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Original article

Consolidation of weak lime mortars by means of saturated solution of calcium hydroxide or barium hydroxide

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ABSTRACT

This paper presents research results on the effects of repeated treatments with saturated solutions of calcium hydroxide (lime water) or barium hydroxide (barium water) on consolidating a friable lime mortar. The influence of lime or barium water treatment on various mainly mechanical characteristics of consolidated lime mortar was studied in detail by means of tests on non-standard specimens fabricated from a poor mortar of 1:9 vol. lime-to-sand ratio. The traditional lime water technology and barium hydroxide treatment were further compared with distilled water and lime water with added metakaolin. Lime water treatment of a specific lime mortar was shown to be effective after a sufficiently large number of applications (160 saturations) into a weak lime mortar. No consolidating effect of distilled water on the compressive strength of the tested mortar with a low lime content (1:9) was observed. The mechanical characteristics of the tested mortar were not improved by treatment with lime water with added metakaolin. Barium water treatment significantly increased mainly the tensile strength of the tested lime mortar.

1. Research aims

Discussions on the use of a solution of calcium hydroxide in water (often referred to as "lime water") for consolidating weak inorganic porous materials have been going on for decades. In the Czech Republic, multiple applications of lime water have frequently been prescribed by the central national conservation office as the only acceptable consolidation treatment for lime renders. Such massive application of lime water as a consolidation agent for conserving historic rendered façades has raised much discussion, and has aroused the resistance of some regional authorities and practicing restorers, leading to the involvement of our team in laboratory research on this contentious issue. The authors of this paper take a neutral position, and their research aims to offer an objective evaluation of the influence of adding lime water to friable mortar, and to ascertain the degree of consolidation. The consolidating effects not only of lime water but also of multiple applications of some other treatments were investigated: distilled water, lime water blended with metakaolin, and barium water (a barium hydroxide saturated solution in water). In this study, barium hydroxide was considered as an alternative "traditional" consolidant to calcium hydroxide, and potentially more effective, because it is much more soluble in water than calcium hydroxide. With respect to the distilled water, its effects were investigated with reference to the type of mortar and the shape of the specimens. The lime water with added metakaolin was tested in accordance with recently published research results.

2. Introduction

Until the recent publication by the authors of this paper [1], there was a lack of experimentally supported publications and detailed information about the effects of lime water treatment on weak lime mortars. Some papers presented only marginal data [2] or the results attained under certain limited conditions may be too broadly interpreted [3], and may be arbitrarily extrapolated into conditions where no knowledge is available, and thus no justification or evidence exists [4]. Though the number of relevant articles is quite small, a detailed literature review is beyond the scope of this paper. Only the most relevant experimental studies are mentioned, leaving aside reviews [5], theoretical works analysing, for example, very important questions of binding mechanisms [6,7], and also papers illustrating confusions in terminology (lime water against lime wash) [8] or presenting discussions and arguments against the application of lime water for consolidating mortar and stone [9].

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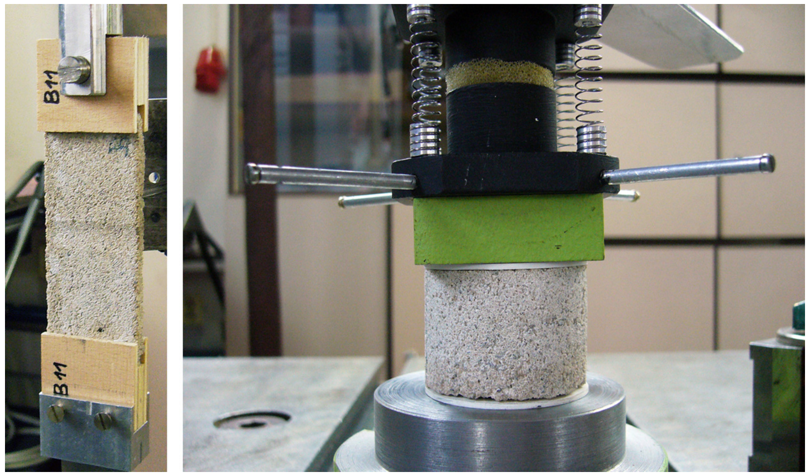

Fig. 1. Testing specimens – tubes for compressive and thin plates for tensile tests.

