1

$\text{g}\cdot\text{cm}^{-3}$ and comply with EN 771-1 standard for protected constructions [73].

Figure 4(b) shows moisture content variation. The moisture content of samples shows a great decrease in values. For $\text{RB}_{0.87}\text{CO}_{0.13}\text{CN}_0$, $\text{RB}_{0.74}\text{CO}_{0.26}\text{CN}_0$ and $\text{RB}_{0.6}\text{CO}_{0.4}\text{CN}_0$, their moisture content between 28 and 56 days of curing decreases from: 18.75% to 13.39%, 15.63% to 14.53% and 13.84% to 7.13%, respectively. The moisture content values decrease from 28 to 56 days in ambient curing temperature as 28.58%, 7.03%, and 48.48%, respectively. These results were compared with that obtained of [74], indicating that moisture content decreases when the percentage of eggshell powder increases. While for $\text{RB}_{0.87}\text{CO}_0\text{CN}_{0.13}$, $\text{RB}_{0.74}\text{CO}_0\text{CN}_{0.26}$ and $\text{RB}_{0.6}\text{CO}_0\text{CN}_{0.4}$ the moisture between 28 and 56 days of curing decreases from: 21.06 to 15.93%, 20.22% to 10.88% and 18.93% to 16.98%, respectively. The decrease in the moisture content value in ambient curing condition was 25.78%, 46.19%, and 10.30% at 28 to 56 days, respectively. According to [75], the moisture content decreases with an increase in percentage of crushed aggregates. As for $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$, $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$, $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$ and $\text{RB}_1\text{CO}_0\text{CN}_0$, their moisture content at 28 to 56 days of curing decreases from: 17.59% to 14.79%, 16.34% to 12.46%, 15.70% to 14.92%, 15.41% to 5.27%, 15.09% to 12.49%, 20.19% to 14.39% and 19.35% to 15.03%, respectively. The decrease in the moisture content value at 28 to 56 days of curing in ambient condition was 15.91%, 23.74%, 4.96%, 65.80%, 17.22%, 28.72%, 22.32%, respectively.

Figure 4(c) indicates that when there is an increase in the percentage of calcined eggshell at 900°C , and a decrease in the percentages of grog, the water absorption test slightly decreases then later and increases. For $\text{RB}_{0.87}\text{CO}_{0.13}\text{CN}_0$, $\text{RB}_{0.74}\text{CO}_{0.26}\text{CN}_0$ and $\text{RB}_{0.6}\text{CO}_{0.4}\text{CN}_0$ the water absorption test decreases as 29.16% to 28.88%, and increases of 29.21% to 29.80% and 26.57% to 28.60% up to 28 and 56 days of curing, respectively. However, there is a decrease in water absorption with an increase in the percentage of coconut shell which follows an increase as mentioned in the formulations for $\text{RB}_{0.87}\text{CO}_0\text{CN}_{0.13}$, $\text{RB}_{0.74}\text{CO}_0\text{CN}_{0.26}$ and $\text{RB}_{0.6}\text{CO}_0\text{CN}_{0.4}$ with values as 44.22% to 40.02%, 49.38% to 47.81% and 55.55% to 51.18% up to 28 and 56 days of curing, respectively. The decrease in the water absorption value in ambient curing temperature was 9.49%, 3.17%, and 7.86% at 28 to 56 days, respectively. Results are in line with [76], who demonstrated how water absorption decreases when curing time increases.

The mix design of both calcined eggshell and coconut shell with the different formulations are given below with their corresponding water absorption for $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$, $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$ and $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$. The water absorption at 28 and 56 days of curing decreases and increases from: 40.68% to 39.13%, 34.80% to 35.16%, 49.38% to 48.31%, 40.68% to 41.17%, 34.39% to 34.08% and 47.27% to 60.72%, respectively. The decrease in the water absorption content value at 28 to 56 days of curing in ambient condition was 3.81%, 2.16%, and 0.90% for $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$, respectively. While the increase in the water

absorption value at 28 to 56 days in ambient temperature was 1.03%, 1.20%, 28.45% for $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$, respectively. These results were compared with that of [77], indicating the type of bricks which become more porous when water absorption ranges between 20 and 55%. However, the results of [53] showed the capacity of bricks to absorb water and also increased as the porosity of bricks increased.

Generally, mortars based on calcined eggshells absorb less water. These results are similar to those found by [78], who obtained less absorbent concretes based on eggshells.

