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INVESTIGATION OF THE DEGRADATION PHENOMENA OF THE LUXEMBOURG SANDSTONE IN THE ROYAL MUSEUM FOR CENTRAL AFRICA (BELGIUM)

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Abstract

The Royal Museum for Central Africa in Tervuren was built in the beginning of the 20th century. The outer walls and ornamental elements were almost exclusively constructed in massive blocks of Luxembourg sandstone, a stone well suited as building material. Despite the stated good quality, the facades locally suffer from exposure to weathering. Moreover, certain zones show severe damage due to rain water infiltration originating from defects in the water evacuation system which is entirely hidden within the walls. As a consequence, important damage to the sandstone blocks in the form of crack-formation, scaling, spalling and (salt) staining, is noticed.

This paper presents the results of an investigation carried out in the framework of the restoration strategy aiming to explain degradation and damage phenomena in relation to the properties and varieties of Luxembourg sandstone. Detailed visual observations with regard to the architectural concept was followed by a sampling plan and a test program. Physical and microscopic analysis allowed to establish the relationship between rock type, colour and weathering effects. The test program consisted of the determination of physical and mineralogical properties, hardness profiles obtained by means of the portable DRMS device (Drilling Resistance Measurement System), ultrasound velocity measurements and the determination of the actual salt contamination. The strengthening effect of a number of consolidation tests, using tetraethoxysilane (TEOS), was also evaluated by means of hardness profiles.

Keywords: Luxembourg sandstone, degradation, restoration strategy

1. Introduction

At the instigation of the Belgian King Leopold II, the Royal Museum for Central Africa in Tervuren (Figure 1) was a cornerstone of his glorious masterplan for the city of Brussels at the dawn of the 20th century. The concept for the museum was inspired by the French Beaux Arts style of the museum Petit Palais in Paris, and also designed by the French architect Charles Girault. This huge monumental construction is a typical museum building in the tradition of the contemporaneous fine arts musea in several European capital cities.

Almost entirely constructed with massive blocks of Luxembourg sandstone, a stone well suited as a building material in the prevailing oceanic temperate climate (Camerman 1954), the building is suffering from degradation processes due to weathering. In several locations severe damage is observed as a result of rainwater infiltrations. The entire water evacuation system is constructed inside the walls and can only be inspected from its entry points on the roof. Interruptions in the leaded pipe network caused large amounts of water to infiltrate in the walls during long periods. This caused important damage to the sandstone blocks with crack-formation, scaling, spalling and (salt) staining as a result (Figures 2 and 3).

Figure 1. Royal Museum for Central Africa at Tervuren.

Figure 2. (Salt) staining underneath the cornice where the water evacuation system is hidden behind the wall. Two varieties of the Luxembourg sandstone can be seen: a warm yellow coloured variety below the cornice and a light grayish one above it.

Figure 3. Scaling of the calcareous sandstone blocks underneath the cornice.

This paper presents the results of an investigation with as objective to explain the degradation phenomena in relation to the properties and the possible varieties of the Luxembourg sandstone. These varieties are visually characterized by a warm yellow colored stone, which is present in the majority of the building (lower part in Figure 2) and a light grayish colored one (upper part in Figure 2). Moreover, this investigation aimed to identify the damage phenomena causing the unsystematic breaking and falling down of square blocks from the dentil profile underneath the cornice.

Both varieties of the Luxembourg sandstone were investigated to determine their differences in porosity, pore size distribution, ultrasound velocity and petrographic properties. The diagnosis of the damage phenomena is based on in-situ ultrasound velocity measurements, quantitative determination of the salt load and hardness profiles obtained with a portable DRMS (Drilling Resistance Measurement System). These investigations were preceded by a detailed visual observation of the building to determine the sampling locations and a test program with regard to the architectural concept and detailing. The strengthening effect of a number of consolidation tests, carried out using tetraethoxysilane (TEOS), was evaluated as well by means of hardness profiles.

2. Experimental part

A petrographic examination by means of thin sections was performed on core drilling samples (Logitech PM5 Autolap, ZEISS Axioplan).

The porosity and pore size distribution were determined by mercury porosimetry (Micromeritics Autopore IV).

Ultrasound velocity measurements were carried out in situ with a BP 7 Steinkamp in 10 selected locations on corner blocks, balusters and dentils. The measurements on corner blocks and dentils were carried out by positioning the transmitter and the receiver at a distance of 7.5 cm from the corner, therefore a travel distance of 10.6 cm for the sound waves was realized. On the corner blocks, three measurements were carried out per stone block from which an average is calculated. The measurements on the balusters were carried out by positioning each sensor on opposite sides of the rounded stone, creating a travel distance between 9.7 and 10 cm. Two measurements in orthogonal directions were carried out per baluster, one measurement per dentil.

