

Research Article

Maximizing the Sustainability of Cement Utilization in Building Projects through the Use of Greener Materials

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Greener technologies and sustainable developments are currently among the main tools used by many industries in shaping the world for a better future. The construction industry that is known to have numerous negative impact on sustainability is now wide awake on sustainable measures which can aid in reducing its negative impact. In this work, green cement was produced from pyroprocessed clay (PC) at 800°C and mixed together with Portland cement. This paper presents both laboratory tests and some field applications of green cement application. Laboratory tests performed included setting times, compressive strength, and shrinkage. Field applications of the green cement are shown. Results from the work showed that well-proportioned greener cement gained strengths between 11% and 30% more than Portland cement at standard curing period of 3, 7, 14, and 28 days. However, in real statistical terms, there was no difference between Portland cement and green cement strength performance. Shrinkage from both total and autogenous tests also showed insignificant differences between the two cements. The study recommends the use of green cements with pozzolanic origin than only Portland cement as a way to maximize sustainability in building projects.

1. Introduction

The path to sustainability provides three important components, namely, environment, economy, and society which are kept healthy and balanced both now and in the future. These three components have been termed as the triple bottom line (TBL) and projects that impact negatively on any of the three components threaten sustainability [1]. The term sustainability has a plethora of definitions; however, almost all the definitions provided by researchers have commonalities which are synonymous with the term “green.” Green materials have the characteristics of less energy and resources and high performance ability [2]. It has been pointed out that the greenest project and products are not entirely green themselves but are used to minimize impact on the environment as well as the economy and society. The terms sustainability and green technologies have been well put together under the definition of sustainability provided

by the Brundtland report² in 1987 [3]. The report defines sustainability as developments that meet the needs of the current generation without compromising the ability of the future generation to meet their own needs [3]. Currently, the threats on the components of sustainability are driving worldwide focus on sustainable development.

The worldwide construction industry is a major threat to sustainable development. Modern construction without the use of cement is virtually impossible. The production of cement-based materials, that is concrete and mortar, uses incredibly large amounts of cement. Aside, water concrete is known to be the second most widely used material in the world [4]. The cement and concrete industry is very vital and a dynamic sector upon which many national economies hinge on. Despite the numerous benefits of the cement and the concrete industry, the cement production and consumption sectors face many challenges that threaten sustainability. Cement is fundamentally an energy intensive material and moreover

their production uses large amounts of nonrenewable materials. Generally, about 4.882 MJ is spent in producing tonnes of cement [5]. Furthermore, the cement industry generates between 5% and 10% of the global harmful anthropogenic gases that impact negatively the atmosphere [6]. With the world production of cement estimated to reach 5 billion tonnes by 2030 [7], there seems to be an alarming situation in the future. Nowadays, cement industries and buildings professionals are advocating for the use of industrial by-products and friendly environmental materials that could mitigate the negative impacts that threaten sustainable development.

The cement industry in most developing countries such as Ghana depends solely on imported Portland cement for almost every infrastructural project. The trend of cement consumption over the years in Ghana has been increasing progressively and it has been estimated to reach over six million tonnes by 2020 from the current annual consumption of four million tonnes. Due to cost variation as a result of cement clinker importation, unstable cement price often persists in these countries. For so many years in Ghana, there is always an annual increase in cement prices. For instance, the average price in large towns was GhC15.00 (\$4.00) in 2009, GhC23.00 (\$6.00) in 2013, and GhC30.00 (\$9.00) currently. The consequence of this results in high cost of building projects, which indeed affects rental cost depriving most people especially urban dwellers from acquiring decent accommodation. Meanwhile, many people, almost half of the population in developing countries, live on less than \$1.00 a day, which consequently affects ones purchasing power.

The rise in unpleasant slum structures around most of the urban cities in Western African nations including Ghana could either be a direct or indirect effect of the cost of cement in most Western African countries. In nations where decent accommodation is virtually far-fetched for the ordinary person, poor environmental conditions are important issues that impact negatively the pillars of sustainable development. A major question is that in the absence of cement production plants, could there be economic relief with a conscious reliance on greener products in Ghana which may be available to the construction industry?

Greener materials available in Ghana could be used as novel materials since it could substantially reduce the cost spent on importing cement ingredients and provide reduction in cement cost. Literature has provided a lot of information on materials used in the cement industry that are termed as greener or sustainable materials. Such materials include industrial by-products such as fly ash, silica fume, and slag. Other natural materials and calcined materials such as calcined clay, shales, and metakaolin also used in the cement as mineral admixture fall under the category of greener materials [8]. All these materials are used because of their less embodied energy as compared to Portland cement. It is reported that less than half of the energy used to produce cement (approximately 2.1 MJ) is needed for processing greener materials. Aside embodied energy, these greener materials have been reported very well in literature as materials that improve sustainability of concrete structures [9]. It has been reported that between 20% and 30% of cement replacement with any of the mentioned greener materials

TABLE 1: Physical and chemical properties of Portland cement and pyroprocessed clay (PC).