Figure 4(d) shows apparent porosity. The apparent porosity of samples shows a constant increase in values. So for $\text{RB}_{0.87}\text{CO}_{0.13}\text{CN}_0$, $\text{RB}_{0.74}\text{CO}_{0.26}\text{CN}_0$ and $\text{RB}_{0.6}\text{CO}_{0.4}\text{CN}_0$, their apparent porosity remains constant and increases from: 58.33% to 58.33%, 58.33% to 58.33% and 52.08% to 54.16% up to 28 and 56 days of curing, respectively. While for $\text{RB}_{0.87}\text{CO}_0\text{CN}_{0.13}$, $\text{RB}_{0.74}\text{CO}_0\text{CN}_{0.26}$ and $\text{RB}_{0.6}\text{CO}_0\text{CN}_{0.4}$ the apparent porosity at 28 and 56 days of curing decreases from: 87.50% to 79.16%, 91.66% to 89.58% and 104.11% to 93.75%, respectively. These results were compared with that of [76], indicating which apparent porosity decreases when curing time increase. For $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$, $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$ and $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$, their apparent porosity at 28 and 56 days of curing decreases, remains constant and increases from: 77.08% to 75.00%, 66.66% to 66.66%, 91.66% to 91.66%, 77.08% to 77.08%, 66.66% to 64.58% and 87.50% to 112.50%, respectively. These values of apparent porosity are greatly improved due to increase in pores size of mortars and the cohesion mixture decreases [79]. However, the type of bricks with higher porosity are recommended for its thermal insulation properties [80].

Figure 4(e) revealed an increase in the percentage of calcined eggshell sample at 900°C, while there is a decrease in the percentages of grog, as the compressive strength increases. For $\text{RB}_{0.87}\text{CO}_{0.13}\text{CN}_0$, $\text{RB}_{0.74}\text{CO}_{0.26}\text{CN}_0$ and $\text{RB}_{0.6}\text{CO}_{0.4}\text{CN}_0$ the compressive strength test at 28 and 90 days of curing increases from: 1.38 to 1.87, 2.70 to 4.61 and 3.88 to 4.14 MPa, respectively. These results are in agreement with [41], indicating the increase of mechanical properties. The compressive strength values increase from 28 to 90 days in ambient curing condition as 35.50%, 70.74%, and 6.70%, respectively. While on the other hand, there is an increase in compressive strength with an increase in the percentage of coconut shell, then a decrease from above mentioned formulations for $\text{RB}_{0.87}\text{CO}_0\text{CN}_{0.13}$, $\text{RB}_{0.74}\text{CO}_0\text{CN}_{0.26}$ and $\text{RB}_{0.6}\text{CO}_0\text{CN}_{0.4}$ with values as 1.52 to 3.01, 2.01 to 4.26 and 1.34 to 3.42 MPa up to 28 at 90 days of curing, respectively. The increase in the compressive strength value in ambient curing temperature was 98.02%, 111.94%, and 155.22% at 28 to 90 days, respectively. These samples have revealed a gain in compressive strength from 28 to 90 days, according to [81]. The different values such as 2.01, 2.70, 3.01, 3.42, 3.88, 4.14, 4.26 and 4.61 MPa respectively are higher than the Cameroonian [49] standards (which sets compressive strength at 2 MPa). Thus, seven values 2.70 MPa, 3.01 MPa, 3.42 MPa, 3.88 MPa, 4.14 MPa, 4.26 MPa and 4.61 MPa are

highest than the Netherland NEN 3835 standard [82] (which sets compressive strength and falls within the range limit of 2.5 - 5 MPa), while these results are similarly with [83], who demonstrated that compressed earth bricks stabilized by 8% of cement achieved the compressive strength between 2.5 and 3.5 MPa. The compressive strength is profoundly affected by firing temperature, method of production and physical, chemical and mineralogical properties of the raw materials [59]. The better improved values of compressive strengths contribute to the creation of an environmental friendly building materials, and promote a circular economy as stated by [84], and also to achieve sustainable development of building materials [85]. However, these results are applied in building and construction materials and decoration as stipulated by [86]. Indeed, a high percentage of silica (SiO_2) has reacted with calcium oxide (CaO) forming calcium-silicate-hydrate (C-S-H), which increases compressive strength [87]. While the curing time increased, the hydration or lime-pozzolan reaction increased, which accelerated the pozzolanic reactivity [87].

The formulations of the mix design of both calcined eggshell and coconut shell, are given below with their corresponding compressive strength such as $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$, $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$ and $\text{RB}_1\text{CO}_0\text{CN}_0$. Their strength between 28 and 90 days of curing increases from: 1.30 to 1.89, 0.73 to 1.40, 1.34 to 2.22, 0.29 to 0.58, and 1.54 to 2.39 MPa, respectively. For $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$ the strength between 28 and 90 days of curing decreases from: 1.16 to 0.85, 0.74 to 0.57 MPa, respectively has demonstrated on how compressive strength decreases when the percentage of coconut shell increases [88]. The increase in the compressive strength value in ambient curing condition was 45.38%, 91.78%, 65.67%, 100%, 55.19% at 28 to 90 days, respectively. While the decrease in the compressive strength value was 26.72%, 22.97% at 28 to 90 days, respectively. These results have been compared with that of [60], indicating the significant increase of the compressive strength at ambient curing, and have been presented a gain of the compressive strength values from 28 to 90 days [1] [5], this is due to pozzolanic effect of calcined eggshell and coconut shell [79].

