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Case study

# Analysis of co-fired clay and palm kernel shells as a cementitious material in Ghana

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ABSTRACT

The treatment of clay through a calcination process at high temperatures have been the usual and a common means of producing clay pozzolan as a supplementary cementitious material. However incorporating waste biomass as a component material in clay is very uncommon. This work analyzed the use of palm kernel shells as a component material in clay and were calcined at a high temperature of 800 °C. The palm kernel shells were used to replace clay at 10%, 20% and 30% by weight. Strength activity index prescribed by ASTM C311 was used to determine the maximum mixture proportion between calcined clay and palm kernel shells. The calcined clay and palm kernel shell mixtures that gave the maximum strength were subjected to an incremental replacement dosage of Portland cement between 10% and 40% by weight. Test results indicated that the maximum strength mixture proportion between clay and palm kernel shells was obtained at 20% replacement of clay. Moreover the maximum value that showed a better strength performance through the incremental replacement by the calcined material was also at 20% Portland cement replacement. The study recommended the use of palm kernel shells to a limit of 20% clay replacement. The is because at higher content of palm kernel shells in clay calcined at a high temperature, more unreactive crystalline phases are formed that inhibit reactivity of pozzolanic active phases. The use of 20 wt.% of palm kernel shells in clay to produce a supplementary cementitious material provides a sustainable means of waste disposal via construction application.


## 1. Introduction

The construction industry of today has well embraced the use of supplementary cementitious materials (SCMs) either in blended cement formation or added separately to concrete mix as a mineral admixture [12]. Using SCMs in concrete formulation is widely known to improve cement based products performance through the filler and pozzolanic effect. The filler effect leads to the generation of portlandite (CH) at the early hydration of cement whereas pozzolanic effect is the reaction that occurs between portlandite generated from cement and the silicate and aluminate phases in SCMs leading to the formation of secondary products such as calcium silicate, calcium aluminate and calcium aluminosilicate hydrates that

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enhance strength properties. Malhotra and Mehta [13] have reported that SCMs utilization provides a sustainable way of disposing waste-byproducts via concrete applications. The application of SCMs in concrete could replace between 20 and 30% of Portland cement and this leads to a significant reduction of harmful anthropogenic gases such as carbon dioxide, NOx and $SO_3$ produced from the production of cement [14]. It is stated in the work of Yang [15] that one most practical means of producing economical concrete is through the use of SCMs. The most widely used SCMs are industrial by-products which include slag from pig iron production, fly ash from coal combustion plants, and silica fume form ferrous producing plants [12]. Metakaolin produced from high purity kaolin clays at temperatures from 600 to 900 °C are recently introduced SCMs into the world of concrete formation [8,10].

Research findings on the use of supplementary cementitious materials such as calcined kaolinitic clays and heat treated palm kernel shells as possible materials as SCMs have been well documented [8,10,16,6,7]. For palm kernel shells, their ashes are usually obtained from boilers and electricity generation plants or industries [17,6]. These industries operate at higher temperatures ranging from 700 to 900 °C to generate waste palm fuel ashes. However, from extensive search of literature, research regarding co-fired clay and palm kernel shells is very insufficient.

In Ghana, palm kernel shells are obtained from palm oil producers. Until recently, palm kernel shells were perceived as waste material having problems with their disposal especially in palm oil producing areas. Currently, palm kernel shells are used as a source of fuel for many companies in various industrial productions. The waste products have now been identified as a useful energy source, however the waste generation from oil producers far outweighs its consumption by industries. There are huge tonnages of these palm kernel shell wastes dumped on sites around many of the palm oil producing areas in the country. There is the need for some form of attention on the disposal problems regarding the shells in palm oil producing areas of Ghana.

There has been an earlier investigation by Atiemo [1] that has shown that there exists a potential use of the material as a silica component and fuel source in clay pozzolana production. Silicate source from ashes of palm kernel shells is observed as an added advantage to the reactive pozzolanic phases in calcined clays. Production of clay pozzolana in Ghana by CSIR-Building and Road Research Institute consumes palm kernel shells. However, there is a major gap with regard to the optimum use of palm kernel shells in the calcination of clay. Reactive pozzolanic phases are very much dependent on the temperature of calcination. Most biomass materials attain more reactive pozzolanic phases at temperatures below 800 °C. In this work, the main objective was to investigate the contributions of palm kernel shells calcined at the clay calcination temperature of 800 °C. Already Bediako [9] has shown that the optimum calcination temperature for the clay used was at 800 °C. The main hypothesis for this work is this "Does the content of palm kernel shells incorporated in clay calcined at 800 °C affect the calcined material reactivity with Portland cement?"

## 2. Materials and methods

### 2.1. Materials

The materials that were used for the study included palm kernel shells, clay, Portland cement, sand, a chemical admixture and potable water. The palm kernel shells were obtained from the Konongo area in the Ashanti region of Ghana. The clay used for the study was obtained from Nyamebekyere, a small farming village in the Ashanti region of Ghana. Ordinary Portland cement used was obtained from Ash grove, Chenuate, Kansas-United States. A high range water reducer (HRWR) of polycarboxylate origin was used as a superplasticizer. The sand used conformed to ASTM C778 and the potable water used was from the taps of University of Missouri- Kansas City (UMKC). Table 1 shows the Portland cement properties obtained from Ash grove.

### 2.2. Methods

#### 2.2.1. Clay and palm kernel shells mixture proportioning and pellet formation

A sample of the clay obtained from the field was air dried for about 3 days and were ground into smaller unspecified sizes. The palm kernel shells were preconditioned by washing them in a barrel and allowing them to dry for 48 h. The dried palm kernel shells were then ground with a hammer mill into smaller particles. Figs. 1 and 2 shows sample grounded clay and palm kernel shells. The proportioning of the clay and palm kernel shells were done based on the bulk densities of the two materials. The percentage of the constituents was by weight. The bulk densities determined for clay and palm kernel shell were 1.32 and 0.9 respectively. Table 2 shows the mixture name and percentage contents of clay and palm kernel shells. After proportioning, small round pellets were formed. The pellets formation was performed in a rotating cylindrical bucket operated by a low speed motor. During rotation, potable water was sprayed on the mixture leading to the formation of pellets or nodules which were further dried in an open space.

#### 2.2.2. Calcination process, milling and sieving

Dried pellets were calcined in an electric furnace (Barnstead Thermolyne 6000 furnace) which was operated at 800 °C for a period of three hours. During the calcination process, pellets samples were put in a ceramic bowl and placed in the furnace. After the three-hour period, the furnace was switched off and the bowl and its contents allowed to cool down in the furnace