Open Journal of Applied Sciences, 2022, 12, 1595-1603
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Physical and Mechanical Characteristics of Ash Concrete from Palm Nut Shells: Pouzzolanic Effect

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How to cite this paper: Adama, S.M., Paul, J.O.S., Souleymane, O. and Edjikémé, E. (2022) Physical and Mechanical Characteristics of Ash Concrete from Palm Nut Shells: Pouzzolanic Effect. *Open Journal of Applied Sciences*, **12**, 1595-1603.
https://doi.org/10.4236/ojapps.2022.1210108

Received: August 8, 2022
Accepted: October 15, 2022
Published: October 18, 2022

Abstract

The use of agricultural waste in construction is an advantage favorable to environmental sanitation, the preservation of non-renewable resources but also to the execution of an ecological work. The objective of this work is to study the influence of the addition of palm nut cockles ash as an adjuvant on the physico-mechanical properties of concrete. For this study, ordinary concretes and ash concretes were made and subjected to physical and mechanical characterization tests at different maturation periods. The results of the tests carried out indicate that the presence of ash reduces the workability and porosity of the concrete and then increases the density of the concrete to 6.3%. In addition, we found that incorporating the ash improves the mechanical strength of the concrete compared to the control concrete. Thus, the compressive strength of ash concrete is 32.07 MPa and that of splitting is 2.76 MPa at 28 days, which is satisfactory vis-à-vis the threshold of construction projects for ready concrete for use, which recommends a minimum of 25 MPa (compression) and 2.6 MPa (splitting) at 28 days. This improvement in mechanical performance can be attributed to the pozzolanic effect of the constituents of the ash. Therefore, the ash from palm nut shells can be used to improve the mechanical properties of concrete.

Keywords

Recycled Concrete, Lvegetable Matter, Mechanical and Physical Properties

1. Introduction

The environmental problems linked to the presence of agricultural wastes are becoming increasingly worrying and constitute a major issue for developing nations. It is therefore necessary not only to preserve the environment and non-renewable resources, but also to works in an ecological manner. Thus, the use of agricultural waste (palm nut shells, coconut shells, etc.) in concrete is an alternative to the problem of depletion of natural resources and to cleaning up the environment and the setting of life. Indeed, its speed of manufacture, its installation, its low cost, and its mechanical performance as well as its durability have contributed to increasing its use for all types of structures such as buildings, bridges and nuclear power plants. Also, concrete is the most used material in construction around the world [1]. Moreover, the Ivory Coast is one of the major palm oil producing countries where the presence of a huge amount of waste (shells of spoke nuts). One possibility is to use this waste as aggregate in concrete. Indeed, some authors such as [2] and [3] have respectively demonstrated the high porosity and the high water absorption capacity, their high silica content (77.1% ash) and reduction of mechanical performance with increasing proportions of palm nut cock. Other authors such as [4] and [3], to improve mechanical performance and durability, propose the treatment of shells from lime and fly ash. Thus, the Geomaterials team was particularly interested in the ash from palm nut shells for the recovery of this waste. This study is part of the process of sustainable development and its objective is to use ash as an admixture in concrete. To do this, 5% of the total mass of the cement is incorporated into the formulation, followed by a physical and mechanical characterization of the witness concrete and ash specimens.

2. Material and Methods

2.1. Raw Material

This study focused on ash concretes as well as ashless control concretes. These concretes were kept as prescribed by standard [5]. The characterization of the fresh concrete was done with an Abrams cone then by a hydrostatic weighing machine and a press for hardened concrete. In the table below we present the characteristics that justify the use of raw materials for the manufacture of our concrete test specimens (**Table 1**).

The presence and the proportion of silica and alumina show a possible pozzolanic reaction of our ash with the cement because according to standard [6], natural pozzolans contain 60% to 85% silica (SiO_2) and alumina (Al_2O_3). Also, different equipment such as Abrams cone, hydraulic press and hydrostatic weighing machine are used for characterization.

2.2. Methods

2.2.1. Concrete Formulation

The ash used in this work is the product of the combustion of palm nut shell waste. However, according to [2] and [7], the production of CO_2 during combustion is zero. The quantity of ash used as an adjuvant is equal to 5% of the total mass of the cement. The different mixtures carried out for the preparation of concrete are contained in **Table 2**.