Figure 4(f) shows elastic modulus. The elastic modulus of samples shows a great increase in values. So for $\text{RB}_{0.87}\text{CO}_{0.13}\text{CN}_0$, $\text{RB}_{0.74}\text{CO}_{0.26}\text{CN}_0$ and $\text{RB}_{0.6}\text{CO}_{0.4}\text{CN}_0$, their elastic modulus between 28 and 90 days of curing increases and decreases from: 8.41 to 10.79, 9.74 to 9.51 and 5.85 to 12.00 MPa, respectively. In general terms, the use of highly porous materials (water-absorbent materials) can reduce elastic modulus of concrete [89]. While for $\text{RB}_{0.87}\text{CO}_0\text{CN}_{0.13}$, $\text{RB}_{0.74}\text{CO}_0\text{CN}_{0.26}$ and $\text{RB}_{0.6}\text{CO}_0\text{CN}_{0.4}$ the elastic modulus between 28 and 90 days of curing increases from: 9.46 to 10.36, 8.46 to 13.25 and 5.72 to 12.53 MPa, respectively. The increase in the elastic modulus value in ambient curing temperature was 9.51%, 56.61%, and 119.05% at 28 to 90 days, respectively. These results were compared with that of [90], indicating the use of adequate content of lightweight sand results in an increase in elastic modulus. And finally for $\text{RB}_{0.74}\text{CO}_{0.13}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.27}\text{CN}_{0.13}$, $\text{RB}_{0.6}\text{CO}_{0.13}\text{CN}_{0.27}$, $\text{RB}_{0.87}\text{CO}_{0.065}\text{CN}_{0.065}$, $\text{RB}_{0.67}\text{CO}_{0.26}\text{CN}_{0.07}$, $\text{RB}_{0.67}\text{CO}_{0.07}\text{CN}_{0.26}$ and

RB₁CO₀CN₀, their elastic modulus at 28 and 90 days of curing increases and decreases from: 9.74 to 10.32, 4.95 to 10.06, 9.05 to 12.60, 7.11 to 9.92, 4.39 to 8.20, 3.25 to 8.21 and 10.89 to 8.78 MPa, respectively. The elastic modulus values increase from 28 to 90 days in ambient curing condition as 5.95%, 103.23%, 39.22%, 39.52%, 86.78%, 152.61%, respectively, and decrease as 19.37% for sample (RB₁CO₀CN₀) at 28 to 90 days in ambient curing condition. However, the use of water-absorbent materials can reduce elastic modulus of concrete [89]. Moreso, in this study, it was established that addition of coconut shell particle greatly improved elastic modulus [91].

