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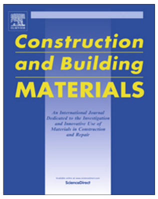

The influence of zeolite and powdered Bayburt stones on the water transport kinetics and mechanical properties of hydrated lime mortars

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HIGHLIGHTS

- The use of CL90 mortars with pozzolanic replacement materials is investigated.
- Two natural pozzolanic materials are investigated: zeolite and Bayburt stones.
- Water transport kinetics of CL90 mortars is improved for masonry construction.
- Dewatering has a significant effect on the mechanical properties of CL90 mortars.
- Mechanical properties of CL90 mortars are enhanced with pozzolanic materials.

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ABSTRACT

The purpose of this paper is an investigation of the possible role of zeolite and powdered Bayburt stones on the fresh and hardened properties of hydrated lime (CL90) mortars. Parameters studied in this paper form the main barriers to the use of hydrated lime in construction practice. Enhancement of these parameters is vital for mortar/substrate optimisation in masonry construction. The major concern of this paper therefore is the combination of wet mortar and brick substrate and most significantly the interaction between them at fresh and hardened states. The results show that transfer sorptivity and time to dewater hydrated lime mortars can be manipulated when zeolite and powdered Bayburt stones are used as replacement materials to the binder. Long setting time of CL90 mortars is decreased with the increasing replacement levels of both zeolite and powdered Bayburt stones. Experimental results also showed that the increasing replacement levels of zeolite and powdered Bayburt stones resulted in a dramatic increase in compressive strength and these results are also supported with the microstructural images. The ability to enhance water transport kinetics and mechanical properties of hydrated lime mortars with zeolite and powdered Bayburt stones should not be underestimated as this enables such materials to be used in construction practice more competently. These results have important practical consequences, not only in the initial adhesion of the mortar to the substrate but also in the strength of the set material and therefore the use of hydrated lime mortars may be encouraged if zeolite and Bayburt stones can improve the fresh and hardened state properties of these mortars.

1. Introduction

Lime based materials have been used in construction since ancient times [1]. When mixed with sand, lime was most commonly used to form external renders or mortar for brick or stone masonry. A range of lime types exists in construction commonly classed as being either hydraulic (setting and hardening by reaction with water) or non-hydraulic. The non-hydraulic lime is composed of calcium hydroxide ($Ca(OH)_2$) derived from relatively pure limestone ($CaCO_3$) that following calcining to form calcium oxide (CaO) and releasing CO_2, is then hydrated (slaked) to form the hydroxide. This type of lime is referred to chemically as hydrated lime and in [2] as “air lime” but frequently in construction simply as “lime”.

Most modern mortars use Portland cement (PC) as the binding material and a fine aggregate such as sand. Lime based materials,

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particularly hydrated lime, when mixed in the same water:binder ratio as for example PC, makes a mortar with much lower workability. This might be overcome by adding more water to the fresh mix but this significantly increases the setting time, reduces the strength and possibly the durability of the hardened mortar. This is the other, perhaps greater, barrier to the use of lime in building construction coupled with loss of trade skills in the handling of lime mortars and renders. It must be emphasised that the choice of the binder plays a significant role in the compatibility of the masonry construction especially in restoration and conservation work and hence an inappropriate binder could lead to an increased deterioration of the restored structure [3].

In masonry construction, mortars, renders and plasters are applied in the freshly-mixed wet state as thin layers to absorbent substrates such as brick, stone and concrete block and they are dewatered by varying amounts by these substrates prior to setting. Dewatering begins immediately when freshly-mixed mortars are placed on top of absorbent substrates. Although this paper solely addresses the brick–mortar–brick configuration and the unidirectional absorption of water from the freshly mixed mortars into the dry brick substrates for the practically important case of jointing mortars, it must be noted however that when mortars are placed next to the absorbent substrates, dewatering also takes place. As a consequence of this interaction, fresh and hardened properties of mortars as well as the overall masonry performance are affected significantly. Dewatering of mortar not only affects the strength of the hardened mortar, but also the adhesion of the mortar to the substrate material [4]. For the practically important case of jointing mortars applied in 10 mm layers to a typical facing brick, 40–60% of the original mix water is lost [5]. The significance of the loss of mix water during dewatering of freshly mixed mortars when in contact with a dry absorbent substrate was previously reported in [6]. The study showed that dewatered mortars resulted in an increase in compressive strength compared to non-dewatered mortars.

