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Cocoa Pod Husk Ash as Partial Replacement of Cement in Concrete Production

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Abstract

The need for housing and other works, which require the use of cement, is rising due to rapid population increase. This study determines the suitability of cocoa pod husk ash (CPHA) for the partial replacement of cement in concrete production. The results showed that 6% replacement produced medium workability. Also, 12% and 18% replacements produced compressive strengths within the targeted design strength of $20 - 25\ Nmm^{-2}$. Again, 6% CPHA replacement recorded a tensile strength of 4.02 N/mm^2. Thus, the study showed some promise for the use of CPHA to partially replace cement in concrete production in some developing countries.

Keywords: Concrete; Cement replacement; Cocoa Ash; Concrete workability; Compressive strength.

1.0 Introduction

The cost of cement used in concrete works in developing countries such as Ghana is on the increase and barely affordable, yet the need for housing and other construction works that require the use of cement keeps increasing exponentially due to rapid population rise and urbanisation. Consequently, many researchers have advocated for the use alternative binding materials to replace or partially replace cement in construction works, particularly in concrete production, as concrete is one of the major construction material worldwide (El-Dieb and Kanaan, 2018; Cohen, Peled and Bar-Nes, 2019). This could reduce the cost of construction and make low-cost buildings affordable in many rural and urban areas in developing countries, which depend on cement as the only binding material in construction works.

Accordingly, the interest of the construction community in using waste or recycled materials in concrete production is increasing because of the emphasis placed on sustainable construction (Yin *et al.*, 2018; Bamgbade *et al.*, 2019). Improper disposal of waste into the environment directly results in the damage of natural climatic conditions, thus, the use of waste materials in building construction is of utmost importance in mitigating climate change (Bell *et al.*, 2018). In Ghana, there are many districts where cocoa is grown. Cocoa is a seasonal crop, which constitutes the main and only stream of income for most farmers in southern Ghana. When cocoa is harvested, the pod husk is thrown away as a waste because many people do not know its economic benefit. Heaps of cocoa pod husk wastes are usually seen in most cocoa-growing communities in Ghana and the management of this waste is a challenge for many rural communities, as the waste is mostly burnt and the resulting ash blown away by the wind. Notwithstanding this, Onyelowe (2016) indicates that CPHA can be used as a stabilizer for weak lateritic soils in road construction and as such, should be seen as a resource and not waste which will increase Ghana's environmental burdens.

This study aims to determine the suitability of CPHA for use in partial replacement of cement in concrete production for low-cost buildings in developing countries. The study focuses on ascertaining the optimum replacement level of OPC with CPHA that will still give the required compressive strength as well as compare the setting times of OPC paste with OPC - CPHA pastes at various replacement levels. The significant characteristics of cementitious materials is the pozzolanic activity associated with the increase in the strength as well as the economic savings made in replacing high volumes of more costly cement with typically less cost per volume of a pozzolan (Sumesh *et al.*, 2019).

Traditionally, concrete consists of the dispersed phase of aggregates (ranging from maximum size coarse aggregates down to the fine sand particles) embedded in the matrix of cement paste: this is a Portland cement concrete with four constituents (Portland cement, water, stone and sand). These basic components remain in current concrete but other constituents are now often added to modify its fresh and hardened properties (Marchon *et al.*, 2018). Similarly, Ramkumar *et al.*, (2020) argue that the constituents of modern concrete have increased from the basic four (Portland cement, water, stone, and sand) to the addition of chemical and mineral admixtures.

The pozzolanic material must be finely for the particle size to be able to have an inert micro-filler effect with the cement to improve the product design and reduce the material and energy consumption. However, natural filler, in comparison with mineral filler offers the following benefits: strong and rigid, lightweight, environmentally friendly, economical, renewable and abundant resource (Hao *et al.*, 2020). Nevertheless, Balla *et al.* (2019) observe that degradation by moisture, poor surface adhesion to hydrophobic polymers, non-uniform filler sizes, not suitable for high-temperature application among others are some of the disadvantages of natural fillers. The increase of a pozzolanic material help increases the rate of hydration with cement, thereby shortening setting time, speed up the strength gain and permeability reduction (Li *et al.*, 2020).