Table 1. Characteristics of raw materials.

	d/D	Mf	Cu	Cc	LA (%)	MDE (%)	SiO_2 (%)	Al (%)	Ca (%)	CT (%)
Gravel	6/25	-	2.2	1.3	28	7			-	
Sand	0/1	2.1	2.2	1.3				-		
Cement		The cement used is Portland blended cement CPJ (32.5 R) locally manufactured by the Company of Cements and Materials (LafargeHolcim) under the name "CimentBélier"								
Ash				-			60.25	2.925	6.92	0.811
Water		The water used for our work comes from the drinking water distribution network of the Côte d'Ivoire Water Distribution Company (SODECI)								

Ranular class (d/D), Modulus of fineness (Mf), Coefficient of Uniformity (Cu), Coefficient of curvature (Cc), Los Angeles Coefficient (LA), Micro-Deval (MDE), Silicon (SiO_2), Alumina (Al), Calcium (Ca), Total carbon (CT).

Table 2. Formulation of the different mixtures.

	Composition of the mixture (kg)				
	Cement	Sand	Gravel	Water	Ash
Sample concrete	47	59.4	114	23.5	0
Ash concrete	47	59.4	114	23.5	2.35

Note: Water/Cement ratios = 0.5. The test pieces were demolded 24 hours after casting and tested at 7, 14, 28 and 90 days.

2.2.2. Characterization

To control the factors arising from the quality and quantity of water for mixing concrete, we carried out the Abrams cone test in the fresh state according to standard [5]. Abrams cone test provides concrete slump class. The mechanical properties (compression, splitting and bending) were obtained using a CONTROLAB IGM hydraulic press with a capacity of 1500 KN with a load speed of 5 kN/s. These tests were carried out on 16 × 32 cylindrical test specimens for compression according to standard [8]. The traction by splitting was carried out on cylindrical 11 × 22 specimens according to standard [9]. Also, the flexural tension was carried out according to standard [10] on 7 × 7 × 28 prismatic specimens. **Figures 1(a)-(c)** shows the measurement of resistance to compression, splitting and bending.

Porosity and density (density) are two important physical quantities of cementitious materials, they play a major role in the durability of concrete. To determine the porosity accessible to water and the bulk density, water porosimetry was used. This method allows an estimate of overall porosity or the open porosity.The measurements were carried out with a hydrostatic weighing machine according to standard [11] (**Figure 2**).

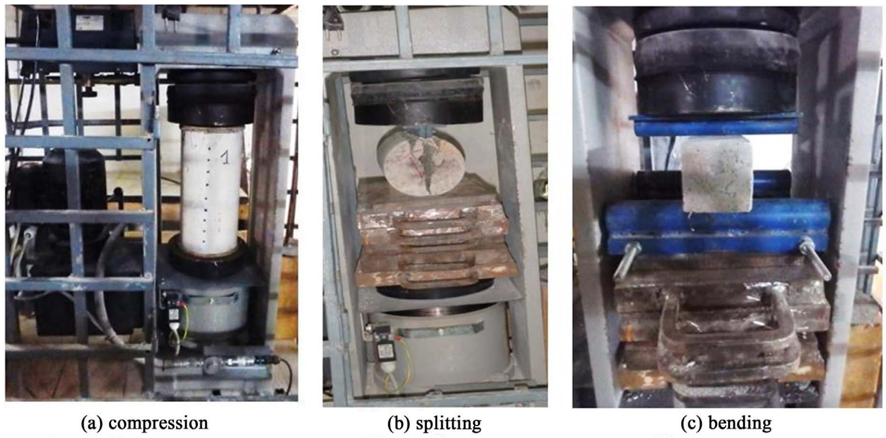

Figure 1. Measurement of resistance to compression, splitting and bending.