The significance of the interaction between water retaining ability of a freshly mixed mortar and the absorbing capability of a substrate is reported in [4,5,7–10]. This further affects the setting time and the strength gain of mortars [11]. The main concern of this paper therefore is the jointing mortars, typically applied to brick, block and stone masonry units. It has conclusively been shown that the rate of dewatering of a wet mix depends on both the suction of the absorbent substrate (the sorptivity, S) and the water retentivity of the fresh mix (the desorptivity, R) [6,8,12]. The desorptivity defines the water retaining ability of a wet mix which means that lower the value of R, the more water retaining the mix. The sorptivity defines the ability of a porous material to absorb water by capillarity. The transfer sorptivity, A, is a function of both R and S and characterises the ability of a porous material to absorb water from a wet mix [12]. These parameters are related by

$$\frac{1}{A^2} = \frac{1}{R^2} + \frac{1}{S^2} \quad (1)$$

Eq. (1), a full derivation of which may be found in [13], has recently been validated experimentally for the case of clay brick withdrawing water from freshly mixed hydraulic lime and cement mortars [12]. Furthermore, an equation developed based on the Sharp Front theory describes the time taken to dewater (t_{dw}) a wet mix by an absorbent substrate [5].

$$t_{\mathrm{dw}} = \left(\frac{L\alpha}{A}\right)^2 \quad (2)$$

where L is the thickness of the mortar bed, A is the transfer sorptivity and α is the parameter that involves both initial and final volume fraction of water and solid contents. Eq. (2) shows that t_{dw} increases as the thickness of the mortar bed L increases, and decreases as the transfer sorptivity A increases.

Manipulating the water absorbing ability of the masonry substrate may not often be possible, therefore we have investigated the possibility of enhancing the water transport kinetics and mechanical properties of hydrated lime mortars using pozzolanic replacement materials such as zeolite and Bayburt stones in this paper. Large number of studies reported in the literature mainly concerns the use of zeolite for improved mechanical properties and durability of concrete [14–17]. Although zeolites are widely used in the concrete industry as pozzolans, their application in mortars in masonry construction is not extensively addressed. Besides 50 billion tons of zeolite reserves [18], recently a province called ‘Bayburt’ is also drawing attention with its natural stone mining in Turkey. Bayburt stones demonstrated a serious potential to be used in hydrated lime mortars as pozzolans due to their high pozzolanic activity and are powdered to be used as replacement materials to the binder. Zeolite and Bayburt stones are therefore carefully chosen in particular as pozzolanic replacement materials to the hydrated lime in this study. The aim of this paper therefore is to investigate the possible role of zeolite and powdered Bayburt stones on water transport kinetics and mechanical properties of hydrated lime and cement mortars. The parameters investigated are transfer sorptivity (A), time to dewater (t_{dw}), consistence, setting time and compressive strength with microstructural analysis. The ability to manipulate these properties of hydrated lime mortars using zeolite and powdered Bayburt stones is vital for wet mortar/substrate optimisation and consequently improved properties of the set material in construction practice.

2. Materials and mix design

Experiments were carried out on freshly-mixed and hardened state mortars using hydrated lime (CL90) as binder. The constituents of the mortars examined were CL90, fine aggregate (sand) and water. CL90 was obtained from Entegre Ltd. and complies with [19]. The designation of CL90 indicates high calcium lime containing not <90% CaO. Zeolite and powdered Bayburt stones used as replacement materials in CL90 mortars are obtained from Rota Mining and Topyay Stone Mining respectively. The chemical composition of zeolite and powdered Bayburt stones shown in Table 1 specifies that these materials contain at least %70 of $SiO_2 + Al_2O_3 + Fe_2O_3$. Various replacement levels of zeolite and powdered Bayburt stones were used to investigate the influence of these materials on the fresh and hardened state properties of CL90 mortars. Mortars of fixed mix proportion (0.75:1:2 mix water:binder:sand) by volume were prepared from CL90 and sieved single source sharp sand. Mortars of similar mix proportions by volume were also studied in [20–22]. The masses of binder and sand needed to produce the required mix proportions by volume were calculated from carefully determined values of density. The same mixing regime described in detail in [8] was followed in which the mass of lime and sand required is calculated from initially determined values of density. Water was placed into the bowl of an orbital paddle mixer and the binder added and mixed for 1 min. Without

Table 1
Main element oxide composition of zeolite and powdered Bayburt stone (Manufacturer's data).

Chemical composition (%)	Zeolite	Powdered Bayburt stone
SiO_2	72	69.2
MgO	0.9–1.2	0.85
CaO	2.4–3.7	2.95
Fe_2O_3	0.7–1.9	1.10
Al_2O_3	10–12	na
na (Not Available)		