Therefore, the partial replacement of cement with CPHA in concrete in this study is focused on the workability of the concrete, compressive strength of the concrete, and split tensile strength of concrete. Workability of the concrete is about the ease of placing and compacting concrete without any segregation (Aslani *et al.*, 2018). Thus, workability of concrete can be classified into three types: unworkable concrete (concrete with a very little amount of water), medium workable concrete (concrete relatively easy to mix, transport, placed and compacted without segregation), and highly workable concrete (concrete very easy to mix, transport, placed and compact) (Aslani *et al.*, 2018; Bamigboye *et al.*, 2020). Similarly, the compressive strength of concrete helps in quantifying the ability of concrete to resists compressive stresses and the split tensile strength of concrete is an important property of concrete, as structural loads make concrete vulnerable to tensile cracking (Feng *et al.*, 2018; Shi *et al.*, 2020).

2.0 Materials and Methods

The study adopted a laboratory-based experimental approach to determine the suitability of CPHA to partially replace cement in concrete production. The materials used for the study were OPC obtained from the Ghana Cement factory (GHACEM), cocoa port husks obtained from Cocoa Research Institute of Ghana, quarried and crushed granite stones of nominal size of 12.5 mm and 19mm with specific gravity 2.676 and 2.685 respectively, sand with specific gravity 2.590, and portable water. The cocoa pod husks were burnt in their fresh state and allowed to cool for three days after burning (uncontrolled air burning). Burning in the fresh state was chosen over burning in the dried state because earlier trials in both states indicated that fresh burning gave comparatively less powdery ash as the inherent moisture yielded more plastic ash (Aberilla, Gallego-Schmid and

Azapagic, 2019). Sieve size of 0.150 mm was used to sieve the ash to obtain fine ash, as the strength contribution of additives to cement is known to increase with fineness (Youssf, Mills and Hassanli, 2016). The 0.150 mm sieve was selected as the smallest most practicable sieve since sieving with smaller size was not possible due to clogging on the sieve.

The cement component of the concrete was subsequently partially replaced with CPHA as an additive. The percentage of the CPHA used in each mix was deducted from the quantity of the cement. The CPHA was added in 6%, 12% and 18% respectively of cement by use of a co-efficient generated from the bulk densities of cement and the CPHA. These percentages were based on the sand equivalent test. Two different W/C of 0.46 and 0.56 were used to assess the effect of varying W/C on the concrete strengths according to BS 5400 and the 1996 Ghana Highway Authority Standard Methods of Test for Soils and Gravels Used in Pavement Works.

Slump test was conducted on each freshly mixed concrete to assess the workability of each mix. A total of 54 Concrete Cubes of size $150\,mm\ x\ 150\,mm\ x\ 150\,mm$ were cast using varying OPC - CPHA Ratio of 100:00, 94:06, 88:12, 82:18 respectively, with 9 cubes per percentage replacement with each mix type for both the control and the partially replaced concrete types. The cubes were cured and crushed after 7, 14 and 28 days respectively to determine the compressive strength. The tensile splitting test was also conducted on cubes from each mix after 28 days of curing. Table 1 below shows the weight of moulded cubes with both W/C ratios.