Property	ASTM type 1	PC
Physical		
Fineness (m ² /kg)	401.7	410.0
Specific gravity	3.13	2.40
Chemical		
SiO ₂ (%)	20.49	67.40
Al ₂ O ₃ (%)	4.26	14.70
Fe ₂ O ₃	3.14	7.83
CaO (%)	63.48	2.19
MgO (%)	2.11	1.67
SO ₃ (%)	2.9	0.15
Na ₂ O + K ₂ O (%)	0.49	1.21
LOI (%)	2.2	4.01

is adequate to achieve better performance of cement-based products, that is, concrete and mortar [10, 11]. The use of processed clay was arrived at because the Ghanaian land is rich with clay of varying compositions estimated to be over 1500 million tonnes [12]. Processing clay and utilizing it as a greener material for our building project could be a prudent way to reduce Portland cement use and probably reduce its cost. Researchers have shown that clay processed at a temperature between 600°C and 900°C is conducive to make clay minerals reactive with Portland cement [13]. In a way the use of processed clay could be a means of ensuring sustainability in the Ghanaian construction industry. This work seeks to give an overview of the performance of green materials (processed clay) use in cement and some successful projects that utilized blended cement and processed clay as greener cement and investigate any difference between them and Portland cement.

2. Material and Methods

2.1. Materials. The materials that were used for the work were ASTM type 1/11 Portland cement, pyroprocessed clay, natural silica sand, a super plasticizer of a polycarboxylate origin, Glenium 7500, and potable water. The cement was an Ash grove cement for Chanute, KS, United States. The clay material was obtained from Mankranso in the Ashanti region of Ghana. The sand used for the study was a graded silica sand that conformed to the ASTM C778. Table 1 presents the compositional properties of the Portland cement and the calcined clay.

2.2. Methods. The raw clay was ground into powder, put in a ceramic bowl (height = 0.15 m, diameter = 0.3 m), and placed in an electric furnace for pyroprocessing at a temperature of 800°C for a period of 2 hrs. After the 2 hrs, the furnace was shut down and the ceramic bowl and its content were allowed to cool for about 24 hrs inside the furnace. Powdered pyroprocessed clay was used to replace Portland cement at 30% by weight and the results were compared with the unblended cement mixture.

TABLE 2: Mortar mixture proportions for compressive strength determination.

Name	Cement (g)	Sand (g)	PC (g)	w/b	Ad (g)	Flow (%)
CON1	500	1375	0	0.485	0.000	107
PC1	350	1375	150	0.485	0.541	107

w/b: water-to-binder ratio; Ad/b: admixture-to-binder ratio.

TABLE 3: Mortar mixture proportions for shrinkage determination.

Name	Cement (g)	Sand (g)	PC (g)	w/b	Ad (g)	Flow (%)
CON2	650	1788	0	0.485	0.0	107
PC2	455	1788	195	0.485	0.9	107

The normal consistency and initial and final setting times were performed in accordance with ASTM C187. This standard prescribes the use of the Vicat apparatus. After obtaining the consistency for Portland cement, that of the cementitious binder was fixed through an iterative method using the water-to-cement ratio of the Portland cement system as a basis, further varying the dosage addition of the superplasticizer. Compressive strength tests were performed in accordance with ASTM C109. The flow of the mortar was adjusted with the help of the superplasticizer in accordance with ASTM C1437. Mortar cubes were cast in 2 metallic cubic moulds and covered under wet burlap and white plastic rubber for 24 hrs after the desired flow was achieved. Each batch of mortar mix produced six specimens. Demoulding of the mortar specimens was done after 24 hrs and cured in saturated lime water for 3, 7, 14, and 28 days. Table 2 presents the mortar mix proportions of control Portland cement and green cement (PC1).

The shrinkage test was performed in accordance with ASTM C596. Mortar specimens were prepared to achieve a flow of $110 \pm 5\%$. For the cement blended mortars, the desired flow was achieved with the aid of HRWR (Glenium 7500). Six mortar prisms were cast with each prism mould having the dimensions of 25 mm by 25 mm by 285 mm. The specimens were covered with a transparent plastic sheet and a moist burlap to prevent evaporation. After 24 hrs of moist curing, the specimens were demoulded and divided into two groups. A total of three specimens each were designated for total and autogenous shrinkage, respectively. Initial lengths of the specimens were taken after 24 hrs of curing with a length comparator in accordance with ASTM C490. Specimens designated for total shrinkage test were placed under curing water for 72 hrs after which their lengths were recorded whilst specimens designated for autogenous shrinkage were sealed with wax and exposed in an environmental chamber at 23°C and 50% relative humidity. The unsealed samples after lime water curing were also exposed to the conditions in the environmental chamber. Length measurements were recorded at 4, 7, 11, 18, and 25 days of exposure. Table 3 presents the mortar formulation for shrinkage determination.