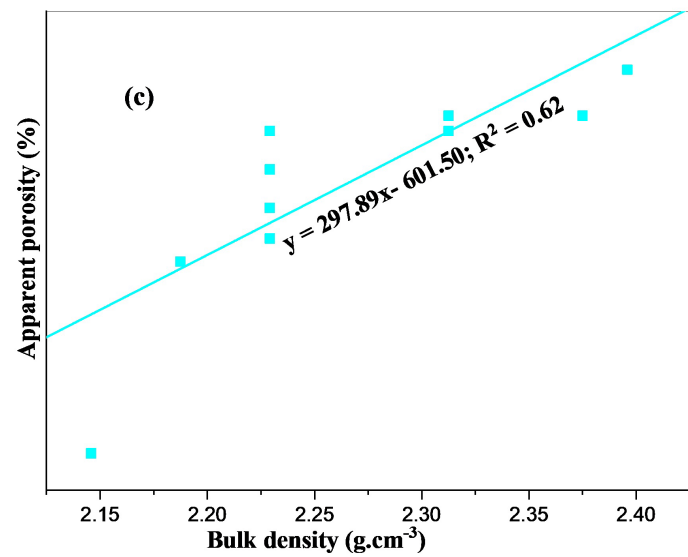
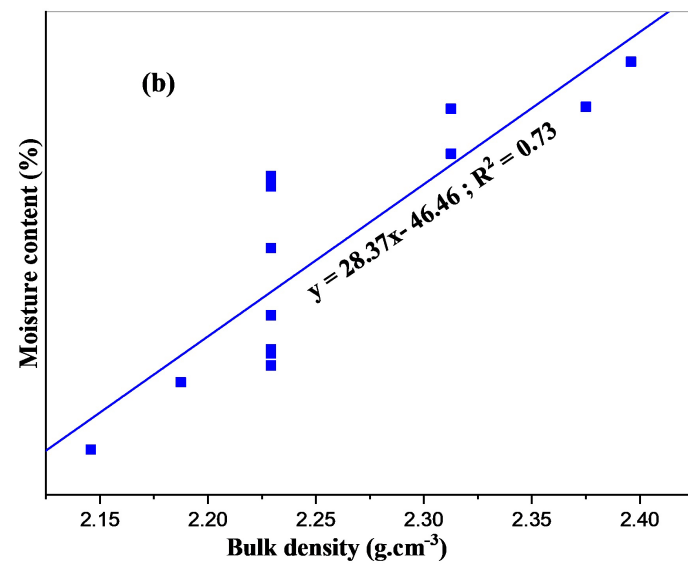
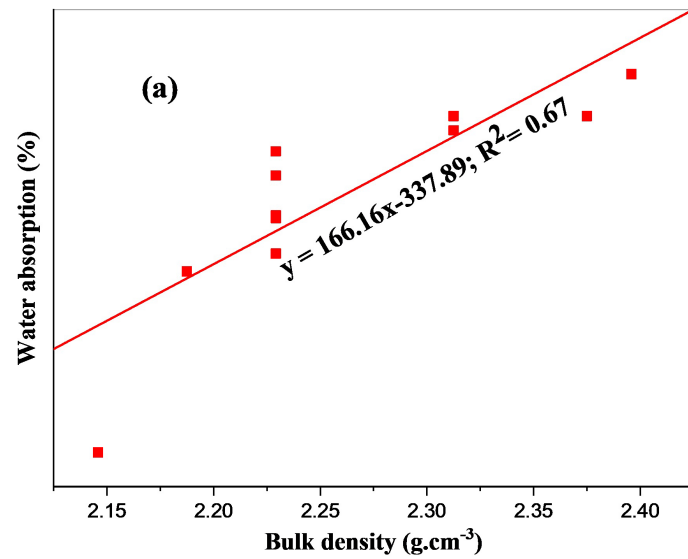
3.5. Linear Correlation between Physico-Mechanical Properties (Water Absorption, Apparent Porosity, Bulk Density, Moisture Content, Compressive Strength and Elastic Modulus)

The correlation coefficient denoted as R^2 is a statistical measure representing the proportion of the variance in the dependent variable that is predictable from independent variables in a regression model. R^2 indicates the strength of the relationship between independent and dependent variables. The different limits range of correlation coefficient are: 0 - 0.2 (weak correlation) means a very little variation in the dependent variable, 0.2 - 0.4 (moderate correlation) means and explains some of the variations in the dependent variable, 0.4 - 0.6 (strong correlation) means a strong part of the variation in the dependent variable, 0.6 - 0.8 (very strong correlation) means and explains a huge portion of the variation in the dependent variable, and 0.8 - 1 (perfect correlation) means and explains all of the variations in the dependent variable.

Correlations between physical properties are shown in **Figure 5** and **Figure 6** at 28 and 56 days. **Figure 7** shows correlations between mechanical properties at 28 and 90 days. However, the correlation coefficients and range limits between properties are shown on **Table 3** below.

Table 3. Correlation coefficients and range limits between properties at 28, 56 and 90 days.

	Water absorption (WA)				Moisture content (MC)				Apparent porosity (AP)				Elastic modulus (EM)			
	28 days		56 days		28 days		56 days		28 days		56 days		28 days		90 days	
	R^2	Range	R^2	Range	R^2	Range	R^2	Range	R^2	Range	R^2	Range	R^2	Range	R^2	Range
Bulk density (BD)	0.67	0.6 - 0.8	0.86	0.8 - 1	0.73	0.6 - 0.8	0.89	0.8 - 1	0.62	0.6 - 0.8	0.85	0.8 - 1	-	-	-	-
Water absorption (WA)	-	-	-	-	0.81	0.8 - 1	0.82	0.8 - 1	0.99	0.8 - 1	0.99	0.8 - 1	-	-	-	-
Moisture content (MC)	-	-	-	-	-	-	-	-	0.77	0.6 - 0.8	0.83	0.8 - 1	-	-	-	-
Compressive strength (CS)	-	-	-	-	-	-	-	-	-	-	-	-	0.66	0.6 - 0.8	0.96	0.8 - 1



