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Effects of Chemical Admixture on Flow and Strength Properties of Calcined Clay Used as a Supplementary Cementitious Material

Mark Bediako[1*] and John Tristan Kevern[2]

[1]Council for Scientific and Industrial Research, Building and Road Research Institute, Kumasi, Ghana.
[2]Department of Civil and Mechanical Engineering, University of Missouri, Kansas City, United States.

Authors' contributions

This work was carried out in collaboration between both authors. Author MB performed the laboratory works and the manuscript writing under the guidance and supervision of the author JTK. Author JTK also managed the editing and technical flow of the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Well-proportioned cement-based materials create durable, long-lasting infrastructure which benefit society. However lack of knowledge, availability, and interest result in many West African, Asia, and South American countries using natural or modified pozzolans without chemical admixtures. This study investigated powdered waste clay brick as a pozzolanic supplementary cementitious material (SCM). The calcined clay material was used to replace cement by weight at 10%, 20%, 30% and 40%. Consistent flow was achieved using a polycarboxylate high range water reducing admixture (HRWR). The results indicate that the application of HRWR increased the flow of calcined clay and Portland cement mortar mixtures. The maximum strength obtained for mixtures between Portland cement and calcined clay mortars was 30% replacement of cement by the calcined clay product. The study showed that a well-proportioned mortar mixture could reduce Portland cement content and CO_2 significantly without compromising the strength and flow properties of the original mixture.

**Corresponding author: E-mail: b23mark@yahoo.com;*

Keywords: Calcined clay; cementitious materials; chemical admixture; high range water reducer; compressive strength.

1. INTRODUCTION

The cement industry around the world over the years has evolved from the use of pure cement to the use of cementitious blends for construction. Numerous studies have shown that supplementary cementitious materials (SCMs) can dilute the amount of clinker required for cement-based materials, which improves eco-efficiency by lowering carbon emission to the atmosphere, and improves of some technical performance of concrete such as strength and durability of the cement matrix [1,2]. SCMs commonly utilized in the construction industry include industrial by-products such as fly ash, silica fume, blast furnace slags. Natural pozzolans are also utilized which include calcined clays, shales, and kaolin clay [2]. Other studies sometimes refer to these materials as mineral admixtures [3,4]. SCM content ranges from 10%-70% by weight of cement replaced. Fly ashes and natural pozzolans are usually used to replace cement between 20% and 30%, whilst silica fume also replaces cement by approximately 10% by weight [5,6]. Slag is reported to replace part of cement to about 70% by weight [7].

The use of SCMs has influence on the water demand of paste, mortar, and concrete in achieving the desired workability. Fly ash usually demand less water and increases fluidity due to the spherical shape [8]. Almost all other SCMs normally show a higher water demand for the desired fluidity compared to the appropriate control [9]. The high water demand associated with the use of certain well known mineral admixtures makes it obligatory to increase the water-to- cement ratio of the matrix when chemical admixtures are not utilized to counter the higher water demand [10]. Erdogdu [11] has also indicated that an increase in water-to-cementitious (*w/c*) ratio causes strength to decrease in concretes. Relating *w/c* to porosity, Durekovic [10] showed that an increase in *w/c* increases the porosity and pore structure within cement paste, mortar, or concrete matrix. The porosity and pore structure of hardened cementitious materials are of vital importance for the performance of mortar and concrete [12]. A higher porous medium would have a higher possibility of promoting the movement of aggressive ions through concrete and mortar which reduces the durability. Minimizing water content or *w/c* to achieve the desired fluidity whilst improving the mechanical properties of concrete is of great necessity.