Some selected projects that have used these greener cements were captured in this study. These included construction of factory warehouse, repair works of a Timber bridge, and a market, all in Kumasi (Figures 4 and 5). The

TABLE 4: Normal consistency and setting times of Portland and green cement.

Name	w/b	ad/b	Setting times	
			Initial	Final
CON3	0.305	0.0	175	215
PC3	0.305	0.6	275	309

results obtained from the laboratory work on the green cement aided in taking the decision to scale up green cement production. This was done by mixing ordinary Portland cement (42.5R) and milled pyroprocessed clay (PC) in a cylindrical mechanical mixer (height = 1.5 m, diameter = 1.7 m). The mix proportion was performed at 70% OPC and 30% PC on weight basis using a digital scale. The capacity of the mixer was able to produce 23 bags of green cement per batch with each bag weighing 50 kg. The green cement produced was used as the main binding agent for the selected field works in making concrete, mortar, and cement blocks. The application of green cement in the field was done in the same manner as using Portland cement.

3. Results and Discussions

3.1. Normal Consistency and Setting Times. Table 4 presents the results of the consistency and the setting times test of Portland cement (CON3) and green cement (PC3). From the table, PC3 required high content of the admixture (superplasticizer) to achieve the desired consistency compared to CON3. This could be attributed to the high surface area and porosity of pyroprocessed clay in the binder paste system confirming the studies of Ganesan et al. [14] and Sinthaworn and Nimityongskul [15].

Both initial and final setting times of the green cement (PC3) were delayed as compared to the Portland cement binder paste (CON3). The addition of the chemical admixture had no significant effect on the extent of the setting time delay. These results confirmed the studies of Brooks et al. [16] and Fu et al. [17] who mentioned that processed clay at temperature of 800°C behaves as pozzolans. Pozzolan materials usually have a slow nature of reaction with Portland cement.

3.2. Compressive Strength. Figure 1 shows the compressive strength of Portland and green cements. At all curing periods, the strength of the green cement performed better than the Portland cement. The 3-, 7-, 14-, and 28-day curing of the green cement attained 19%, 11%, 19%, and 30% strengths higher than the control, respectively. The results showed that the pyroprocessed clay material behaved as a filler at the early curing periods of 3 and 7 days, therefore creating nucleation sites for cement hydration, that is, calcium hydroxide release from solution [18]. The behavior of the material after 7 days also showed the pozzolanic effect of the processed clay. Pozzolan effect takes up lime to form secondary hydrated compounds including calcium aluminate and calcium silicate hydrates that enhance the strength properties of cement and a pozzolan system [19]. Table 5 provides a student *t*-test

TABLE 5: *t*-test on compressive strength of cements assuming unequal variances.

	CONT	PC1
Mean	35.68	39.10
Variance	40.38	44.54
Observations	4	4
Hypothesized Mean Difference	0	
df	6	
<i>t</i> Stat.	-0.74	
$P(T \leq t)$ one-tail	0.24	
<i>t</i> critical one-tail	1.94	
$P(T \leq t)$ two-tail	0.48	
<i>t</i> critical two-tail	2.45	

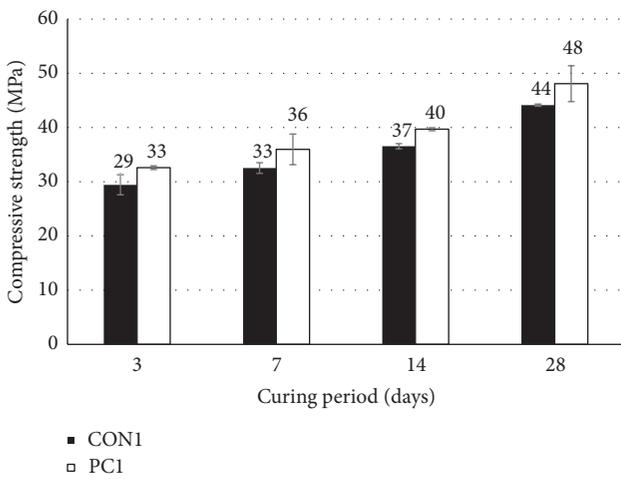


FIGURE 1: Compressive strength of Portland cement and green cement.

between the two cements which showed that the strength achieved between the two materials was statistically insignificant. This meant that there were no significant differences in terms of strength at the standard curing periods at 3, 7, 14, and 28 days. The use of green cements is very much suitable for any work in place of Portland cements.