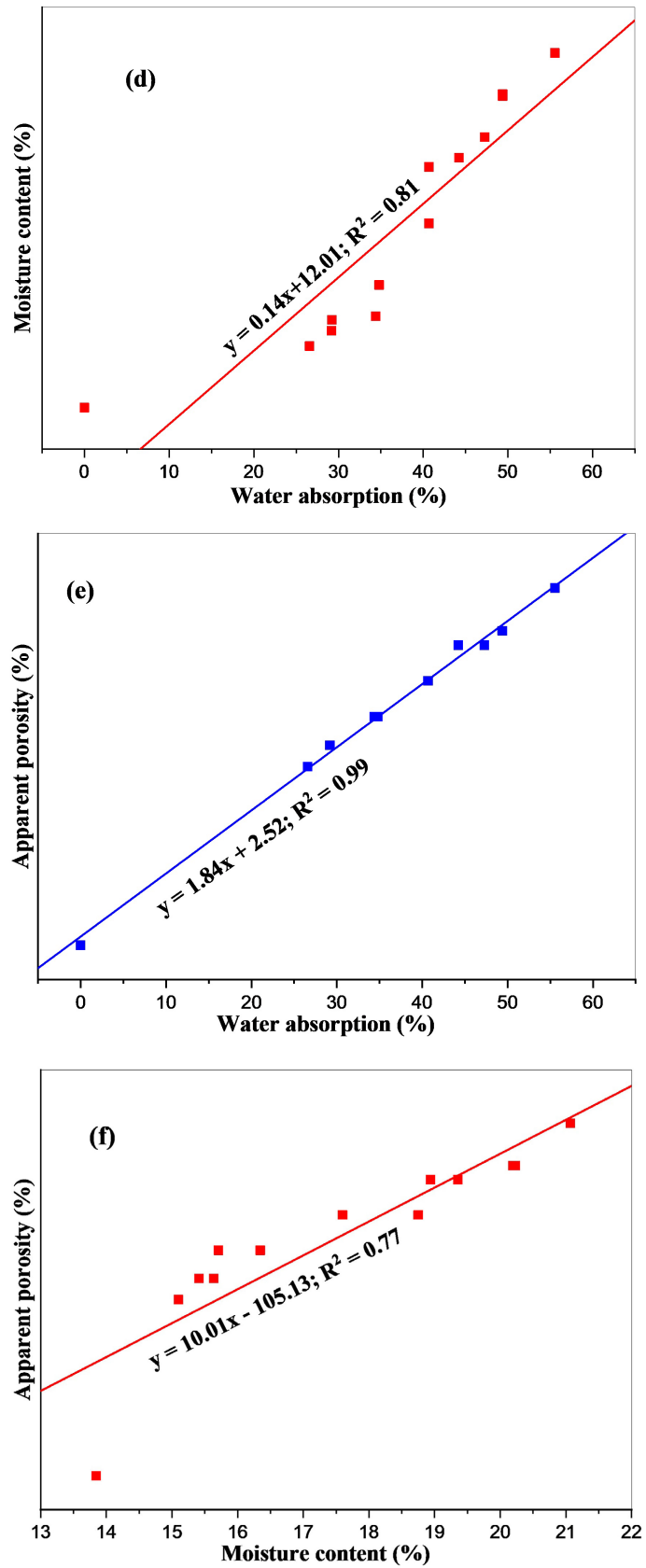
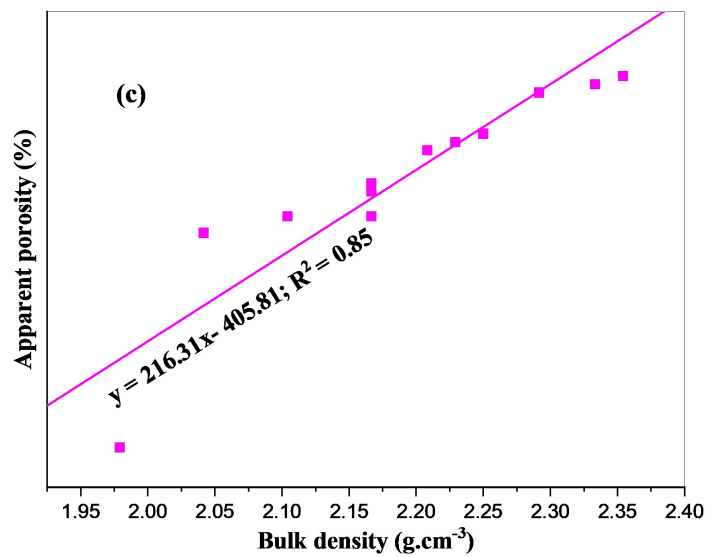
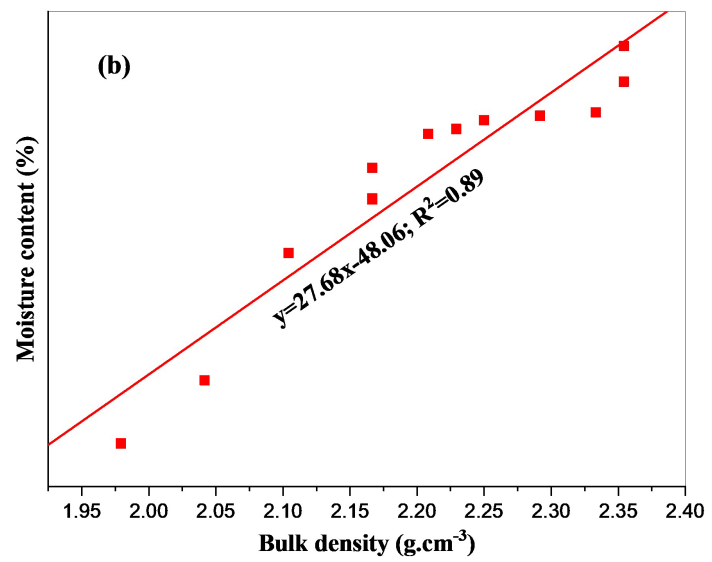
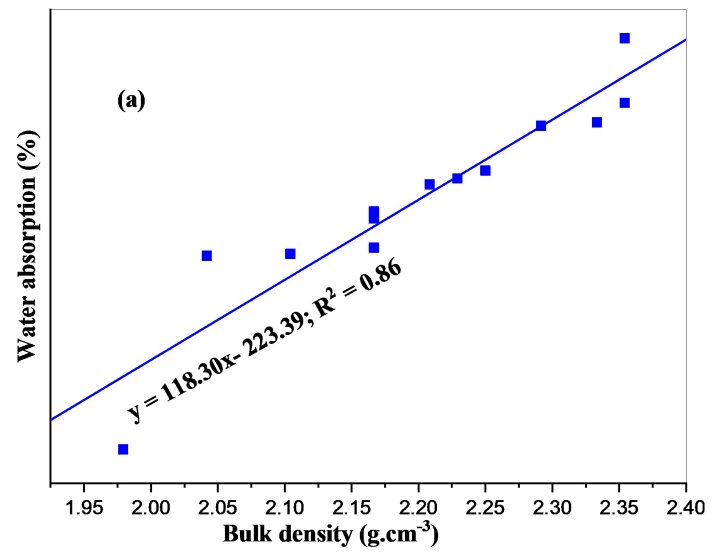