The concrete industry currently utilizes chemical admixtures, water reducing or super plasticizing agents (SP), to maintain or reduce water content in a cementitious matrix whilst maintaining constant rheology and often enhancing mechanical properties [1]. Durekovic [10] defines superplasticizers as water soluble, natural or artificial polymers sometimes used in the concrete industries as dispersing agents during hydration of Portland cement. The dispersing nature of most SPs prevents flocculation of cement particles which allows cement particles achieve more complete hydration. The previous generation of superplasticizers used in the concrete industry included lignosulphates, sulfonated melamine formaldehydes and sulphonated naphtalene formaldehyde condensates [10]. Current SPs and high-range water reducing (HRWR) admixtures are polycarboxylate (PC) and polycarboxylate ethers (PCE) [13]. Tkaczewska [13] analyzed the performance of three commonly used SPs, sulphonated naphthalene formaldehyde condensates, sulphonated melamine formaldehyde condensates and polycarboxylate based SPs and found that though all the SPs used in the study reduced the water demand and enhanced strength properties, polycarboxylate-based SPs gave the most water reduction, constant workability and an improved compressive strength. Burgos- Montos et al. [14] have explained the action of the conventional superplasticizers which include sulphonated melamine (SMF) and naphtaline (SNF) formaldehydes and that of the new generation SPs which includes polycarboxylates ethers (PCE) and polycarboxylate condensates (PC). The SMFs and SNFs disperses cement particles due to an electro stearic mechanism whereas PCEs and PCs form a stearic obstacle to any direct interparticle contact [15,16].

The performance of cementitious materials in the concrete industry has significantly improved due to the influence of SPs and HRWRs. These admixtures allow greater flexibility in SCM dosages and help counter slower strength gain, increased water demand, and allow improved durability [2,9,17]. Calcined clays are also known mineral admixtures which is currently gaining prominence in the SCM industry. The gain in prominence of calcined clay as suitable SCMs has become much stronger in many African and South American countries due to the high presence of clay minerals and lack of suitable geology for cement production. In much of the existing literature, calcined clays have been used as mineral additions without the use of SP admixtures, especially in many African countries [18-21]. In many of the studies, the early and late strength of calcined clay and cement mortars and concretes attained lower or similar strengths compared to the control mixtures [18,20]. Meanwhile some studies have shown that it is possible to achieve higher strength of cement and calcined clay mixtures than control mixtures [13,1]. In this study the primary objective was to investigate the effect that the chemical admixture, HRWR had on the workability and strength of cement and calcined clay mixtures. The specific calcined clay pozzolan was a locally-available crushed waste brick to Ghana.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for the study included ASTM C150 Portland cement which met both Type I and Type II categories, powdered waste clay bricks (PWCB), ASTM C778 graded silica sand, high-range water reducing admixture (HRWR), and potable water. The cement was Ashgrove from Chanute, Kansas, USA. The PWCB was obtained from Council for Scientific and Industrial Research-BRRI brick factory in Ashanti Region, Ghana. The polycarboxylate HRWR, Glenium 7500 was obtained from BASF- United States. Fig. 1 shows the compositional properties of the cement and calcined clay (PWCB).

2.2 Methods

The mortar mixtures were prepared in accordance with ASTM C109. The standard specifies a water-cement-ratio of 0.485 and sand-to-cement ratio of 2.75. The HRWR was used to control the flow in accordance with ASTM C1437. Fig. 1 shows the mortar flow test determination. With this test, a truncated cone was filled with mortar samples and place at the center of the flow table. The truncated cone was removed leaving the mortar sample which was dropped continuously for 25 times. The standard specifies a flow ranging from 105% to 115%. The flow indicates the workability of the sample. PWCB replaced cement at 10%, 20%, 30% and 40% by weight. Table 1 shows the mixture naming designations and percentage proportions of cement and PWCB. Table 2 also gives the mortar proportions by mass of each prepared mortar specimen. The mortar specimen were cast in a 50 mm, 3-gang cube molds. Nine mortar specimens were produced for each mixtures. After 24 hours of moist curing under plastic and wet burlap, the mortar samples were demolded and transferred into a lime saturated water bath. Compressive strength was determined on an average of three mortar samples cured for 3, 7, 14 and 28 days using ASTM C109.