Hardness profiles were obtained by Drilling Resistance Measurements (DRMS, Sint Technology DRMS Cordless 2006). This device continuously records during the drilling the force (N) experienced by the drillbit according to predetermined experimental parameters. The measurements are performed according to the following parameters:
Drilling depth: maximum 40 mm
Rotation speed: 600 rpm
Drilling speed: 5 mm/min

The applied consolidation product is a solvent-free one-component consolidant based on silica acid esters with a dry weight of 53 % (Artisil SVS 100). The product is applied by spraying. The number of treatments is 3 with at least one day between successive applications.

The salt load is determined by analysis of powder drilled (Ø 5 mm) samples lifted at different depths in the stone (0 to 1, 1 to 3 and 3 to 5 cm). The samples are dried until constant weight at 60°C. Approximately 1 g of the dried sample is added to 100 ml of demineralized and deionized water, it is well mixed, and filtered. The ion content of the extract is analyzed quantitatively by means of ion chromatography (IC, Metrohm 761 Compact IC). The results are expressed as weight percentage of the dry sample.

3. Results and discussion

a. Luxembourg sandstone

The Luxembourg sandstone was a significant building material for the construction or renovation of monuments in Flanders and Brussels from the end of the 19th century till the beginning of the 20th century. As the name indicates the stone is quarried in the Grand Duchy of Luxembourg, specifically in Ernzen (Larochette), Dillingen and Gilsdorf as well as in the Belgian province of Luxembourg (Fontenoille, Virton,…) (De Naeyer et al 2005, Groessens 2007 and Stahl 1932).

Petrographic analysis of 10 core drilling samples, revealed two varieties of Luxembourg sandstone that belong to the same geological formation. While the calcareous sandstone is the main building material used for the museum, almost pure sandstone is used for the balusters. Both varieties are characterized by a varying pyrite content. The warm yellow color of the calcareous stone of the Ernzen type is a result of the high pyrite content. Light gray sandstone of the Dillingen type has a lower pyrite content and is restricted to the exposed upper part of the masonry (Figure 2). A lower pyrite content and increased porosity of the Dillingen type rocks might be a characteristic of the sedimentary deposit in the stone quarry where a natural leaching due to groundwater percolation took place. Some calcareous sandstone blocks of the museum building exposed to weathering exhibit a similar bleaching. The majority of the sand grains of both varieties display a size between 100 and 300 µm while the average total porosity varies from 16.6 to 19.7 vol. % consisting of pores with a size generally ranging from 1 to 20 µm with a maximum peak at approximately 15 µm.

b. Ultrasound velocity measurements – assessment of the dentil profile

The principle of ultrasound velocity measurements is based on the determination of the velocity at which a sound wave passes through a sample of known size. The results are indicative for the assessment of the quality of a stone material in terms of cohesion, porosity and homogeneity. The overall results from the in situ measurements on 28 corner blocks, 67 dentils and 30 balusters revealed a sound velocity varying from 2018 to 2944 m.s^{-1}. Figure 4 illustrates some results obtained for both varieties (calcareous sandstone and pure sandstone). The graphs show how the results of the ultrasound velocity measurements are partly superimposed and thus are not suitable to identify the stone varieties or to characterize the architectural elements. However, from the measurements on the dentil profile (Figure 5) the presence of internal cracks can be derived from the ultrasound velocity. Values lower than 2000 m.s^{-1} are considered an indicator for internal damage being already present.

