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Consolidation Testing of Porous Limestone Using Lime Nanomaterials: Optimization, Assessment of Stone Mechanical and Structural Characteristics

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Abstract: In consequence of an array of degradation mechanisms there is a change of stone characteristics used in historic objects. One of the negative changes is deterioration of mechanical properties, which may often lead to losses of original substance and gradual disintegration of works of art or handcraft made of stone. To prolong the lifespan of such damaged cultural-heritage objects a process called consolidation is often carried out within the framework of conservation treatment. During the process of conservation treatment the damaged stone is impregnated with a consolidating material, which is to provide the stone with a new binder capable of renewing its cohesion to a certain extent. Currently, a wide range of organic and inorganic consolidating agents of various characteristics is available, from synthetic polymers to silicic acid esters. Long-term experience shows that not only is the consolidating effect of the actual agent important, but also its lifespan and impact on the subsequent aging of the treated stone. Thus, in the past few years more emphasis has been laid on the compatibility or – to express it more precisely – the material similarity of the agents used in the process of conservation and restoration of works of art or handcraft.

As a result of this requirement there is an effort to use such materials to consolidate stone, which after hardening will have a similar composition to that of the original rock/stone matrix before the consolidation. Within the area of consolidation of calcareous rocks such as limestone there has been quite an intense research in the possibilities of the use of nanomaterials on the basis of calcium hydroxide. Such relatively modern consolidating agents have a high potential to provide – in terms of material – a more suitable equivalent to the consolidants on the basis of silicates.

Even if there is a difference in material, these are used abundantly for consolidation of calcareous materials (which applies not only to the instance of stone). New, in terms of material, suitable nanolime products are made as stable nanosols of calcium hydroxide dispersed in alcohol media. The size of calcium hydroxide particles ranges between 100 and 200 nm with ethanol, isopropyl alcohol or n-propanol serving as dispersion media most often.

At present, the application of consolidating agents on actual objects is preceded by quite detailed studies and testing on reference materials corresponding with their characteristics and composition to the stone used on the historic objects. Testing and subsequent assessment of the mechanical characteristics changes (not only on the surface but also in depth) may not be executed directly on actual works of art or at times, these may be carried out to a limited extent. Of course, the main purpose is to preserve the original work of art and to prevent it from possible damage. Among other reasons, there are restricted options to test on actual objects and a problematic comparison of the test results on substrates of variable characteristics. When working on objects in-situ a critical moment might occur because of their unknown conservation history (e.g. hydrophobization of surface) or other changes in the surface caused by their exposition in the exterior associated with degradation (sulfation and others, water soluble salts etc.). Therefore, tests are carried out on specimens prepared from undamaged types of stone matching the rocks for which the tested consolidant is designated. Yet, in this case the testing material used does not correspond with the degraded stone and does not simulate its characteristics on actual objects where there is usually an increase in porosity and a substantial decline in strength due to weathering processes.

Within the project of Nanolith there have been tests to use nanolime products as an option to consolidate selected types of Leitha limestone, which are mostly porous, biodetritic limestone used for historic sculptural and architectonic purposes in the regions of Eastern Austria and South of Bohemia and Moravia. Particularly, the selection of a suitable testing substrate or – as a matter of fact – suitable test specimens was crucial part of testing and optimization of nanolime products application. Based on experience of previous, similarly focused tests a method for the preparation of the specimens was chosen which would facilitate simulation of a degraded material and at the same time provide homogeneity and reproducibility of their preparation. The aim was to prepare a material of very similar characteristics to those of heavily degraded limestone, i.e. with high porosity and very low strength. The test specimens were prepared by pressing down limestone sand of the same grain and mineralogical composition as selected types of Leitha limestone. Microscopic analysis proved that a substrate could be prepared to match the degraded stone. A rather simple technique was developed to guarantee not only the preparation of the specimens of desired characteristics, but also sufficient homogeneity of the samples essential regarding the reproducibility of the consolidation testing results. To a certain extent the characteristics can be influenced by granulometric composition of the sand used.

A series of tests with a few types of nanolime products was carried out on test specimens prepared in this way, while various options of application and application conditions were tested and compared. Consolidation effectivity was assessed and compared mutually on the basis of mechanical characteristics measurements. Compressive strengths were compared directly, whereas the method of ultrasound transmission was used as an indirect indicator of changes in strength. Ultrasound transmission was also used to discover potential strength gradients originating in possible differences in distribution caused by application of the consolidating agent only on one side of the test specimen (a phenomenon possibly occurring in actual objects too). Consolidation effect could be proved in all the cases of the specimens. After consolidation and hardening of the consolidating agent as a result of formation of calcium carbonate from calcium hydroxide there is an increase in compressive strength as well as increased ultrasound velocity (p-waves). Changes in structure of the consolidated material and depth distribution of the consolidant were studied by microscope using optical and scanning electron microscopy.

Results of the testing were then used while applying nanolime products on several actual objects. Effective consolidation of degraded parts of stone could be proved again using ultrasound transmission.

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