Figure 5. Linear correlation curves of physical properties at 28 days.



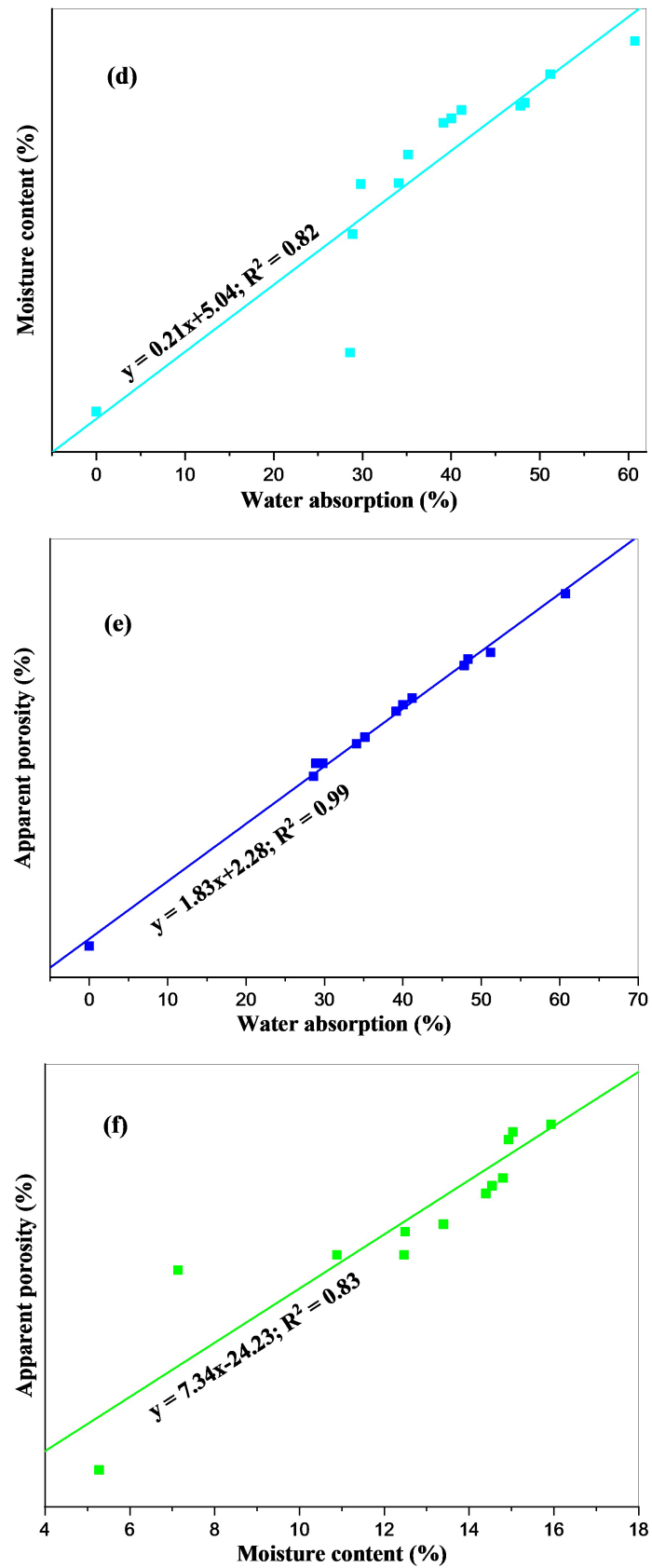


Figure 6. Linear correlation curves of physical properties at 56 days.

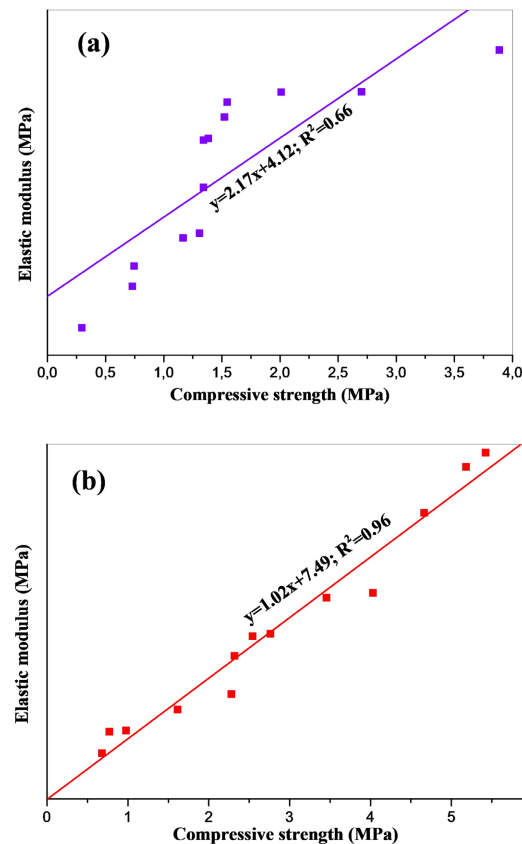


Figure 7. Linear correlation curves at 28 and 90 days of mechanical properties.

The linear correlation curves **Figure 5** shows variation between different physical properties at 28 days of curing such as bulk density, water absorption, and moisture content. **Figure 6** indicates the linear correlation curves of variation between different physical properties at 56 days of curing such as bulk density, water absorption, and moisture content.

Figures 5(a)-(c) and **Figures 6(a)-(c)** show the correlations between bulk density of mortars under investigation and their water absorption, moisture content, and apparent porosity, respectively. **Figures 5(a)-(c)** and **Figures 6(a)-(c)** present a linear increase in their water absorption, moisture content, and apparent porosity with an increase in bulk density, and the correlation coefficients are as follow $R^2 = 0.67$, $R^2 = 0.73$, $R^2 = 0.62$ and $R^2 = 0.86$, $R^2 = 0.89$, $R^2 = 0.85$, respectively. This all shows a very strong correlation and fall within the range limit of 0.6 - 0.8 and 0.8 - 1. Result of correlation between bulk density and moisture content explains that the increase of bulk density with moisture content increases [92]. However, the results of correlation coefficients between bulk density, water absorption and apparent porosity have explained that the bulk density increases with an increase in the water absorption and apparent porosity [93].