Table 1: Weight of moulded cubes

W/C	CPHA / Cured Days	0% (Kg)	6% (Kg)	12% (Kg)	18% (Kg)
0.46	7	8.27	7.95	7.91	7.88
	14	8.26	8.21	8.01	7,88
	28	8.27	8.10	7.95	7.9
0.56	7	8.11	7.92	7.88	7.80
	14	8.21	8.16	8.12	8.07
	28	8.18	8.05	8.04	7.91

3.0 Results and Discussion

3.1 Workability of the Concrete Mixtures

The workability of concrete is the ease with which concrete flows and is a direct indication of concrete mixture quality (Lavado *et al.*, 2020). It is very important in concrete production because when workability is low, it is difficult to work with and makes the concrete to set faster, however, when the workability of concrete is high, concrete becomes watery and leads to a low strength (González-Taboada *et al.*, 2017; Xuan, Poon and Zheng, 2018). Figure 3.1 below shows the slump test results of concrete mixed and partially replaced with CPHA at 0%, 6%, 12% and 18% for the W/C of 0.46 mm and 0.56 mm.

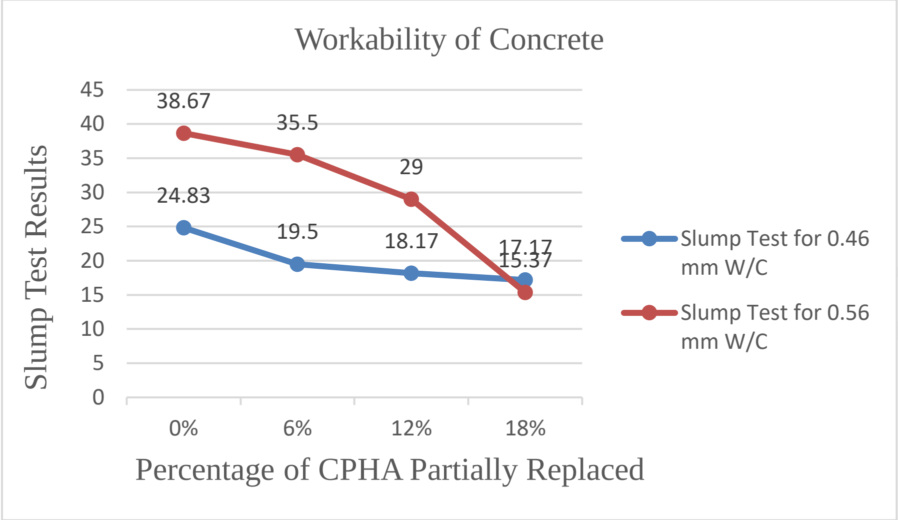

Figure 3.1: Workability of Concrete - Cement Partial Replaced with CPHA

The slump test for all the percentages, as indicated in Figure 3.1, produced a low slump, as all slump values were below 50 *mm*; which is an indication that the concrete had less water and will be difficult to work with. Notwithstanding this, the 6% replacement under both 0.46 and 0.56 w/c produced the highest slumps of 19.50 *mm* and 35.5 *mm* for the 0.46 *mm* and 0.56 *mm* W/C respectively, whereas, the 18% replacement with 0.46 *mm* and 0.56 *mm* W/C produced the lowest slumps of 15.37 *mm* and 17.17 *mm* respectively. Thus, the results indicated the workability of concrete decreased when the CPHA partial replacement with cement was increased. The lower the workability of concrete, the more honeycomb it creates in cubes, and the more the honeycomb the lesser the strength of concrete (Aslani and Gedeon, 2019).

3.2 Compressive Strength of the Concrete Mixtures

The compressive strength of any material is defined as the resistance to failure under the action of compressive force (González-López *et al.*, 2018; Dastgerdi *et al.*, 2019). Thus, the compressive strength of concrete is an important parameter, which gives an idea about all the characteristics of concrete. For this study, the compressive strength of concrete cubes of 0%, 6%, 12%, and 18% of cement partially replaced with CPHA was tested.

Figures 3.2 and 3.3 illustrate the average compressive strengths obtained from the cubes tested in three crushing days (7, 14 and 28 cured days) with 0.46 mm and 0.56 mm W/C respectively.