3.3. *Shrinkage*. Figure 2 shows the shrinkage properties, both total shrinkage and autogenous shrinkage of the two cements. In general, total shrinkage occurs as a result of the loss of evaporable water between the cement-based material (concrete or mortar) and the environment at a specific relative humidity and temperature whereas autogenous shrinkage is caused by a reduction in pore relative humidity as a result of hydration products formation. From the figure, the total shrinkage of the mortars were higher than the autogenous shrinkage. The total shrinkage and the autogenous shrinkage between the two cements were not statistically different from each other from the results of the student *t*-test shown in Tables 6 and 7. It could therefore be inferred from here that, green cement could be an alternative cement to Portland

TABLE 6: *t*-test assuming unequal variance, total shrinkage.

	CON2	PC2
Mean	-0.03	-0.034
Variance	0.001	0.001
Observations	7	7
Hypothesized Mean Difference	0	
df	12	
<i>t</i> Stat.	0.007	
$P(T \leq t)$ one-tail	0.50	
<i>t</i> critical one-tail	1.78	
$P(T \leq t)$ two-tail	0.10	
<i>t</i> critical two-tail	2.18	

TABLE 7: *t*-test assuming unequal variance, autogenous shrinkage.

	CON2	PC2
Mean	0.0	-0.01
Variance	0.00	0.00
Observations	7	7
Hypothesized Mean Difference	0	
df	11	
<i>t</i> Stat.	-1.02	
$P(T \leq t)$ one-tail	0.17	
<i>t</i> critical one-tail	1.80	
$P(T \leq t)$ two-tail	0.33	
<i>t</i> critical two-tail	2.20	

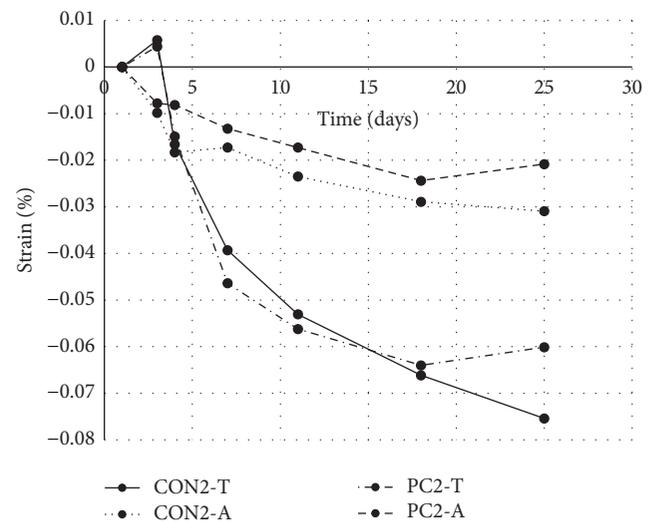


FIGURE 2: Total and autogenous shrinkage of Portland and green cement mortar prisms.

cement without any form of threat to its durability in terms of shrinkage.

3.4. *Field Applications with Green Cement*. The green cement material after successful laboratory investigations was applied for field works. Building products that used the green cement



FIGURE 3: Concrete works at CSIR-BRRI pozzolana factory involving beams, columns, block works, and mass concrete.



FIGURE 4: An unpainted office building of Electricity Corporation of Ghana (ECG) at Kentinkrono in Kumasi, Ghana.



FIGURE 5: Timber bridge that used green cement as concrete at Kaase in Kumasi, Ghana.

included sandcrete blocks, mass, and reinforce concretes. Figure 3 shows a construction work on-going that uses the green cement formulated from Portland cement and calcined clay pozzolan mixtures.

4. Conclusions and Recommendations

4.1. Conclusions. The study formulated a greener cement from the mixture between Portland cement and calcined clay pozzolan. Performance of the formulated green cement was based on setting times, strength, and shrinkage properties. The following conclusions were made from the results of the study.

- (1) The green cement had a delayed setting time than Portland cement.
- (2) The application of the chemical admixture is necessary to improve the flow properties of the green cement.
- (3) The strength performance of green cement was similar to Portland cement at all ages of curing.
- (4) Shrinkage properties between green and Portland cements were statistically insignificant.

- (5) The use of green cement could be an alternative binder material to Portland cement in order to maximize sustainability.

4.2. Recommendations. This work recommends a further study on the life cycle analysis between green cement and Portland cement. Moreover, the Ghanaian construction industry must strive to kick-start the development of a green rating system which will form part of the measures considered before awarding contracts. This will ensure that contractors make optimum use of local construction products in the Ghanaian market.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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