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Case study

Pozzolanic potentials and hydration behavior of ground waste clay brick obtained from clamp-firing technology

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ABSTRACT

In this study, waste clay bricks were collected, ground and used to replace Portland cement between 10 and 40 wt.%. The optimum cement replacement was obtained using compressive strength whereas the degree of hydration and heat evolution characteristics investigated using the thermogravimetric analyzer and the isothermal calorimeter respectively. The compressive strength results indicated that the optimum Portland cement replacement with Ground Waste Clay Bricks (GWCB) was at 30 wt.%. This was due to the high degree of pozzolanic reaction in the GWCB-Portland cement system. The heat of hydration of the GWCB-cement system was also lower than the control system. The use of GWCB is recommended as a suitable pozzolan and their use as a pozzolanic material could be a way to redirect waste generated in clamp-fired brick factories in West Africa.

1. Introduction

Today, the use pozzolanic materials play an important role in modern day concrete formation in terms of cost reduction and other technical benefits such as enhanced strength development, mitigation of thermal effect from cement and prevention of chemical attacks in concretes [1]. Pozzolans are defined as a siliceous or alumino-siliceous material, which possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties [2]. Well known pozzolanic materials highly utilized as construction materials include fly ash, silica fume, slag, metakaolin, calcined clays and ashes from some agricultural materials such as rice husk, sawdust, palm kernel shells, and sugarcane bagasse [3,4]. Pozzolanic materials have been used to replace cement between 20 and 30% by weight of cement [5–7]. Some authors have stated that there is the possibility to replace cement with a pozzolan beyond 30% by weight of cement [8]. It is known that the use of pozzolanic materials for concrete is among the possible ways to produce sustainable concretes [9].

Brick production in most Western African countries usually use the clamp-firing technology. The main raw material for brick production is clay. Fig. 1(A and B) shows clamp-fired clay bricks and waste generated after brick firing. With the clamp-firing method, green bricks are arranged and piled in a rectangular form, interspersed with palm kernel shells, which is a combustible material. At the bottom of the clamp, small open holes are created which serve as a container for firewood, generating fire for the baking or burning of the green bricks. Usually the temperature generated in a clamp during firing is not steady, ranging between 600 and 1200 °C. In Ghana, the Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research (CSIR) is among the major producers of bricks, producing approximately one million pieces of clay bricks annually. The problem with clamp-firing is that for every fired clamp, between 10% and 15% of the product become waste in a form of broken bricks and sometimes under-burnt. Usually these waste materials generated are used for filling potholes of roads whilst portions of it are generated as

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A B

Fig. 1. Clamp-fired bricks and waste generated after firing at CSIR-BRRI brick factory, Ghana.

stockpiles on arable lands. However, fired or baked clay materials are reactive to lime or calcium hydroxide present in cement which leads to the formation of secondary calcium silicates and aluminate hydrates as well as increased in gel-to-space ratio that enhance the strength and durability of concrete [7,10]. Baronio and Binda [11] states that fired clay materials at temperatures between 600 and 900 °C and in an appropriate powdered form are very reactive with cement. The reactivity of fired clay brick is due to the loss in crystallinity of the clay mineral which then converts into a meta-stable or amorphous nature.

One common pozzolanic material which is known in Ghana is calcined clay pozzolan produced from low grade kaolin clays [12]. Waste clay brick pozzolan may become an equivalent alternative to calcined clays. Converting ground waste clay brick into a pozzolanic material may possess less embodied energy than the treatment of virgin clay into a pozzolan. Using waste clay brick as a pozzolan could also lead to the production of sustainable concrete and mortar. For concrete and mortar sustainability, one could infer to obtaining optimum concrete strength with reduced cement content as well as the minimization of the heat generated in concrete. Excessive heat generation in concrete could cause thermal stresses in concrete which can lead to concrete cracking [13,14]. In this study, the main objective was to investigate the strength and hydration properties of Portland cement containing ground waste clay brick (GWCB). Mortar mixes formulated between mixtures of Portland cement and varying amount of waste ground brick were subjected to strength activity index and compressive strength determination. Strength activity tests have been used by several authors to study the pozzolanic effect of supplementary cementitious materials [10,15,16]. Thermogravimetric analysis and isothermal calorimetric studies were used to investigate the hydration and pozzolanic behavior of cement and GWCB-cement blend. Thermogravimetric analyzer is an instrument used to study the calcium hydroxide content within a cementitious system whereas the isothermal calorimeter is also good to study the heat evolution and the cumulative heat generation in a cementitious system. Both tools are appropriate means which have been used by many authors to understand the pozzolanicity of supplementary cementitious materials [17,18] The hydration properties were performed on the pastes. However, the paste formulated for the hydration studies was based on the mortar mix that gave the maximum strength.

2. Materials and methods

2.1. Materials

The materials that were used for the study were Portland cement, ground waste clay brick (GWCB), sand, water and a chemical admixture. The Portland cement was a type I/II cement that conformed to the ASTM C150 [19] obtained from Ashgrove, Chanaute, United States. The GWCB was obtained from the brick factory of CSIR-BRRI in Ghana. Table 1 shows the properties of the Portland cement and GWCB. The ASTM C618 [2] states that for a potential suitable pozzolan, the summation of the SiO_2, Al_2O_3 and Fe_2O_3 must not be less than 70%. The summation of the oxides per the ASTM description is 89.88% and therefore makes GWCB a potentially good pozzolanic material based on oxides composition. The cement and the GWCB Blaine fineness were 401.7 and 410.5m^2/kg

Table 1
Chemical composition of Portland cement and GWCB.

Oxide	PC	GWCB
SiO_2 (%)	20.49	67.35
Al_2O_3 (%)	4.26	14.7
Fe_2O_3 (%)	3.14	7.83
CaO (%)	63.48	2.19
MgO (%)	2.11	1.67
SO_3 (%)	2.9	0.15
Na_2O+K_2O (%)	0.49	1.21