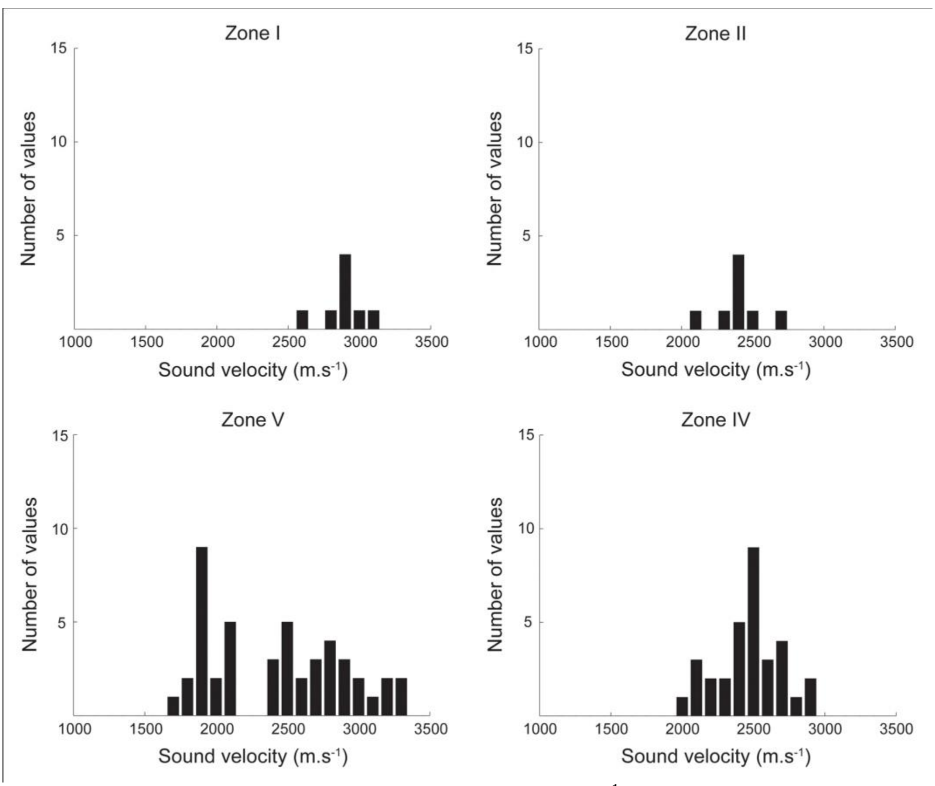

Figure 4. Results of ultrasound velocity measurements (m.s^{-1}) of stone corner blocks (variety calcareous sandstone, zones I (top left) and II (top right)), dentils (variety calcareous sandstone, zone V, bottom left) and balusters (variety pure sandstone, zone IV, bottom right).

Figure 5. Zone below the cornice showing extensive efflorescence of gypsum and loss of some dentils. The outer cm of the stone contains gypsum (2 wt%, further decreasing with depth).

Apart from the damaged dentils, which have already broken off at their rear end, superficial flaking and extensive efflorescence of gypsum can be observed in some areas. Quantitative salt measurements proved that the outer centimeter of the dentil profile contains locally up to 2.2 wt% of gypsum, decreasing with depth. Generally, gypsum is not considered the cause for the damage because of its low solubility and migration properties (Charola et al 2007). However, it cannot be excluded that, due to the high quantity of water infiltrations, gypsum might play a role in the general deterioration phenomenon as an initiator of microfissuration.

The state of conservation of the individual stone blocks, containing between 6 and 12 sculpted dentils, was assessed and criteria were defined based on the results of the ultrasound velocity measurements to assess the risk for any future damage. From the analysis of the results obtained on stone blocks with already missing dentils or where internal damage could be assessed based on the ultrasound measurements, ultrasound velocities above 2800 $m.s^{-1}$ are considered sufficient for the stone blocks to be in a sound condition and that future damage is unlikely. From these findings it is concluded that only about 10 % of the sculpted stones are not in danger of exhibiting damage in the future. The seemingly random breaking off of the dentils can be explained by high amounts of salty water infiltration, possibly engraved by the mechanical forces exerted while sculpturing the dentil profiles, and which resulted in the formation of internal micro-cracks.

c. Salt contamination

The stones directly under the cornice (Figure 2) display at several locations scaling and large areas of gypsum efflorescences. In the outer cm of the Luxembourg sandstone a gypsum content of up to 6 wt% and more rare amounts of nitrates allied to potassium are measured. A systematic correlation between the intensity of gypsum efflorescence, the gypsum content in the stone and the observed damage could not be found. Figure 6 illustrates where gypsum is intensively deposited at the surface following water infiltrations in the wall, while the salt load measured in the stone is almost zero.

Salt extraction is futile due to the low solubility of gypsum. It is expected that proper maintenance interventions to stop further water infiltration will prevent the continuation of the deterioration processes.

Figure 6. A high amount of gypsum efflorescence is seen, while scarce amounts of salts are detected in the underlying stone.

In some cases, as presented in Figure 3, severe scaling is observed while almost no salts are detected in the stone. Supposedly micro-cracks were formed that are a result of the transformation of lime into gypsum and the migration of gypsum to the lower parts of the wall, being transported by the high water load. Once micro-cracks are formed damage caused by freeze-thaw cycles cannot be excluded, despite the fact that the Luxembourg sandstone is considered frost-resistant (Dusar et al 2009).