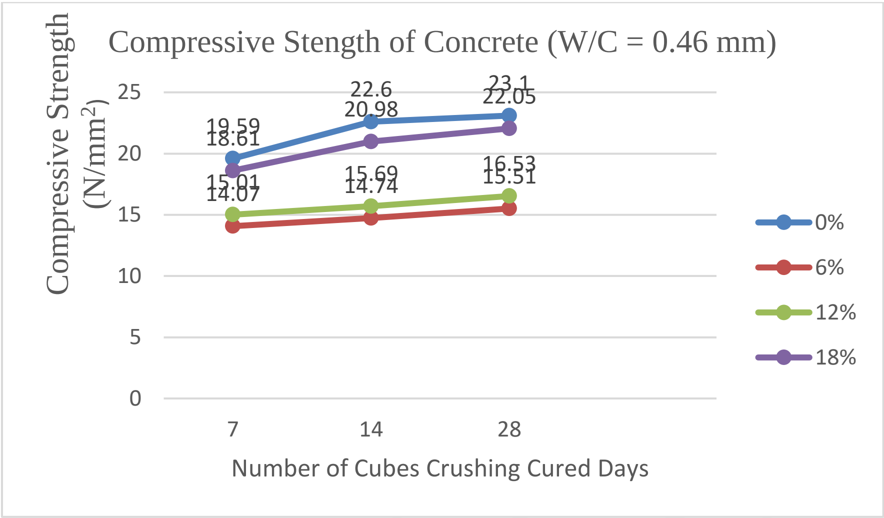

Figure 3.2: Compressive strengths of Concrete – W/C = 0.46 mm

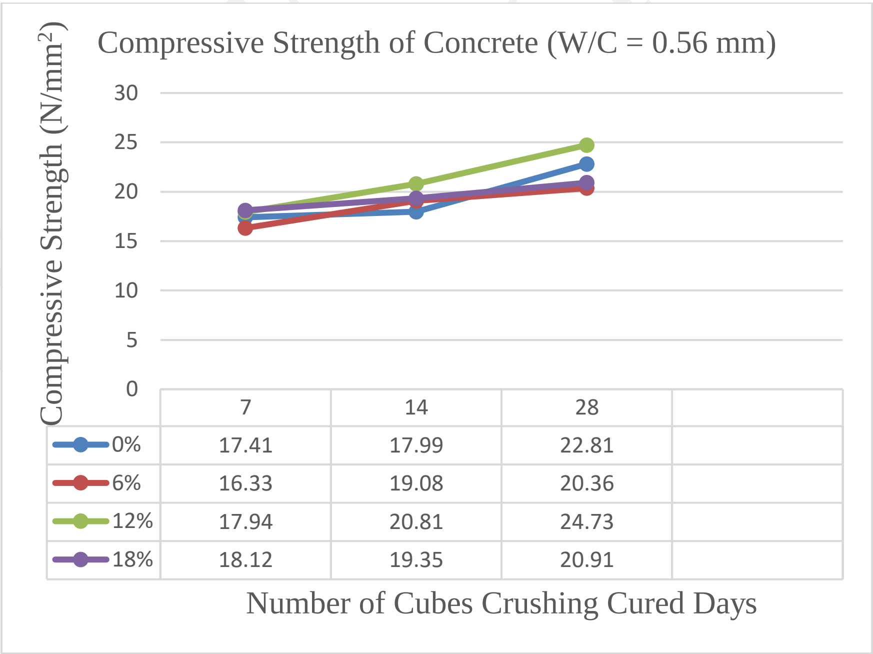

Figure 3.3: Compressive strengths of Concrete – W/C = 0.56 mm

As shown in Figure 3.3, 12% replacement with W/C of 0.56 mm produced the highest strength of 24.73 N/mm^2 after compression with fewer honeycombs as compared to the other mixes. On the other hand, for the 0.46 mm W/C as indicated in Figure 3.2, aside, the 0% cement replacement, 18% replacement produced the highest strength of 22.05 N/mm^2. Both strengths were within the targeted design strength of $20 - 25\ Nmm^{-2}$.