Figure 5(d) & Figure 5(e) and **Figure 6(d) & Figure 6(e)** show the correlations between water absorption of mortars under investigation, their moisture content, and apparent porosity, respectively. **Figure 5(d) & Figure 5(e)** and **Figure 6(d) &**

Figure 6(e) present a linear increase in their moisture content, and apparent porosity with an increase in water absorption, and the correlation coefficients are $R^2 = 0.81$, $R^2 = 0.99$, $R^2 = 0.82$ and $R^2 = 0.99$, respectively. The above shows perfect correlation and fall between 0.8 - 1. Result of correlation between water absorption and apparent porosity also explains why more porous materials with open and interconnected pores have greater water absorption [94]. Moreover, this explains why water absorption depends on the apparent porosity of mortars [95]. However, the result of correlation between water absorption and moisture content shows that the water absorption increases with an increase in moisture content [96].

Figure 5(f) and **Figure 6(f)** show the correlation between moisture content of mortars under investigation, and their apparent porosity. **Figure 5(f)** and **Figure 6(f)** present a linear increase in their apparent porosity with an increase in moisture content, and the correlation coefficients are $R^2 = 0.77$ and $R^2 = 0.83$, respectively. This shows two types of very strong correlation and perfect correlation and fall within the range limits of 0.6 - 0.8 and 0.8 - 1, respectively. Result of correlation between apparent porosity and moisture content explains that the apparent porosity increases with an increase in moisture content [97].