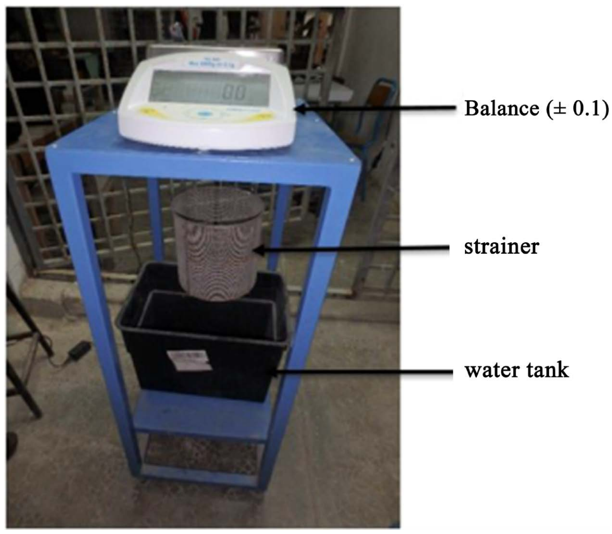

Figure 2. Hydrostatic weighing machine.

3. Results and Discussion

3.1. Behavior of Fresh Concrete

The control concrete and fresh ash slump results determined are 17 cm and 16 cm, respectively. A reduction of 1 cm in workability is observed. This could be explained by the increase in fine particles which reduce the amount of mixing water because of their large specific surface. This result is consistent with the results obtained by [3]. However, these two control and ash concretes are S4 slump class flowable concretes.

3.2. Behavior of Hardened Concrete

3.2.1. Physical Characteristics

Figure 3 and **Figure 4** show the values of the dry density and of the porosity of the concrete specimens respectively according to the maturation time.

Observation of **Figure 3** shows that the addition of ash from palm nut shells increases the density of young concrete between 7 and 14 days compared to

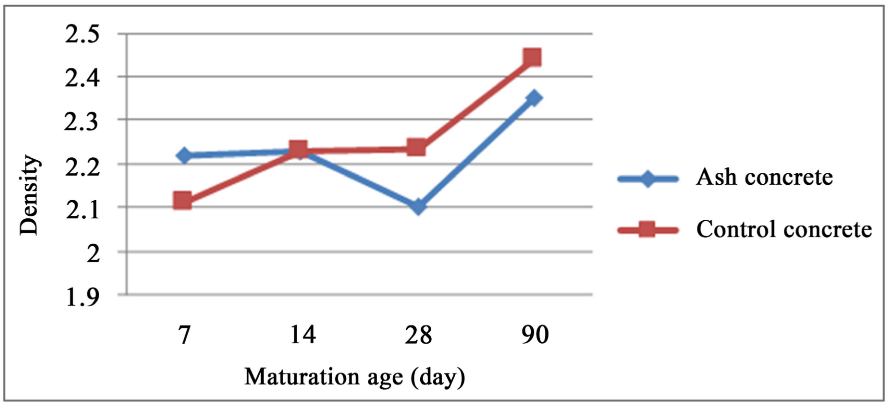

Figure 3. Density of concrete as a function of maturation.

control concrete. This result is consistent with the result of [12] who showed that the presence of clinker powder decreases the volume of air trapped in the mortar. He pointed out that the occluded air volume is 7.2% for the mortar with clinker powder and 8.5% for the benchmark mortar [13]. demonstrated in their study that the addition of granular particles can have favorable consequences if these particles manage to fill the voids of the granular skeleton. For [14], the incorporation of fine mineral additions increases compactness and reduces the volume of intergranular void. However, between 14 and 28 days of maturation this density drops. This is because ash, consisting of fine particles with a large specific surface area, retains a quantity of mixing water, which promotes the appearance of tiny pores during the hydration of the cement. Then, from the 28th to the 90th day, this density gradually increases. Indeed, during hydration, there is a multiplication of hydrates which are hard crystalline structures to clog the various pores leading to an increase in the density of the test specimens. With regard to the density of the control concretes, from the 7th to the 90th day, it gradually increases from 1 to 2.4. During the cement hydration process, hydrates multiply over time resulting in reduction of micropores. Thus, the increase in density contributes to improving the mechanical performance of concrete. Also, this increase in density could be explained by the large amount of siliceous or aluminosiliceous material in the ash of palm nut shells. This ash, in finely divided form and in the presence of moisture, reacts chemically with the calcium hydroxide released by the hydration of the cement to form hydrated calcium silicates. This makes it possible to trigger a pozzolanic reaction by consuming lime and creating new hydrates to clog the micropores. **Figure 4** shows the porosity as a function of the age of maturation.

