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Performance of lime-based mortars at elevated temperatures

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HIGHLIGHTS

- The resistance of lime-based mortars at elevated temperatures is presented.
- Lime-based mortars retain their physical and mechanical properties up to 1000 °C.
- The lack of relevant studies on historic materials is assessed.

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ABSTRACT

The properties and preservation state of historic mortars are closely related to various aspects, such as their constituents and the pathology symptoms they confront, due to extreme environmental conditions or accidental actions (i.e. earthquakes, floods, landslides and fire). Despite the fact that in the recent decades there is extensive research on the impact of elevated temperatures on cement based materials (cement mortars, concrete), there are no relevant studies concerning historic or repair materials. Taken into account that during their service life, historic structures may be subjected to accidental fires (limited or total), the resistance of their building materials to extreme temperatures seems to be a parameter that should be further investigated. To this direction, the paper focuses on the study of a series of lime-based mortars, designed for restoration works, exposed to a range of elevated temperatures starting from 200 °C to 1000 °C. The physico-mechanical properties of the mortar specimens were tested before and after their 2 h maintenance at different temperatures, regarding weight loss, volume change, porosity, apparent specific gravity, dynamic modulus of elasticity, flexural and compressive strength, while macroscopic and microscopic observation was also realised. The evaluation of the results showed that lime-based mortars preserved their structure and characteristics after their exposure to elevated temperatures, while in the case of lime-pozzolan matrix the resistance of the specimens was extremely high, compared to the other binding systems tested.

1. Introduction

Mortars were diachronically a substantial structural element of historic masonries, closely associated with their durability and resistance to ageing and deterioration factors [1–3]. Their functional role (i.e. structural mortars, renders-plasters) and constituents (binding system, aggregates' type and gradation, B/A ratio) determined their properties and often their preservation state [3–6]. Their composition varied, according to their application (renders, bedding, floor substrate), the available raw materials of each area and the technological background of each era, while in most cases historic mortars were based on lime [3,4,6].

The pathology symptoms encountered in historic mortars (i.e. exfoliation, detachments, loosening, cracking, discoloration) may be attributed to a synergy of factors related to their characteristics, the environmental aspects of the area (temperature alterations, humidity, frost, vicinity to the sea, atmospheric pollution), as well as accidental actions such as earthquakes, floods, landslides and fire [1,7].

On the other hand, exposure to fire and elevated temperatures seems to be a significant decay factor of structures and building materials [8–11]. Research on the topic launched at the beginning of the 20th century (1922) [12] and was induced during the last decades, focusing however on cement based materials (cement-mortars, concrete) [13–15].

According to literature [8,9,11,14], when subjected to fire, specific properties of building materials are influenced (i.e. physico-chemical and mechanical characteristics, microstructure

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etc). The decay degree may vary according to the characteristics of the fire (i.e. maximum temperature, fire duration) and the properties of the building materials. The main output of the targeted research was usually the design of fire-resistant materials, as well as the post-fire assessment and repair of the structures. Reference data and scientific knowledge is provided by the relevant Standards [15–20].

Generally, the preservation state and residual strength of building materials after their exposure to elevated temperatures is correlated to a synergy of factors, such as the consistency and structure of materials, the maximum temperature attained, the exposure time, as well as the heating rate [12–14,21,22]. Regarding cement- based mortars and concrete, elevated temperatures influence their constituents in various ways, according to their individual thermal strains (aggregates' expansion, cement paste's shrinkage deformations) [22].

As it is well known, between 100 and 200 °C, the evaporation of materials' free moisture takes place without significant alterations in the structure, while above 250 °C dehydration or loss of the bonded water begins [8]. The cement paste's silicate hydrates (C–S–H gel) decompose above 300 °C, while portlandite decomposes above 500 °C, inducing the degradation of the cement matrix [10,22]. Aggregates, depending on their compounds, are influenced in different temperatures (i.e. siliceous aggregates are generally decomposed in higher temperatures compared to calcareous) [10,22].

Concerning mechanical characteristics, up to 300 °C the residual strength of concrete and cement mortars is not significantly reduced, while between 300 °C and 500 °C strength decreases at a rate of 15–40% [8,10]. Above 550 °C - 600 °C, it is minimized and secondary chemical reactions occur (i.e. decarbonisation of carbonates in both cement paste and aggregates) [14,21–23]. Usually above 800 °C, complete disintegration of the concrete constituents begins [14,21–23].