Rasool *et al.*, 2023 who worked on “Experimental study on strength and endurance performance of burnt clay bricks incorporating marble waste”, and they established a linear correlation between water absorption and apparent porosity, and their results showed a correlation coefficient of 0.92 indicating a perfect correlation. Another researcher such [98] determined a linear correlation between water absorption, and apparent porosity. They also obtained a correlation coefficient of 0.98 for relationship, which is a perfect correlation.

However, [99] determined the linear correlations between apparent porosity, and water absorption, and between bulk density and apparent porosity, respectively. They obtained the correlation coefficients of 0.96 and 0.98 for relationships, respectively, which is a perfect correlation.

Figure 7 above shows the linear correlation curves between elastic modulus and compressive strength at 28 days and 90 days of curing.

Figure 7(a) shows a linear increase in elastic modulus with an increase in compressive strength. The correlation coefficient is as follows $R^2 = 0.66$, it shows very strong correlation and falls within the range limit of 0.6 - 0.8. **Figure 7(b)** shows a linear increase in elastic modulus with an increase in compressive strength. The correlation coefficient is $R^2 = 0.96$, it shows perfect correlation and falls between 0.8 - 1. These results were in agreement with that of [100], indicating that the elastic modulus increases with an increase in the compressive strength.

The relationship between water absorption (WA), and bulk density (BD) at 28 and 56 days of curing increases from $R^2 = 0.67$ to $R^2 = 0.86$ and it is observed that there is a significant effect on the curing condition. On the other hand, at 28 and 56 days of curing, the correlation between moisture content (MC), and bulk density (BD) increases from $R^2 = 0.73$ to $R^2 = 0.89$, and it is observed that there is a

significant effect on the curing condition. While the correlation between apparent porosity (AP), and bulk density (BD) at 28 and 56 days, increases from $R^2 = 0.62$ to $R^2 = 0.85$, it shows a significant effect on the curing condition. Thus, the relationship between MC and WA at 28 and 56 days of curing increases from $R^2 = 0.81$ to $R^2 = 0.82$, showing a non-significant effect on curing condition. While for the relationship between AP and WA at 28 and 56 days of curing, the correlation coefficient value as $R^2 = 0.99$ for all, showing a non-significant effect. And then the correlation between AP and MC at 28 and 56 days of curing, increases from $R^2 = 0.77$ to $R^2 = 0.83$ and it demonstrates a significant effect of curing condition. And finally for the relationship between elastic modulus (EM) and compressive strength (CS), the correlation at 28 and 90 days of curing increases from $R^2 = 0.66$ to $R^2 = 0.96$, indicating a significant effect on curing condition.

4. Conclusion

The aim of this work was to investigate the effect of curing time at 28, 56 and 90 days on the physico-mechanical properties of compressed recycled brick dust mortars using grog by reinforcing calcined eggshell and coconut shell powder for sustainable building construction. The results showed that the compressive strength at 28 and 90 days increases with an increase in the percentage of calcined eggshell from 1.38 to 1.87, 2.70 to 4.61, and 3.88 to 4.14 MPa, respectively. Moisture content at 28 and 56 days decreases with an increase in the percentage of calcined eggshell and coconut shell. Water absorption (at 28 and 56 days) and elastic modulus (at 28 and 90 days) slightly increases then decreases with an increase in the percentage of calcined eggshell. Apparent porosity and bulk density at 28 and 56 days were decreased with the percentage of calcined eggshell increased. The perfect correlation of $R^2 = 0.96$ (between elastic modulus and compressive strength at 90 days) and $R^2 = 0.99$ (between apparent porosity and water absorption at 28 and 56 days) were obtained in this work, and revealed a significant effect. The chemical composition indicates that all samples are identical and presented no formation of intermediates phases. The addition of different percentages of coconut shell and calcined eggshell has greatly improved the physico-mechanical properties of samples.

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Authors' Contributions

Liyong Luc Arnold: Formal analysis, Investigation, Conceptualization, writing original draft, **Linda Lekuna Duna:** Conceptualization, Investigation, Methodol-

ogy, Formal analysis, Validation, writing original draft, **Tchuifon Tchuifon Donald Raoul**: Validation, writing review & editing, **Fotsop Cyrille Ghislain**: Formal Analysis, writing review, **Adjia Zangue Henriette**: Formal Analysis & editing, Formal analysis, **Nsouandele Jean Luc**: Writing review & editing, Formal analysis.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

Conflicts of Interest

No potential conflict of interest was reported by the authors.

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