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Strengthening of Weak Historic Renders with Traditional and Innovated Consolidation Treatment

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Abstract: The presented study was aimed to proof consolidation effects of different families of consolidants: inorganic agents (lime -based or silica-based solutions or sols), organic agents (silicic acid ester based consolidant) and their combination on the characteristics of weak mortars prepared in laboratory with different types of aggregates. Besides exploring consolidant-substrate interaction also the pozzolanic activity of the aggregate and the binder mortar component after reaction with lime (calcium hydroxide solution) was investigated in order to understand and describe the strengthening mechanism into consolidated mortars. As the study was based on experimental research, the production of mortar test specimens represented an important preliminary work. Different mortar components (various types of sand in terms of phase composition, clay, lime) and the same ratio of the aggregate and the binder were used in various mortar mixtures. Various mineralogical types of aggregate were used with the same grain size distribution (600 pieces of tubes of 40 mm in outer diameter, of the height of 40 mm and depth of 4 mm were prepared for testing the compressive strength, for the tension tests 550 thin plates of dimensions 40 mm x 100 mm x 4 mm were cast and 600 beams 20 x 20 x100mm were made for testing the flexural strength and other characteristics of reference and consolidated mortars). The sand used for mortar specimens was characterized by microscopic examination of thin section and also by X-ray diffraction, X-ray fluorescence spectroscopy and thermal analysis. The pozzolanic activity of the sands (reactivity with calcium hydroxide) was determined by means of the thermal analysis and supplemented by wet silicate analysis. The amount of the effective matter in the consolidant was the same for all agents per the square unit for all mortar types and specimen shape. One set of specimens was prepared as the reference set of mortars without any treatment and the second set was used for the evaluation of various consolidating agent effects.

The following consolidation treatment was studied:

- lime water – saturated solution of calcium hydroxide in distilled water
- dispersion of nanoparticles of calcium hydroxide in alcohols (CaLoSiL IP 15)
- colloidal solution SiO_2 in water
- silicic acid ester solution (TEOS –based)
- colloidal solution SiO_2 and lime water (combination)
- colloidal solution SiO_2 and CaLoSiL IP 15 (combination)
- TEOS and lime water (combination)
- TEOS and CaLoSiL IP 15 (combination)
- barium water - saturated solution of barium hydroxide in distilled water
- ammonium oxalate solution in distilled water

Two months after impregnation procedure, the consolidated specimens were tested and obtained data evaluated. Mechanical tests – compressive, tension and flexural strength, peeling tests, drilling resistance; physical tests focused on porosity a water transport parameters – pore size distribution, water absorption in certain time and a microscopic investigation of new compounds distribution in the depth profile of the treated specimen were performed. Chemical analyses involved thermal analyses, X-ray diffraction, EDXRF and SEM-EDS analyses. Thermogravimetric analysis (TGA) was used for monitoring the pozzolanic reaction extent of different binders and aggregates used in

mortars after reaction with calcium hydroxide. Suspensions consisting of the binder or the aggregate (particle size under 125 microns) and lime (in ratio 1:1) were prepared for this purpose. Resulting reaction compounds were quantified by TGA and their presence was proved by X-ray diffraction. Both analyses confirm, besides the calcium hydroxide and carbonate, the presence of CSH and CAH phases. TGA was also used for investigation of changes in mineralogical composition in lime mortars (ratio lime: aggregate 1: 9) before and after the treatment by consolidating agent. The presence of consolidant unfortunately distorts the area where CSH and CAH phases can be detected, so in this case TGA gave just information about the quantity of calcium carbonate. TGA also confirms that samples were fully carbonated (calcium hydroxide was not present). Hydraulic compounds, detectable by means of XRD, were not found in the samples of mortars. Beside the study of model mortar specimens, also real historic mortar samples were characterized and physical-chemical properties were determined.

The results from experiments focused on lime water efficiency, compared to nano-lime based consolidants, showed that the lime water spraying technology may provide acceptable results on a certain class of ancient lime mortars, from the technical point of view and also from the aesthetic point of view. The treated plasters should ideally be well packed and porous, without compact surface crust layers. However, lime water is not suitable in all situations, and a consolidation effect can be only achieved with a very large number of applications (more than 100), which typically releases and washes away sand grains and the binder of the original surface layers. This changes the appearance of historic surfaces together with apparent white hazing when there are a large number of repeated applications. The risk of mobilizing water-soluble salts in historic plasters is high. If soluble salts are present, the potential damage should be considered carefully.

The lime water treatment was also compared with some other, less labour-intensive technologies. Dispersions of calcium hydroxide in alcohols, which are marketed under the trade name CaLoSiL, were the most promising agents. The major advantage with these agents is that they can be applied much more rapidly than tens to hundreds of lime water cycles and they deliver higher amount of lime in each cycle. While lime water contains only small calcium ions, sized about 0.1 nm, calcium hydroxide particles in CaLoSiL are considerably larger (50-200 nm). This property may limit the use of nanolime dispersions for consolidation of mortars with fine pores or with less pore interconnectivity. Nanolime dispersion CaLoSiL 15 applied to mortar, where the majority of pores were around 100 μm in diameter, was efficient enough to achieve significant strengthening effect after one-day lasting consolidation treatment (7 applications of the consolidant. every 2 hours).

The combined application of lime-based consolidants (lime water, nano-lime dispersions) and silica based consolidants (silica sol, silicic acid ester solution) was studied with finding that both lime water or the calcium hydroxide nano-dispersion are more effective in consolidation of lime mortar when they are applied in combination with silicic acid ester or silica sol consolidant.

The experiments proved on series of model mortars with different aggregate brought the knowledge that the strengthening efficiency due to consolidation is influenced significantly by the aggregate type used in the consolidated mortar.

All the tested consolidation agents showed a positive strengthening effect when they were used for consolidation of poor lime mortar. Entirely different results were achieved when the same consolidants were used for strengthening of soil based mortar. Silicic acid ester solution-based product was efficient for consolidation of this type of mortar.

Study of the pozzolanic activity of various types of sand in mortars showed that the grains of sand may be reactive with calcium hydroxide and can participate in the formation of hydraulic compounds when they are subjected to calcium hydroxide for a long time (several months at room temperature). In treated lime mortar samples, however, the products of this reaction were not detected, probably because of the relatively small amount of these substances in mortar and their X-ray diffraction amorphous character.

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