Efflorescence of sodium sulfate with an open fern structure is detected in several locations, especially in areas near the repointing with cement mortar. The surface in these areas contains up to 4 wt% sodium sulfate decreasing with depth. A salt extraction with a poultice made from kaolin clay, sand and cellulose fibers is recommended to prevent further material loss.

d. Mechanical surface properties

Hardness profiles obtained by the DRMS device show that the global conservation state of the Luxembourg sandstone is good. Surface weathering generally ranges from 3 to 7 mm depth and reaches exceptionally a depth of 11 mm. A rather positive consolidation effect was obtained after three applications with a 100% product of TEOS (Figure 7, upper part). After the treatment a higher mechanical resistance of the weathered areas is measured at certain locations when compared to the underlying stone material.

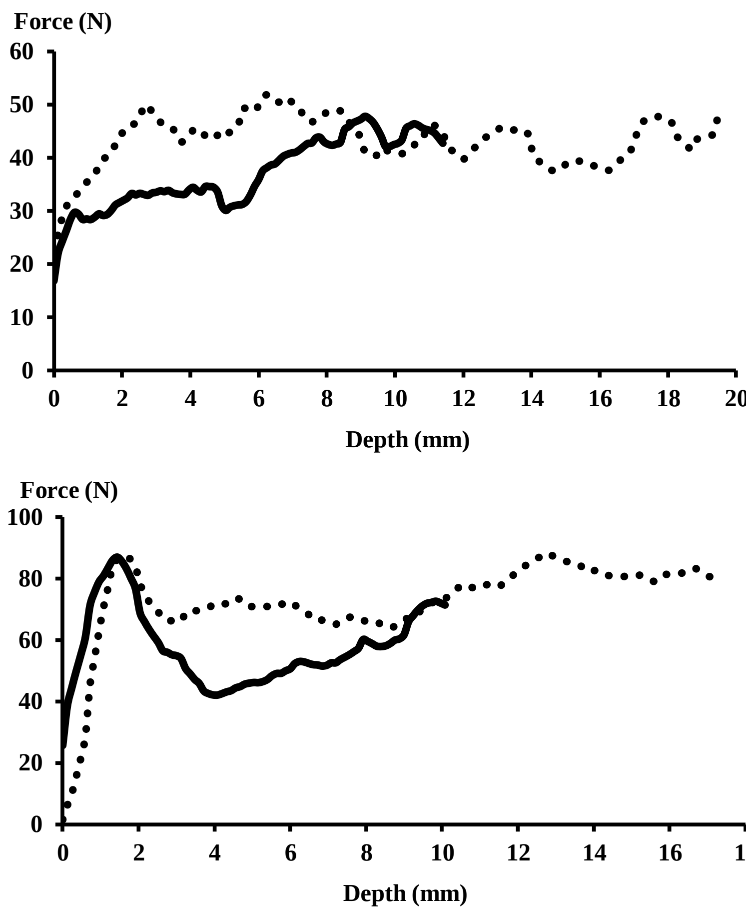

Figure 7. Hardness profiles of Luxembourg sandstone characterized by a weathered zone of 7 mm (upper part) and by a calcinated layer of a few millimeter depth (lower part) before (solid line) and after (dotted line) 3 applications with a 100% solution of TEOS.

The carbonate content in the Luxembourg sandstone is between 15 to 34% (Dusar et al 2009) and results locally in the formation of a so called calcinated layer or hard superficial millimetric layer, which is formed after the construction of the building. Underneath this layer a somewhat weathered layer is noticed. The consolidation using

TEOS insufficiently improved the mechanical properties of the weathered area underneath the dense outer layer (Figure 7, lower part).

Hence, it was finally recommended to opt for two applications of the product, which corresponds to a consumption of approximately 2 $l.m^{-2}$.

4. Conclusions

An investigation was carried out in the framework of the restoration strategy aiming to explain degradation and damage phenomena in relation to the properties and varieties of Luxembourg sandstone.

Petrographic analysis revealed two varieties of Luxembourg sandstone that belong to the same geological formation: a calcareous sandstone being the main building material used for the museum and an almost pure sandstone used for the balusters.

Ultrasound velocity measurements proved to be not suitable to identify the stone varieties or to characterize the architectural elements.

From the results of salt analyses, a general contamination with gypsum is concluded. A systematic correlation between the intensity of gypsum efflorescence, the gypsum content in the stone and the observed damage could not be found. Severe scaling is observed although locally almost no salts are detected in the stone. Supposedly micro-cracks were formed that are a result of the transformation of lime into gypsum and the migration of gypsum to the lower parts of the wall, being transported by the high water load.

A rather positive consolidation effect was obtained with a 100% product of TEOS applied on stone blocks showing surface alteration generally ranging from 3 to 7 mm. However, in case of the presence of an outer calcinated layer, the weathered layer underneath it was insufficiently consolidated.

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