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Review

Lime mortars with heat treated clays and ceramic waste: A review

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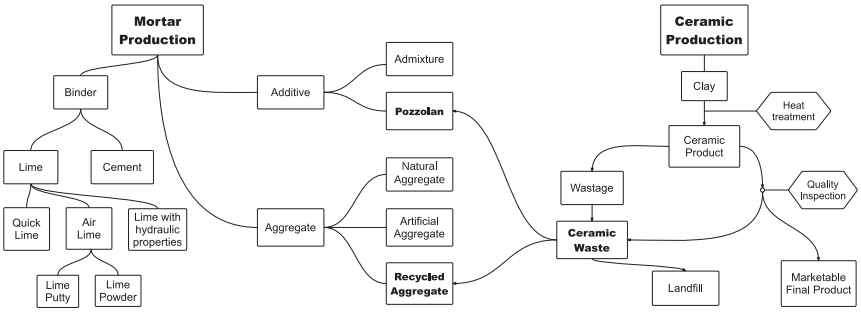
HIGHLIGHTS

- The use of air lime mortars with ceramics is well known from the past.
- Fine particles of heat treated clays have proven to be potentially pozzolanic.
- Repair mortars must have a behaviour similar to the ones already in place.
- Knowledge of old mortars is fundamental for the conservation of the built heritage.
- The use of ceramic waste in mortars has technical and environmental advantages.

GRAPHICAL ABSTRACT



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ABSTRACT

The formulation and use of lime mortars with ceramic particles has, in the past, been a very common technique. Knowledge of such used techniques and materials is fundamental for the successful rehabilitation and conservation of the built heritage. The durability that these mortars have shown encourages the study of the involved mechanisms, so that they may be adapted to the current reality. The considerable amount of waste from old ceramics factories which is sent for disposal might present an opportunity for the production of reliable improved lime mortars. In this paper a number of studies that characterize old building mortars containing ceramic fragments are reviewed. The most important research undertaken on laboratory prepared mortars with several heat treated clays types is presented, specifically with incorporated ceramic waste. Some studies on the pozzolanicity of heat treated clays are examined and the heating temperatures that seem most likely to achieve pozzolanicity are presented. It was verified that some heating temperatures currently used by ceramic industries might correspond to the temperatures that will achieve pozzolanicity.

Contents

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1. Introduction

Ceramic dust and grains, mostly from bricks, tiles or decorative elements, have been widely used in mortars in the past. The variety of these materials was mainly influenced by their availability and it was observed that when they were combined with certain substances the resulting mortars have improved characteristics. Over time, it has been demonstrated that the addition of small ceramic particles confers improved characteristics on lime mortars and that pozzolanic reactions might occur, thus providing mortars with hydraulic properties.

The economic advantage and the quick-setting property of Portland cement led to a growth in its production for several decades, which in turn resulted in a decline in the use of air lime mortars. However, cement-based products were found to be incompatible when it came to repairing and replacing mortar in old buildings. The effectiveness of repair mortar is based on properties such as flexural and compressive strength, water vapour permeability, water absorption by capillary action and drying. When well selected and applied, repair mortar can help prevent severe pathologies that might cause serious damage to a building. The repair of lime-based masonry systems with cement-based mortars is a great example of a solution that is not only not compatible with the old systems, because of their short life span, but, that can also cause strong and accelerated degradation of the pre-existing materials.

When combined with lime, ceramic dust may act as pozzolan when its silica and alumina content react with the calcium oxide from lime. In addition to the specific surface area of the ceramic material being significant, this reaction is essentially governed by the heating temperatures and consequent amounts of silica and alumina in the amorphous state.

Although heating temperatures used in more recent industrial ceramic products may be higher and more homogeneous than older ones, the behaviour of their waste when used as lime mortar constituents is not yet well known. However, their use may be an effective possibility.

About 30% of the industrial ceramic products are considered unfit for use and are in most cases sent to landfill. Their great strength and resistance to degradation make the problem of processing ceramics waste unmanageable [1]. Therefore, incorporating these waste materials in lime mortars might prove to be both technically and environmentally advantageous.

Previous research has shown that while there have been some studies performed on mortars with ceramics waste, most of them relate to cement mortars. On the other hand, results from air lime mortars studies have not offered an in-depth characterization of industrial ceramics waste, which should be systematize.

This paper sets out to review the environmental aspects and the most significant research related to heat treated clays and ceramics incorporated in old mortars, in order to assess the viability of using waste from ceramics plants as a component in repair and substitution lime-mortars.

2. Historical background

Research work carried out in old buildings and archaeological sites indicates that the use of hydrated lime mortars with several additions was very common. These additions were intended to improve the behaviour of mortar and were obtained from natural sources in their earliest forms. Products such as heat treated clay and ash have been often detected in old mortars. It is also known that heat treated clays from ceramic products such as bricks were extensively milled and incorporated in lime mortars in ancient times.

The first records of hydrated lime mortars with clayish additions date back to constructions in Babylon from 3000 B.C. [2]. It is believed that the Phoenicians, whose period of influence lasted from 1200 to 800 B.C., also fostered the use of these mortars [3]. Signs of the use of brick waste in the rendering mortar of water cisterns were also detected in the period of Solomon's kingdom (970–931 B.C.) [3]. Later, mortars from II B.C. with ceramic pozzolanic materials were also found in Greece [2].

However, it is in the Roman Empire that the use of such materials becomes more evident. The first documents that specify the use of brick shards in mortars are by Catone and Vitruvius [3]. In that period, brick dust was frequently used as a pozzolan in the absence of natural ones [4]. It was given various names. Most common were *opus testaceum* and *cocciopesto* [2,5]. These materials were intended to give hydraulic characteristics to air lime mortar and sometimes waterproofing features. *Cocciopesto* mortar contained milled brick, which could be in the form of both dust and grain. Mortars with brick dust were applied as wall rendering or plastering materials and for floor covering. Crushed bricks were more often used for masonry mortars, especially in structural elements, such as arches or foundations [2], as well as for rendering elements with hydraulic requirements, such as baths, water conduits, reservoirs and cisterns. Nowadays it is common to find these mortars in Roman archaeological sites [6–13], but it is also possible to find them in later constructions, for example from the 14th, 15th and 16th centuries [8,14–17], up to the 19th century [18].

In fact, a considerable number of historical monuments from the Ottoman period, and particularly from the Byzantine period, were built with this type of mortars. Constructions such as Hagia Sophia Cathedral [6,19], the Medieval City of Rhodes [19], and churches, monasteries and cathedrals in Kiev [20] and Israel [21], dating back to the Byzantine period, are just a few examples of the wide use of ceramic fragments in lime mortars at that time. In these cases, several researchers highlight, not only the waterproofing characteristic of the mortars, which is very important in dry climatic conditions [21,22], but also their performance as important elements of earthquake resistant masonry systems [20,23,24].

This technique spread throughout Europe and other continents. In India there are records of brick waste incorporation in mortars, called *surkhi* [25] and in Arabian countries and Turkey this product was known as *homra* and *horasan,* respectively [8]. In Oman this type of mortar was known as *sarooj* [26].