In general, **Figure 4** shows that the porosity of the control concrete decreases considerably as a function of the age of maturity of the concrete. In fact, during the hydration of the cement, new hydrates are formed which reduce the porosity of the concrete. However, ash concrete has three phases of evolution: The first phase (7th to 14th day), shows a slight increase in porosity from 13% to 14%. This slight increase in porosity could correspond to the start of hydration of the cement. On the other hand, during the second phase (14 to 28 days), the

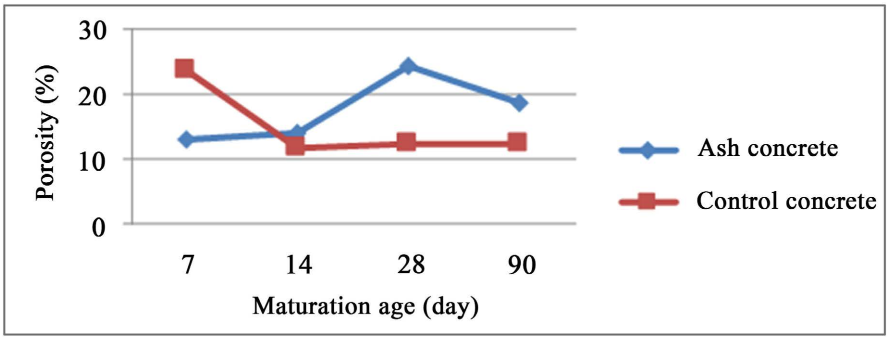

Figure 4. Porosity according to the age of maturation.

porosity of the ash concrete increases considerably, it goes from 14% to 24%. During setting and hardening, the ash particles interact in the cement hydration process by changing the structure of hydrated products. Thus, many micropores appear making the concrete porous. Finally, from the 28th to the 90th day, a drop in porosity is observed. Indeed, this drop in porosity could be explained by the development of the pozzolanic reaction which creates secondary hydrates over time and which helps to reduce the pores in the concrete [15].

3.2.2. Mechanical Characteristics

The results of compressive, splitting and bending strength are shown in **Figures 5-7**, respectively.

In general, the observation of **Figure 5** shows that the strength of concrete with ash is higher than the control concrete from the 7th to the 90th day. It goes from 19.7 to 26.5 MPa for the control concrete and from 30.2 to 30 MPa for the concrete with ash. Adding ash to concrete increases the kinetics of cement hydration [16]. Indeed, the cement uses the silica contained in the ash to accelerate the formation of hydrates. Thus, at a young age between 7 and 14 days a strong increase in resistance is observed. It goes from 30.2 to 36.2 MPa. On the other hand, between 14 and 90 days of maturity, a progressive reduction in this resistance is visible, ranging from 36.2 to 30 MPa. This can be explained by the fact that when mixing the different raw materials, part of the mixing water was absorbed by the ash. Thus, during the cement hydration process this water is reused, causing the appearance of micropores in the concrete. Also, the presence of water absorbed by the ash could promote the formation of ettringite which helps reduce resistance. This observation was made by [16], who showed during their work that the formation of ettringite leads to a decrease in the compressive strength of concrete. However, the minimum recommended strength for load-bearing concrete in the building is 25 MPa at 28 days. At this same maturation period the ash concrete is at 32.07 MPa. This performance of ash concretes compared to control concrete could also be explained by pozzolanic activity of the ash from the palm nut shells in the concrete.

Figure 6 shows a progressive increase in the flexural strength by splitting of the control concrete from the 7th to the 90th day of maturity. This implies that the hydration of the cement leads to a multiplication of hydrates which

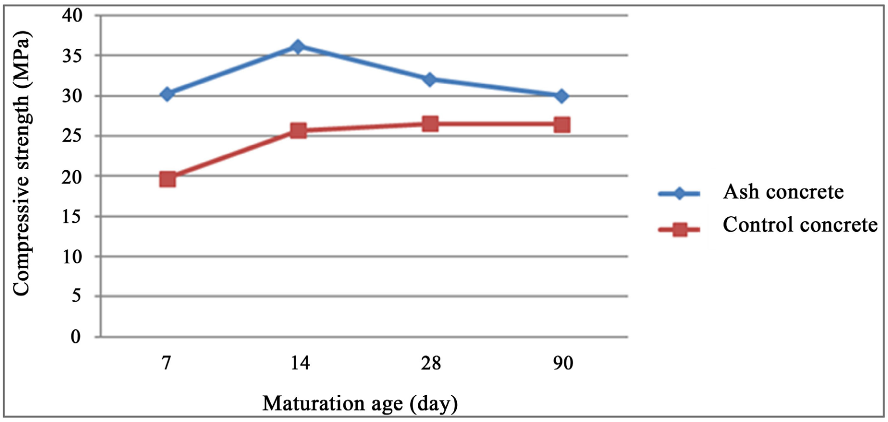

Figure 5. Compressive strength according to the age of maturation.