The effect of lime water applied *in situ* for restoring wall paintings on lime mortar rendering has been investigated by I. Brajer and N. Kalsbeek [10]. These researchers systematically tested lime water treatments from the point of view of the application procedure, the number of applications (20–70 cycles), dosage and maturation. They concluded that continuous "wet" applications bring about a consolidation effect, unlike applications with "drying" breaks, which do not consolidate the wall painting. However, the observed consolidation tended to concern fixation of a released surface paint layer, for which lime water was recommended in some older literature [11]. (It is interesting to note that the so-called "traditional" lime water was not included by Friedrich Rathgen in the list of consolidation techniques that he compiled in 1898. In former Czechoslovakia, F. Petr added lime water to the list of recommended treatments in 1953, without any reference [12]). I. Brajer and N. Kalsbeek did not carry out any objective measurements of mechanical characteristics in their study.

In the field of measuring the mechanical characteristics important results were published by C. Price [13] and his team [14]. Although this work concerns limestone restoration, it has helped considerably in the presented study. C. Price applied lime water in 40 cycles on stone and also on crushed limestone sand. He found a very small increase in the amount of calcite in the material, no observable change in the mechanical characteristics, and no consolidation effect on the crushed material.

Lime water effects and the use of metakaolin as an additive in lime water were studied by M. Tavares, R. Veiga and A. Fragata [15]. They recommended the use of lime water and lime water with metakaolin for consolidating old rendering with low cohesion on the basis of laboratory and in situ tests results, and concluded that the tested consolidants increase the mechanical resistance of the superficial layers.

Notwithstanding the research referred to above, there has been a considerable lack of knowledge concerning the method of lime water treatment of renders. A thorough experimental programme was therefore carried out, aimed at revealing the fundamental behaviour of weak lime mortars when subjected to multiple saturations and evaporation of distilled water, a saturated solution of calcium hydroxide in water ("lime water"), lime water with added metakaolin, and saturated solution of barium hydroxide.

3. Experimental

3.1. Lime mortar test specimens

On the basis of a literature survey indicating very slight effects of multiply wetted historic mortars or stone with lime water, as regards to both penetration depth and strengthening, the authors designed and prepared specific test specimens in the form of short tubes for compressive tests and plates for tensile tests (Fig. 1 and Table 1). The specimens were made of lime mortar prepared in laboratory from powdered lime hydrate and river sand. The white air lime hydrate (CL90) Čertovy schody, Czech Republic, of a great purity (98.98% of CaO + MgO) was used. The most frequent particle diameter found in lime was 15 μm and 90% of particles were smaller than 38 μm (the particle size distribution was measured using a Laser analyser CILAS 920). The specific surface area of used lime was 16.5 m^2/g (by means of gas adsorption, BET method, using the device Micromeritics ASAP 2020).

As the aggregate of the mortar, a quartz sand was used (sand quarry Borek, Czech Republic). Mineralogical composition of the sand was determined by means of optical microscopy (thin section of the sand was investigated by the polarizing microscope Zeiss NU2) and XRD analysis (Bruker D8 Advance system with Cu-anode ($\lambda_{K\alpha}$ = 0.15418 nm) and variable divergent apertures at convention Bragg-Brentano para-focus Θ–Θ reflective geometry, step 0.02° 2 Θ, step time 188s). The sand consisted mainly of quartz, but particles of quartzite, marlstone, granitic rocks, K-feldspar and plagioclase were also determined using petrographic microscope. XRD analysis identified quartz, feldspars, illite, and/or muscovite, and chlorite. Particles of the sand Borek were sorted in grain size fractions by means of sieving before preparing the laboratory mortar. The grain size distribution of the aggregate for mortar specimens, Table 2, was designed so that it reproduced the grading of the historic render aggregate. For this purpose, the historic lime render with quartz aggregate was sampled from a medieval castle and the sample of 200 g was dissolved by the acid dissolution. The

Table 1
Specimens parameters.

Specimen shape	Length (cm)	Width (cm)	Thickness (cm)	Volume (cm^3)	Treated surface (cm^2)	Porosity (MIP) (%)
Tube (compression test)	3	4	0.55	17.3	37.7	27
Plate (tension test)	10	4	0.5	20	40	