Evaluation of the Effectiveness of Masonry Consolidation Treatments Based on Scratching Tomography

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Abstract: A challenge in the restoration of historical buildings is the correct identification of materials which need to be strengthened in order to guarantee their durability and the evaluation of the results of consolidation treatments which may be applied during their repair. Methods which make such a complex characterization possible are rare. This paper presents an investigation carried out at the University of Mons (Belgium) in collaboration with the technical support and control unit, restoration directorate, of the Walloon region, aiming to evaluate the effectiveness of consolidants used to strengthen stone masonry. The characterization of the materials is based on a novel semi-destructive scratching method which allows tomographic representation of the strength of the damaged and treated areas. This paper describes the experimental methodology and presents results from laboratory experiments as well as a case study.

Key words: Consolidation treatment, ethyl silicate, lime wash, scratching test, stones.

1. Introduction

Masonry materials are likely to be affected by alteration phenomena with either a natural or anthropogenic origin. As a consequence of alteration phenomena, damage may appear, affecting the quality of the materials. Within this framework, technicians engaged in the maintenance and restoration of structures use specific treatments which are designed to restore material characteristics. There are several treatments available, such as consolidant products which are generally applied to masonry aiming to improve its mechanical properties and cohesion. However, it is difficult to determine whether or not these treatments are indeed necessary. Moreover, it is very difficult to assess the extent to which the selected treatments have provided the expected effects. The literature presents several non-destructive or micro-destructive techniques that may be used in practice in order to estimate the degradation of materials as well as the impact of treatment. Unfortunately, most of these techniques are limited to qualitative data that are often insufficient for characterization [1].

The research outlined in this paper aims to propose a new testing methodology that could offer the ability to objectively quantify the level of alteration of a material as well as the effects induced by the treatments. This methodology could also be developed further for in-situ application.

2. Methodology

It has been widely discussed in the literature [2-4] that cutting tests can provide information concerning the strength of masonry materials based on the measurement of forces generated on a tool while cutting a material surface. Indeed, the tangential force
acting on a nominally sharp rectangular cutter while cutting is proportional to the intrinsic specific energy of the material being cut $\varepsilon$, the depth of cut $d$ and the cutter width $w$.

$$F_i = \varepsilon wd$$

A strong correlation exists between the intrinsic specific energy and the uniaxial compressive strength, as illustrated in Fig. 1.

Two main tests are currently in use at the University of Mons for characterizing building materials based on cutting tests (Fig. 2): the scratching test and the micro-drilling test. The analysis of the signals recorded during the tests, in conjunction with the interpretation of the phenomenological model, allows the user to quantitatively measure a material’s intrinsic specific energy which is highly correlated to mechanical properties like the uniaxial compressive strength [2-4].

Scratching based tomography consists of cutting tests using an automated shaper, thus creating a groove in the material by performing successive cuts at a pre-determined depth. The cutting depth used for this research was 125 µm, while cuts were performed at a fixed rate of 10 cm/s. The tangential and normal components of the total force generated on the cutter are recorded continuously while testing. The data acquisition frequency was set at 800 Hz to obtain an axial resolution of 125 µm. A tomography toolbox developed using the MATLAB environment was applied after testing to generate the tomography image.

A color code was applied to the tomography data to visualize the mechanical strength in two dimensions, thus mapping and characterizing the extent of altered regions inside the geo-materials. Fig. 3 illustrates the application of scratching tomography to an extruded mud brick filled with lime mortar. The heterogeneity of the mud brick and both extrusions filled with mortar can be clearly observed on the tomography images.

This technique can be combined with the micro-drilling test which can be performed in-situ in order to evaluate the effectiveness of treatments, providing means for quality control after application [5, 6]. Fig. 4 illustrates the comparison of the results obtained with scratching tomography to those obtained using the micro-drilling technique to characterize the heterogeneity of a layered limestone. The advantage of
3. Laboratory Results

Several tests were performed in the laboratory to evaluate the methodology and its ability to characterize the effectiveness of the consolidation treatments used in the field.
in Belgium for heritage conservation. Two main treatments, ethyl silicate and lime wash, are often recommended by the heritage administration in Wallonia for improving the quality of altered materials. Both treatments have been applied to different types of limestone to estimate their performance. The application of the products was conducted according to the guidelines of the BBRI-CSTC (Belgian Building Research Institute). The treated materials were tested several times at different dates after application to evaluate the evolution of the effectiveness of the treatment with time (Fig. 5).