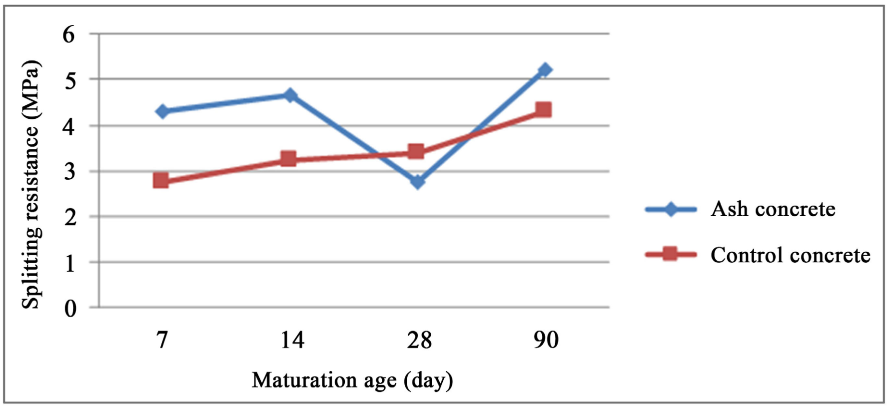

Figure 6. Splitting resistance according to the age of maturation.

promotes the resistance of the test pieces. On the other hand, the evolution of the resistance of ash concrete has three phases: The first phase, from the 7th to the 14th day, shows a slight increase in resistance. This can be explained by the onset of hydrate formation. The second phase from the 14th to the 28th day indicates a sudden decrease in this resistance, it goes from 4.65 to 2.76 MPa. This drop in mechanical performance is reflected in the formation of micropores during the hydration of the cement. This is because the water adsorbed by the ash is continually used by the cement to hydrate, causing voids inside the concrete. Finally, from the 28th to the 90th day, the resistance of the ash concretes increases remarkably. It goes from 2.76 to 5.23 MPa. This could be explained by an increase in hydrates or pozzolanic activity which reduces micropores during the cement hydration process and therefore improves the strength of the concrete.

Analysis of the evolution of the flexural strength of the different specimens shows that the flexural strength of the control concrete gradually increases until the 90th day of maturity. It goes from 0.58 to 0.64 MPa and this could correspond to the cement hydration phase which leads to the multiplication of microcrystallines, thus improving the mechanical performance of concrete. In addition, the strength of the ash concrete decreases from the 7th to the 14th day, it drops from 1.01 to 0.76 MPa. This shows that during the cement hydration process, micropores appear in the concrete and weaken its strength. However, this resistance increases remarkably from the 14th to the 90th day of maturity, going from 0.76 to 1.01 MPa. In fact, the hydration of the cement leads to the multiplication of hydrates and this implies a reduction in voids making the concrete denser and therefore more resistant.

4. Conclusion

At the end of this study, the results obtained confirm that a reduction in workability is observed with the addition of palm nut ash. In terms of physical properties, there is a variation in density and porosity. In terms of density, an increase is visible from 7 to 14 days, followed by a decrease from 14 to 28 days and again an increase from 28 to 90 days. As for the porosity an increase from 7 to 28 days and from 28 to 90 days a considerable decrease. In addition, the mechanical properties of ash concretes are generally superior to that of control concretes. Also, this performance of ash concretes is greater than the minimum values of 25 MPa (compression) and 2.6 MPa (splitting) at 28 days used by design offices in Côte d'Ivoire in the design assumptions for structures in reinforced concrete. Thus, the ash from palm nut shells (CCNP) has active elements allowing pozzolanic activity improving the physico-mechanical properties of concrete.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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