As already has been mentioned and according to literature, the performance of lime-based mortars at elevated temperatures has not been studied yet in details [24–27], although other deteriorating phenomena have been envisaged [1,28]. However, as identified by the archaeological remnants or by historic sources, many monuments were subjected to fire during their service life, which was either limited or total [29–31]. In addition, it is considered that fire safety criteria should be taken into account during the restoration and rehabilitation of monuments [30,31], in order to:

- determine and in cases predict the post-fire residual strength capacity of historic masonries and of the building materials themselves
- design and apply compatible and effective repair materials, resistant to elevated temperatures, especially in the case of the rehabilitation of historic structures that should fulfil fire safety criteria (i.e. churches, buildings of general use).

In this paper, five series of lime-based mortars have been designed, manufactured and tested. The specific proportion and type of raw materials used was defined by the former analysis results of a great number of historic mortars [3,6,7,32]. Twenty eight days after their manufacture, 2 specimens of each mortar series were subjected to elevated temperatures (200 °C, 400 °C, 600 °C, 800 °C and 1000 °C). Afterwards, the samples were kept at environmental conditions for 24 h and their physico-mechanical properties were recorded. The test results were comparatively evaluated to identify the properties that have to be taken into account when the mortars' resistance at high temperatures has to be studied.

2. Materials and methods

According to an extensive research performed in mortar samples taken from different monuments of Greece and dated throughout a large period of time, historic mortars were mainly based in lime and lime-pozzolan [3,6]. In many cases, clayish material or brick dust was added also as a pozzolanic material [3,6]. Aggregates were usually natural, of siliceous origin, while crushed brick was also added [3]. Their gradation was mainly 0–8 mm, while the B/A ratio ranged from 1/2 to 1/3 [3,6,32].

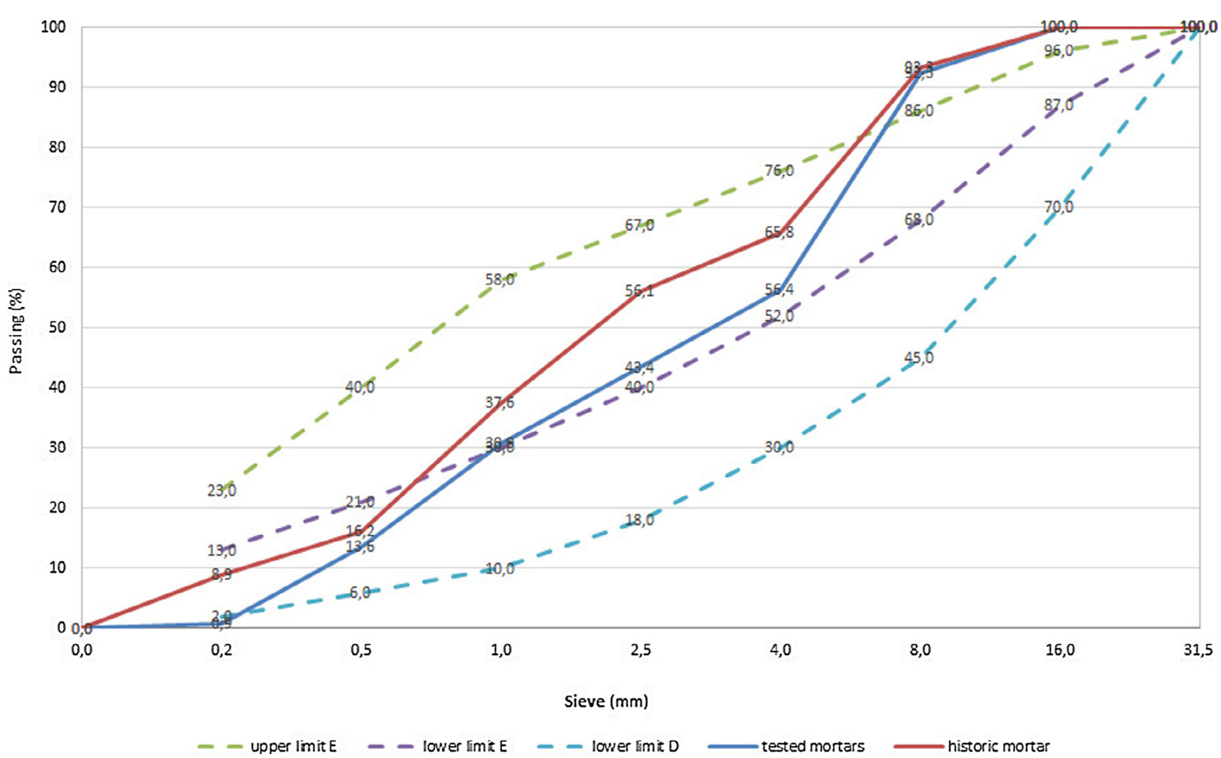

Fig. 1. Aggregates' gradation curve of a historic mortar and of the tested mortars.