The first tests were performed after the treatments were applied to Maastricht Limestone [7, 8]. The main results are presented in Fig. 6. In addition, tests were performed on three different limestones from Cyprus, characterized by different physical properties (e.g., porosity and mean pore size). Only the ethyl silicate treatment was applied to these stones.

4. Observations

The scratching tomography method applied to Maastricht limestone shows the effectiveness of ethyl silicate for consolidation purposes, and also illustrates that lime wash appears to be inefficient at an early age (Fig. 6). The tomography visualization makes it possible to determine the penetration depth of the treatments and to estimate the increase in resistance of the materials following the treatments.

The results from the limestones from Cyprus (Fig. 7) show that the efficiency of the treatments also depends on the properties of the rock treated. The same application seems to be ineffective on the first two samples (Kivides and Paxna) and effective on the last one (Lympia). Properties like capillarity, pore size and specific surface area of the rock pore network may be important parameters for this type of treatment and should be analyzed in detail in the future.

5. Case Study

The tomographic methodology was applied to the restoration works of the St. Christopher Church located in Racour, Belgium (Fig. 8). The church is a romano-gothic edifice built during the 14th century with Overlaar Quartzite, Gobertange Limestone and Lincent micaceous chalk. The Lincent chalk is very sensitive to weathering (Fig. 9). The heritage administration in Wallonia is in charge of the restoration works and chose to apply consolidation treatment to Lincent stone to protect it against further damage. The Civil Engineering Department of the University of Mons was contacted to evaluate the efficiency of the suggested treatments on this particular Lincent micaceous chalk [9].

Blocks of Lincent stone of sufficient size for laboratory tests were sampled from the ruins of the old St. Peter Church in Lincent to evaluate the performance of the two consolidation treatments envisaged for the restoration of the Racour church: lime wash and ethyl silicate. The results obtained from the two treatments, two months after their application, are illustrated by the tomography images in Fig. 10 (lime wash treatment) and Fig. 11 (ethyl silicate treatment). In both cases, it is observed that the blocks of Lincent chalk treated were initially strongly heterogeneous. The variation of the colors within the material is directly proportional to the variation of local resistance. The results of the evaluation of the consolidation treatments are absolutely not convincing at the present time:

1. The lime wash does not cause any apparent modification in terms of mechanical resistance, but does however tend to form a film, which could fill the surface porosity of the material and reduce its drying rate, thus increasing the likelihood of surface disintegration or scaling in the event of freezing or salt crystallization;

2. The ethyl silicate increases the mechanical strength of the material surface very superficially, from a thickness of a few tens of microns to about a hundred microns at most. The reinforced zone does not appear continuous.
Fig. 5  Illustration of treatment application and testing procedure.

Fig. 6  Tomographic visualization of: (a) ethyl silicate; (b) lime wash treatments on Maastricht Limestone; the color code corresponds to the force (N) required to scratch the material.
Fig. 7  Tomographic visualization of the stone before (left) and after treatment (right); the color code corresponds to the force (N) required to scratch the material.
Fig. 8  St. Christopher Church, Racour, Belgium.

Fig. 9  Illustration of the weathering of Lincent stone.

Fig. 10  Tomography of Lincent stone after lime wash treatment; the color code corresponds to the force (N) required to scratch the material.
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6. Conclusions and Prospects

Scratching based tomography, developed at the University of Mons, has shown its capacity to characterize the effectiveness of consolidation treatments used in heritage conservation. This new technology makes it possible to assess characteristics, such as penetration depth and any increase to the strength of the materials, which are fundamental to the effectiveness of the treatments. Laboratory experiments conducted on several types of stone have shown that the treatments in use in Belgium are not efficient on any of the stones tested, except perhaps on Lympia stone. Therefore, it is recommended to perform this type of testing to assess the consolidant performance before deciding on any type of consolidation treatment. The application of the scratching tomography methodology in a case study makes it possible to avoid improper solutions for the conservation of weathered stone.

Considering the preliminary results obtained from this research, several complementary investigations are now in progress to investigate the influence of physical parameters, such as porosity, capillarity and pore size, on the effectiveness of the ethyl silicate consolidation treatments. The authors are also of the opinion that the effectiveness of the surface treatments cannot be evaluated correctly without being accompanied by accelerated ageing tests of the treated materials.

References


