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Research paper

# Efficiency factors of burnt clay and cement kiln dust and their effects on properties of blended concrete

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ABSTRACT

This research examines the efficiency factors ($k$) of burnt clay (BC) and cement kiln dust (CKD) and their effect as a substitute for Portland cement (PC) on the properties of concrete. Different blends were tested under different points in time. X-ray diffraction (XRD), X-ray fluorescence (XRF) and scanning electron microscopy (SEM) techniques were used for determining mineralogical composition and characterizing of the material used. Results showed that, replacing PC with up to 20% CKD had a negligible effect on concrete strength and durability while addition of higher percentages of CKD and the presence of BC resulted in reduction of strength. The CKD-concrete blends resulted in higher $k$ and strength than the BC blends. The changes in $k$ values after the age of 28 days were negligible in both materials at all percentages of replacement. The alkali-silica reaction (ASR) tests showed that all specimens experienced changes in length. In general, these changes in specimens lengths tended to reduce with time. The initial surface absorption tests (ISAT) showed that blended concrete experienced a reduction in flow rate compared with the control mixture. The XRD, XRF and SEM analyses showed different concentrations of binders for the different concrete blends.

## 1. Introduction

The worldwide requirement for cement-based materials has increased drastically while different countries' environmental protection regulations have restricted the cement production process and made it more expensive. Therefore, supplementary cementing materials (SCM) have been widely used as partial replacement to Portland cement (PC) including industrial by-products like cement kiln dust (CKD), a fine powdery material generated as by product of cement manufacturing process, and natural pozzolanic materials like burnt clay (BC). These siliceous or aluminous materials, which are similar to raw materials used in manufacturing PC, exhibit cementitious and/or pozzolanic properties due to the physical and chemical properties.

Al Rawas et al. (1998) found that the main factors significantly affecting the quality of pozzolanic activity of BC were the chemical composition, calcination temperature, and duration of calcination. Hago et al. (2002) concluded that the best curing conditions for BC cement mixtures could be obtained by leaving them in the sun or open air without cover or addition of water; the longer the dry curing period the higher the strength of the mixtures. They recommended a minimum 21 days curing period. Al Rawas and Hago (2006) evaluated different types of BC produced in Oman. They found that Fanja and Al-Fulaij clays complied with the ASTM C618 standard for producing good pozzolans whereas Bahla clay fell below the minimum standard requirement. Ansah et al. (2014) studied BC, which was activated by mechanical means through roll milling and ball milling as well as chemically by the addition of 1–4% m/m sodium-sulfate ($Na_2SO_4$). Their compressive strength results showed that the activated pozzolana could be used to replace up to 40% PC and satisfy EN 197-1 and ASTM C595 requirements. Al-Chaar et al. (2013) found that BC pozzolan could be substituted fly ash (FA) in satisfaction of ASTM C618. They also found that BC was effective in controlling ASR and produced about 15% less heat of hydration than class F FA.

While CKD is used in many applications worldwide (Ismail and Belal, 2016; Loutou and Hajjaji, 2017; Miller and Azad, 2000; Moon et al., 2009; Ahmed et al., 2009; Taha et al., 2004; Yoobanpot et al., 2017; Yoon et al., 2010), most CKD produced in Oman is disposed of in landfills. The engineering, environmental, and economic benefits of using CKD as a PC replacement in concrete have been discussed by many researchers. Al-Jabri et al. (2006) found that the use of CKD in small quantities (e.g. 15%) had no effect on concrete strength. Taha et al. (2007) recommended using CKD in low-strength concrete. Maslehiddin et al. (2008) reported that using CKD to replace 10% of the PC in a cement mortar did not affect ASTM C150 requirements for PC and improved concrete's compressive strength. On the other hand, Najim et al. (2014) found a systematic decrease in strength and increase

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in porosity in mortar with the increase of CKD. Maslehddin et al. (2009) suggested that substituting CKD for cement should be limited to 5% in weight due to the increase in chloride content, which leads to corrosion of reinforcement.

## 2. Efficiency factor: definition and calculation

An efficiency factor (k) is defined as the part of SCM in pozzolanic concrete, which can be considered equivalent to PC as it has the same properties as concrete without SCM (k = 1 for PC). For comparing the relative performance of different SCMs in regard to PC, the practical concept of *k* and models of evaluation have been introduced by different researchers. Smith (1967) used compressive strength as a basis for estimation of the *k* value because it is a simple and consistent industrial test. The cementing efficiency *k* of FA is defined as a mass of FA which is equivalent to a mass kFA of cement in terms of strength development. The difference between the contribution of PC and FA to strength development is the *k* factor. The model is given in Eq. (1).

$$\frac{w}{c_m} = \frac{W}{c + kFA} \tag{1}$$

where; $\frac{w}{c_m}$ = effective water/cement ratio (w/c) with regard to its strength benched against a control mixture without FA, W = water content in kg/m$^3$, c = cement content in kg/m$^3$, $k$ = efficiency factor and FA content in kg/m$^3$. $k$ is calculated using two mixtures; one with known quantity of FA and the other without FA. Both mixtures should have similar compressive strength 28 days after casting. The water content (W) is varied to minimize variation in slump.