Table 1. Physical and chemical properties of Portland cement and calcined clay powder

Property	Portland cement	PWCB
Physical		
Fineness (m^2/kg)	401.7	411
specific gravity	3.13	2.45
Chemical		
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	1.69
SO_3 (%)	2.9	0.15
Na_2O+K_2O (%)	0.49	1.21
LOI (%)	2.2	4.01

Table 2. Mixture proportions of cement and PWCB

Mix name	% Content	
	Cement	PWCB
CON	100	0
10B	90	10
20B	80	20
30B	70	30
40B	60	40

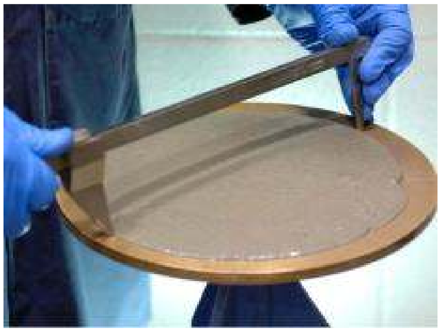

Fig. 1. Flow testing for mortar according to ASTM C1437

Table 3. Mortar mixture proportions, volume and flow

Mix	Mass (g)					Vol (cm3)	Flow (%)
	Cement	PWCB	Sand	Water	HRWR		
CON	740	0	2035	359	0.0	1376	107
10B	666	74	2035	359	1.0	1385	111
20B	592	148	2035	359	2.0	1393	110
30B	518	222	2035	359	4.0	1402	107
40B	444	296	2035	359	5.0	1410	108

3. RESULTS AND DISCUSSION

3.1 Flow of Mortar

Fig. 2 shows the relationship between PWCB and HRWR. All flows achieved were within the prescribed limits specified by the ASTM C1437 ranging from 105-115%. The figure indicates a polynomial relationship between the two variables. An increasing amount of the PWCB corresponded to an increase in the percentage of HRWR required to achieve the desired workability. This trend could be attributed to the high specific surface area of PWCB compared to Portland cement. This trend confirms the investigations of Hassan et al. [22] that stated that an increased volume fraction and surface area of binder would require a higher dosage of HRWR.

3.2 Compressive Strength

Fig. 3 shows the compressive strength results of Portland cement replaced with calcined clay between 10% and 40%. As expected, strength increased with curing age. The results also show that cement replaced with 30% calcined material obtained maximum strength at all stages of curing. This indicated that 30% cement replacement was enough to react with portlandite formed from cement hydration to form secondary hydrates and therefore improved the strength properties [23]. The performance of calcined clay material at 40% showed excess unreacted materials of the calcined materials in the matrix resulting in lower strength. On the other hand, 10% and 20% content of the material may not have been enough to consume all excess portlandite.