3.3 Split Tensile Strength of Concrete

Tensile strength is an important property of concrete because concrete structures are highly vulnerable to tensile cracking due to various kinds of effects and applied loads (Jin *et al.*, 2019). Figure 3.4 indicates the variations in split tensile strength as a function of the CPHA weight in percentages.

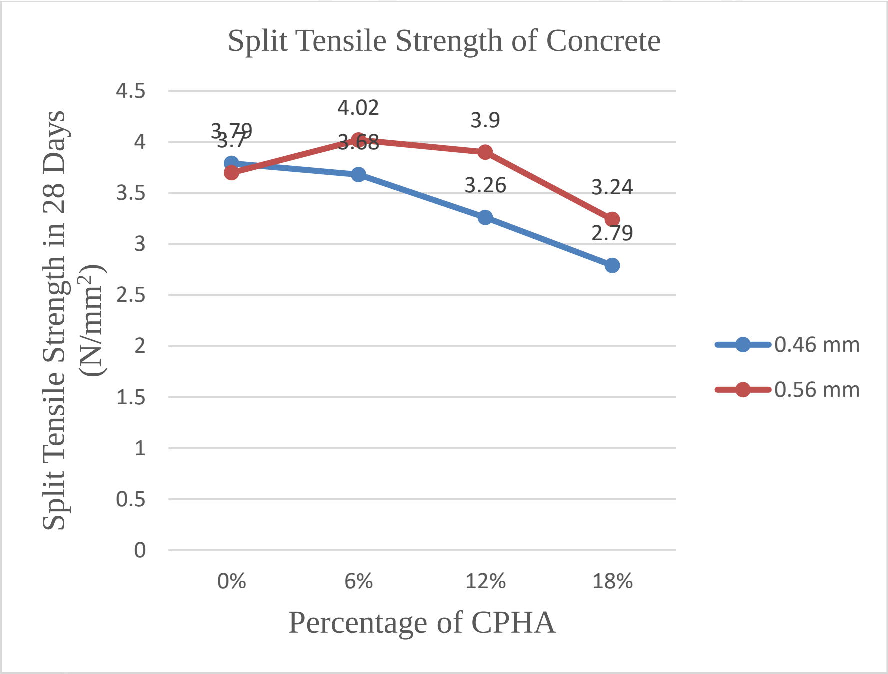

Figure 3.4: Splitting Tensile strength of Concrete in 28 cured days

There was a reduction in the tensile strength with W/C of 0.46, as CPHA volume increases. This can be attributed to the chemical reaction at the interface between the filler particles and the matrix (sand, cement and aggregate) which may be weak to transfer the tensile stress. However, the 6% CPHA replacement under both 0.46 and 0.56 W/C ratio recorded the highest strengths of 3.58 N/mm^2 and 4.02 N/mm^2 respectively. This is an indication that CPHA can be used in concrete works that demand higher tensile strength.

4.0 Conclusion

The study showed some promise for the use of CPHA to partially replace cement in concrete production. The 6% replacement under 0.56 mm W/C produced the highest slump of 35.5 mm, which is a medium slump and thus, indicates medium workability. Similarly, 12% replacement with W/C of 0.56 mm produced the highest compressive strength of 24.73 N/mm^2 and 18% replacement with 0.46 mm W/C produced 22.05 N/mm^2 strength, which are both within the targeted design strength of $20 - 25\ Nmm^{-2}$ for low-cost buildings in some developing countries. In addition, the 6% CPHA replacement under both 0.46 and 0.56 W/C ratio recorded the highest tensile strengths of 3.58 N/mm^2 and 4.02 N/mm^2 respectively. The study, therefore, concludes that CPHA can be used to partially replace OPC in the production of concrete for low-cost buildings in some developing countries.

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Competing Interests

The author declare no competing financial interests.

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