Hassablallah and Wenzel (1995) proposed a strength-based method to obtain the *k* for FA which was based on comparing the compressive strength of two concrete mixtures having the same workability. One contained only cement and the other had the same cement content as the first, but with FA added. The contribution of FA is the difference in compressive strength at 28 days between the control mixture ($f_c$) and the blended mixture ($f_b$). They defined the ratio of this difference as the strength of $f_c$ as a pozzolan efficiency factor (Eq. (2)). According to this method, positive *k* values indicate strength improvement while negative *k* values indicate strength loss.

$$k = \frac{f_b - f_c}{f_c} \tag{2}$$

Babu and Rao (1996) re-evaluated the results of earlier researches using FA to calculate the efficiency factor for this material, considering the relation between the compressive strength and w/c, age, and percentage of replacement. They stated that the overall efficiency factor *k* for a pozzolan may be assessed by the sum of two separate factors and called the first factor as general efficiency factor ($k_e$), which is constant for all percentages of replacement, and the second was considered a percentage efficiency factor ($k_p$),which varies with the replacement level as given in Eq. (3).

$$\left(\frac{w}{c_o}\right) = \left[\frac{W}{C + kf}\right] = \left[\frac{W}{C + k_e f + k_p f}\right] \tag{3}$$

where; $kf = k_e f + k_p f$, $w/c_o$ = the effective water/cement ratio, $w$ = the water content in kg/m$^3$, C = the content of cement in kg/m$^3$ f = the content of fly ash in kg/m$^3$, $k$ = the overall efficiency factor, $k_e$ = general efficiency factor and $k_p$ = the percentage efficiency factor. Overall *k* was assessed as a combination of the general efficiency factor ($k_e$) and the percentage efficiency factor ($k_p$). They concluded that the overall cementing efficiency *k* of FA cannot be adequately represented by a single value as reported by many investigators.

In other research, Babu and Kumar (2000) used the same method as proposed by Babu and Rao (1996) for estimating the efficiency factor of ground granulated blast furnace slag GGBS. They re-evaluated the results of earlier GGBS research to quantify the 28-day k, using GGBS replacement levels varying from 10 to 80%. They found that the overall *k* for GGBS is similar in values to previous findings with no GGBS.

Papadakis and Tsimas (2002) and Papadakis et al. (2002) developed another model for calculating *k* for different SCMs compared with PC. They used Eq. (4) to calculate the compressive strength of concrete without SCM and Eq. (5) for calculating the compressive strength of SCM concrete.

$$f_c = K\left[\left(\frac{1}{\frac{w}{c}}\right) - a\right] \tag{4}$$

$$f_c' = K\left[\left(\frac{1}{\frac{W}{C + kp}}\right) - a\right] \tag{5}$$

where; $f_c$ = the compressive strength for concrete without SCM, K = a parameter depending on the cement type, c = the cement content in kg/m$^3$, W = water content in kg/m$^3$, a = a parameter depending on the time and curing, $f_c^{'}$ = the compressive strength for concrete with SCM, $k$ = the efficiency factor and p = the SMC content in kg/m$^3$.

Rajamane et al. (2007) used the Bolomey formula (Eq. (6)) to predict compressive strength of concrete with SCM.

$$f_c' = \left[A*\left(\frac{1}{\frac{w}{c}}\right) + B\right] \tag{6}$$

where; A and B are constants dependent on age and cement type.

Pekmezci and Akyuz (2004) studied the effects of the optimum usage of natural pozzolan on concrete compressive strength and developed Eq. (7) for calculating the compressive strength and efficiency factor for Ferret.

$$f_c' = K_B\left[\left(\frac{c + kf}{w + V}\right) - K'\right] \tag{7}$$

where; $K_B$ = Bolomey coefficient, $K^{'}$ = a coefficient that was developed from experimental results, $V$ = the volume of voids and $w$ = the water content in kg/m$^3$, c = the cement content in kg/m$^3$ and $kf$ = Ferret efficiency factor.

Oner et al. (2005) used similar model to that of Pekmezci and Akyuz (2004) to calculate *k* and apply it to determine the optimum percentage of FA as replacement to PC that can give the strongest concrete. They found that the strength of the concrete increased with an increase in the amount of FA up to 40%, beyond which strength started to decrease with further addition of FA.

Although the works were related to materials that have been successfully used in construction for long time, no literature was found on research that was conducted to determine the efficiency of BC and CKD.

From the above discussion, it is clear that most of the researchers have used different SMCs and different models to calculate k. However, the main idea of evaluating the difference in strength due to presence of supplementary materials by calculating the cementing efficiency factors *k* was similar to the one initiated by Smith (1967).

In this research, the model proposed by Smith (1967) was adopted for calculating the efficiency factor *k* for CKD BC separately.