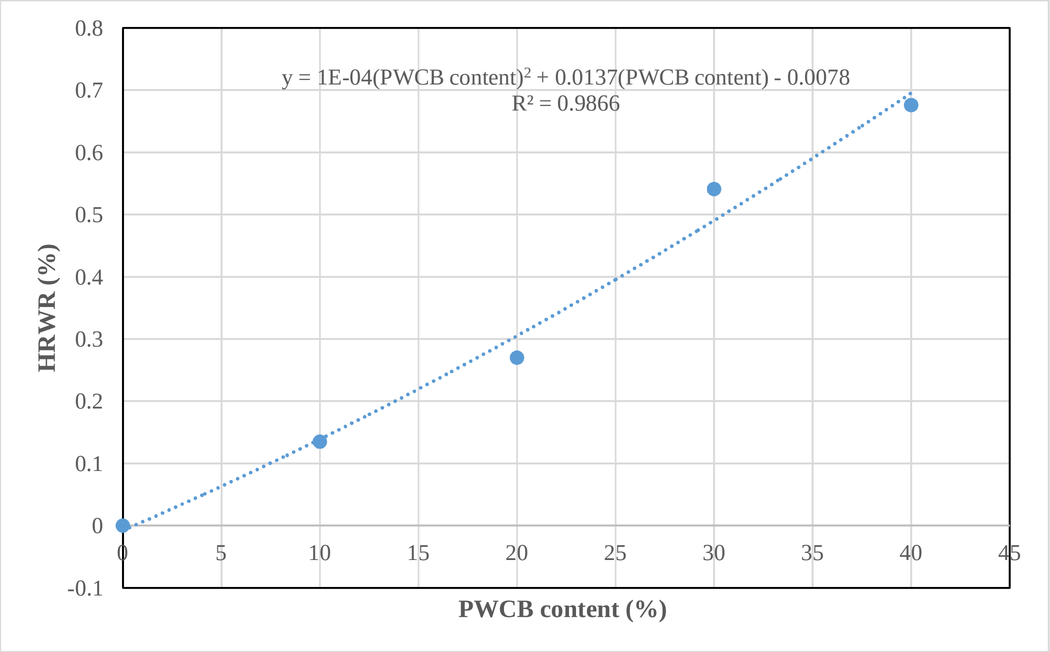

Fig. 2. The relationship between PWCB content and HRWR

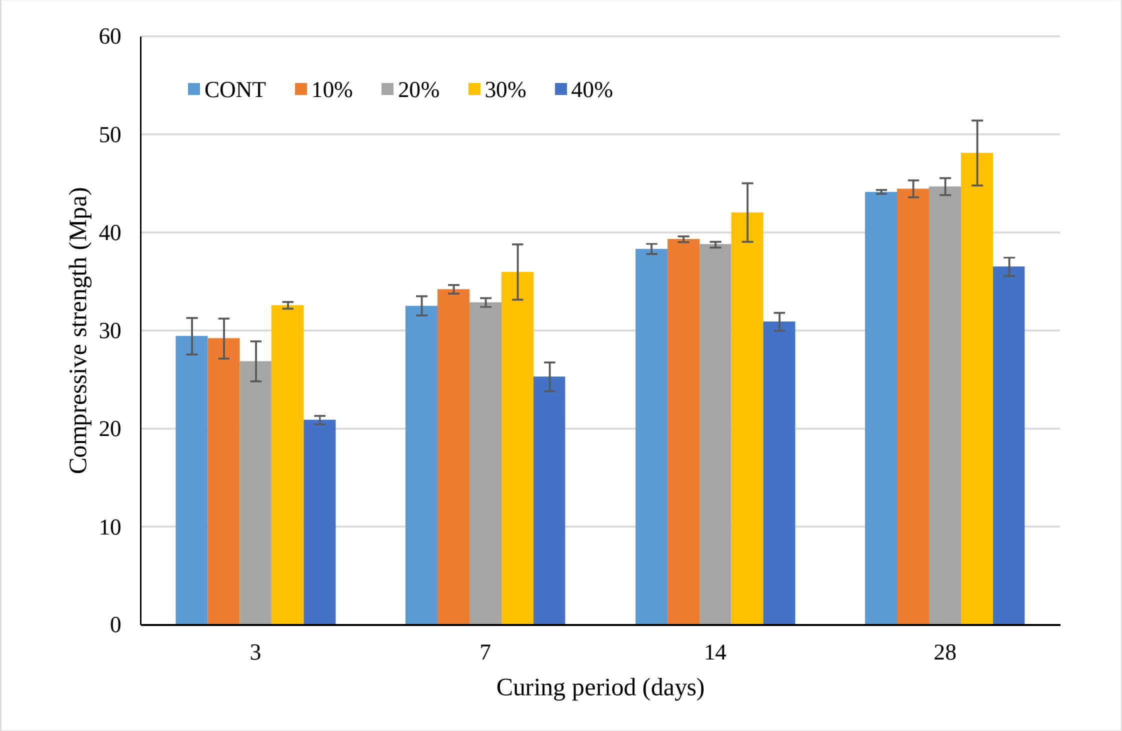

Fig. 3. Compressive strength of Portland cement and calcined clay (PWCB)

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The following conclusions are made from the study

1. The demand for chemical admixtures in the form of high range water reducer generally increased with increasing content of calcined clay material in the cement matrix.
2. The use of chemical admixtures helped to arrive at the suitable content needed to maximize strength of the cement and calcined clay pozzolan blend.
3. Beyond 30% replacement level of cement with calcined clay the strength decreased rapidly. At those levels the excess of calcined material was an inert filler. At the content beyond 30%, strength performance reduces.

4.2 Recommendations

Further studies are required to analyze the hydration and degree of pozzolanic reaction at 30% of PWCB used to replace Portland cement.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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