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Review

Pozzolanic properties of brick powders and their effect on the properties of modified lime mortars

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HIGHLIGHTS

- Waste brick dusts as pozzolanic material for lime mortars were investigated.
- The diversities of brick dust properties of different origin are illustrated.
- Amorphous phase content is a main factor affecting pozzolanic activity.
- The mechanical properties are closely related to the reactivity of brick dust.

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ABSTRACT

The article deals with the evaluation of six brick dusts which were characterized regarding their chemical and mineralogical composition, amorphous phase content, granulometry and specific surface area. The pozzolanic activity was determined by the modified Chapelle test. The analysed brick dusts were used to prepare modified lime mortars in which lime hydrate was replaced by 50% of brick dust. The flexural and compressive strengths of the mortars were determined and pozzolanic activity was calculated from the compressive strengths. The pozzolanic activity of brick dusts is dependent in particular on their amorphous phase content, particle size distribution and specific surface area. Pozzolanic activity increases with increasing amorphous phase content in the brick dusts. Pozzolanic activity has an effect on the strength of modified lime mortars. The higher is the pozzolanic activity value of the added brick dust the higher are the initial and long term strengths of the modified lime mortars.

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1. Introduction

Air lime, hydraulic lime, and mixtures of lime and reactive additions are the most common materials to have been used as plaster binders over the course of human history. Inorganic additions such as crushed brick bodies, crushed glass and slags have been identified in historical plasters preserved on facades up to the present day. Plant ashes (e.g. from grain straw or vine-shoots) were often added to lime due to their high content of reactive amorphous SiO_2 [1,2]. Pozzolanic additions increase the strength of hardened mortars via the formation of C-S-H and C-A-H compounds. When pozzolan in mortar requires a higher amount of water, it has a detrimental effect on mechanical properties [3]. Brick body often occurs in the plasters of historical buildings in the Czech Republic. The aim of the described work was the assessment of various types of brick bodies from the point of view of their reactivity and influence on the properties of hardened mortars. The aim was to reach general conclusions as brick shards are not readily able to react with lime.

1.1. Pozzolans and pozzolanic activity

Pozzolans are defined as silicate or aluminosilicate substances which by themselves possess no binding ability, but if finely dispersed will react with calcium hydroxide and water at ordinary temperature to form C-S-H (calcium silicate hydrates) or C-A-H (calcium aluminate hydrates). These compounds solidify, harden and are stable in the air and underwater [4–6]. These compounds are more resistant to the action of acid gases in the surrounding environment than the product of the lime carbonation ($CaCO_3$) occurring in lime plasters [3].

Pozzolans can be categorized according to their origin as being either natural or technogenic. The group of natural pozzolans includes tuffs, schists, diatomaceous earth, some types of fine-grained calciumsilicate materials, pumice, basalt, chalcedonies, opals, micas and feldspars [3,5]. As regards technogenic pozzolans, various kinds of industrial by-product including fly ashes from high temperature combustion, silica fume, ashes from biomass combustion, burnt clays and other such materials can be used [1,3,7–9]. Many of the above-mentioned pozzolans were used in the more distant past; mortars containing these pozzolans had high strength and durability in wet conditions and so were used for the aquatic construction of public baths, aqueducts, bridges and jetties, i.e. structures exposed to an excessive amount of moisture, or even liquid water. The pozzolanic activity of pozzolans is the key reason for their use in lime mortars [3,10–15].

Pozzolanic activity is the ability of substances to react with calcium hydroxide in the presence of water at ordinary temperature to form hydration products. It can be determined as the amount of calcium oxide required for the reaction with the pozzolan and by the reaction kinetics of the reaction. Calcium hydroxide is a base partially dissociated in an aqueous medium ($pK_B = 2.37$).

$$Ca(OH)_2 \leftrightarrow Ca^{2+} + 2OH^- \quad (1)$$

A saturated solution of calcium hydroxide has a pH of 12.45 at 25 °C. A high concentration of OH^- ions causes the breakage of bonds in SiO_2, silicates and aluminosilicates, producing simple ions [3,16] according to the following scheme:

$$\equiv Si{-}O{-}Si\equiv + 8\ OH^- \rightarrow 2\ [SiO(OH)_3]^- + H_2O \quad (2)$$

$$\equiv Si{-}O{-}Al\equiv + 7\ OH^- \rightarrow [SiO(OH)_3]^- + [Al(OH)_4]^- \quad (3)$$

The resulting silicate and aluminate ions in contact with Ca^{2+} ions form hydrated silicates of CSH-type compounds, calcium aluminate C_4AH_{13}, hydrated gehlenite C_2ASH_8, and $C_3A{\cdot}CaCO_3{\cdot}12H_2O$ [16–18]. The silicate components dissolve more rapidly than aluminate and a higher concentration of Ca^{2+} is needed for the formation of calcium aluminate. First, CSH gels precipitate on the particles of pozzolans, after which calcium aluminates precipitate in the form of hexagonal sheets on the surface of those CSH gels [19].

Pozzolanic activity may be determined by chemical methods, mainly based on the reaction of pozzolans and calcium hydroxide contained in lime or resulting from the hydration of cement [4,5,20]. Other methods are based on determining the mechanical properties of cement mortars in which part of the cement is replaced by pozzolan [5]. Physicochemical methods, such as thermal analysis, solution calorimetry, XRD analysis, and conductivity measurement techniques may also be used to determine the reactivity of pozzolans [4,21–24].

1.2. Brick dust

In the past, the brick bodies of used brick products or rejects usually crushed to a grain size of about 1 mm were utilised as a pozzolan. Currently, brick dust is a by-product of the production of calibrated brick components that are treated by grinding to achieve precise dimensions for mortar-free walling. This very fine dust is used as a filler material in the raw mix at some brick-kilns or it becomes unexploitable waste.

Ceramics (including brick products) are defined as inorganic non-metallic materials which are nearly insoluble in water and contain crystalline compounds (about 30% by mass). The basic raw material is brick earth with a predominant component of clay minerals. It is processed into a workable mass and after shaping is usually burned to a temperature above 800 °C, when the microstructure of the body hardens.

Clays are mixtures of clay minerals that are hydrated aluminosilicates from the chemical point of view. Kaolinite, illite, chlorite, halloysite and montmorillonite are the most important clay minerals as far as ceramic technology is concerned. They are crystalline substances with a layered structure in which layers of SiO_4 tetrahedrons and AlO_6 octahedrons alternate. In addition to clay minerals, ceramic raw materials can also contain other minerals, such as crystalline and non-crystalline modifications of SiO_2, feldspars, zeolites, carbonates, oxides or hydroxides of iron and aluminum, sulphates, non-crystalline clay minerals of the allophane group, and other minor inorganic and organic impurities [25].

Heat treatment (600–900 °C) leads to the dehydroxylation of clay minerals and the creation of reactive amorphous phases [4,26,27].

Physically bound water evaporates from a ceramic body at temperatures up to about 100 °C. Brick materials, which are mostly formed from illite clays, release physical bonded water up to 300 °C, chemically bound water is released within the temperature range of 400–450 °C, and the dehydroxylation of clay minerals occurs within the temperature range of 450–700 °C. During the