LABORATÓRIO NACIONAL
DE ENGENHARIA CIVIL

International Symposium

Stone Consolidation in Cultural Heritage

Extended Abstracts

Editors: José Delgado Rodrigues and Dória Costa

LNEC, Lisbon, 23-25 March, 2022

Marble biomineralisation: Pilot application results at the Arch of Septimius Severus

José Delgado Rodrigues
Laboratório Nacional de Engenharia Civil, Lisbon, Portugal, delgado@lnec.pt
João Aguiar
Nova Conservação, S.A., Lisbon, Portugal, joaoaguiar@ncrestauro.pt
Nuno Proença
Nova Conservação, S.A., Lisbon, Portugal, nunoproenca@ncrestauro.pt
Maria João Revez
Nova Conservação, S.A., Lisbon, Portugal, mariajoaorevez@ncrestauro.pt

KEY-WORDS: Pentelic marble sugaring; biomineralisation; onsite testing; compatible consolidation; sustainable heritage conservation

INTRODUCTION

The Arch of Septimius Severus, in richly decorated Pentelic marble, was erected in the Roman Forum in 203 CE by the Senate to celebrate the victories of its namesake Emperor against the Parthians. It consists of three arches, framed by Corinthian columns with plinths featuring Roman soldiers with Parthian prisoners; the campaigns of Septimius against the Parthians are depicted above the lateral arches.

The monument's sculpted surfaces showed advanced decay, with active degradation processes inducing clear phenomena of disintegration, flaking, and fracturing, and causing the loss of considerable portions of stone material. This reality, affecting one of the most valuable monuments of the Roman Forum, required all stabilisation works to prove fully compatible with the fragility of these millennia-old marbles.

Also, this exceptional Arch sits in the Colosseum Archaeological Park, a natural setting decisively contributing to the cultural significance of its World Heritage-listed archaeological remains. Thus, the Park managing authority, Parco Archeologico del Colosseo, launched the PArCo Green project, fostering greener practices in all Park activities, including (heritage) conservation.

The compatible conservation of a work of such outstanding cultural value and the environmental and sustainability concerns of the Parco Archeologico del Colosseo were the premises upon which a bio-consolidation pilot intervention was implemented on the stone surfaces affected by problems of disintegration and pulverisation. The main goal of this study was to validate biomineralisation as a method to consolidate deteriorated marble surfaces, especially those affected by sand disintegration patterns.

PILOT

Treated area

The zone selected for biomineralisation trials comprised three planes (south, west and north) of a plinth located in the south pillar of the Arch, around 6 m² in area, with figurative reliefs carved in marble, still legible – significant lacunae notwithstanding –, some with grooves from the original carving tools (Fig.1).

Fig. 1: West plane of the plinth before (left) and after (right) the biomineralisation treatment.

The pilot area, like all of the Arch's surfaces, was affected by cracks, fractures, scaling, and chipping, causing instability and significant mass losses. Sand disintegration ('sugaring'), a typical deterioration pattern on exposed marble surfaces, was extensive, especially on the sculpted protruding parts. Soiling and incipient biocolonisation were also visible, as well as metal clips and mortar fills from previous interventions.

Procedures

Surface treatment

The implemented biomineralisation treatment is based on the Granada method, with a selective activation of carbonatogenic bacteria residing on the marble's deteriorated surfaces via application of a nutrient medium (Jroundi *et al*. 2010; Rodriguez-Navarro *et al.* 2015), manufactured by KBYO under the trade name Myxostone-M3P®. The effective presence of carbonatogenic strains in the Arch was analytically confirmed.

These are aerobic bacteria sensitive to ultraviolet radiation, and therefore treatment requires UV-sheltering and air circulation, achieved here by superimposing layers of common black woven plastic nets. To avoid contamination, a stringent protocol was followed to manipulate, clean, and store working tools, instruments, and containers. After initial characterisation tests, the product was applied for 8 consecutive days; the treated area remained protected for 30 days to allow process completion, after which a new set of characterisation tests was carried out. Visually, there were no colour alterations to the stone substrates (Fig.1).

Characterisation tests

Given the significance of the object, only a few methods could be considered: the peeling test, providing a direct measure of treatment-induced changes in surface cohesion; and the sponge test, which reflects treatment-induced changes in stone porosity, allowing an indirect assessment of the consolidation action.

The peeling test, following the protocol in Drdácký *et al.* (2012), was applied to surfaces without any decorative detail, with most measurements obtained on an uncarved surface left by the detachment of a large piece of stone. The sponge test, using the Pardini and Tiano (2004) method, was carried out on flat surfaces where good contact between the sponge and the stone could be achieved.

RESULTS AND DISCUSSION

Fig. 2 displays the results of the water absorption test performed in the same areas before and after treatment. Absorption after treatment was significantly reduced in both areas, demonstrating that the amount of calcite deposited via bioconsolidation is large enough to have a clear impact in absorption features.

Results of the peeling tests are also shown in Fig. 2. Since before and after tests must be performed in distinct zones, the graph presents average values obtained in each condition (untreated/treated). Averages were computed point by point following the sequence of measurements made in a same test spot; in total, 10 and 14 areas were tested, respectively, before and after treatment, to ensure result robustness. The peeling tests showed a significant cohesion increase after treatment, with mass losses 5-10 times lower than those before treatment.

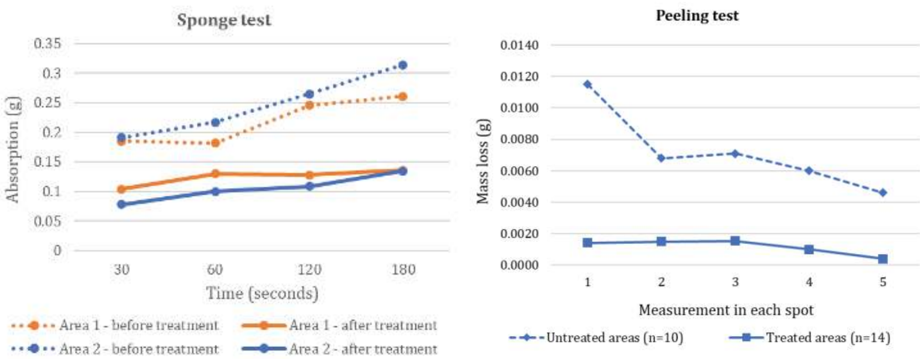

Fig. 2: Sponge test (left) and peeling test (right) results before and after treatment.

The Granada biomineralisation method, with Mixostone-M3P© as nutrient medium, has been proven effective and compatible in the lab (Rodriguez-Navarro *et al*. 2003) and onsite (Rodriguez-Navarro *et al*. 2015; Ettenauer *et al*. 2011; Delgado Rodrigues and Ferreira Pinto 2019). The tests in the Septimius Severus pilot corroborate these findings, indicating that consolidation was effectively achieved.

CONCLUSIONS

Gently touching the treated areas showed a clear improvement in the stability of the most deteriorated areas, and the tests demonstrated that the treatment was effective enough to induce some surface strengthening and reduce mass loss. On surfaces this valuable, consolidation must be carefully balanced to avoid excessive contrasts between treated areas and underlying substrates, to prevent long-term detrimental effects. The calcitic nature of both substrate and bioconsolidation product and the clear but low resistance increase confirm biomineralisation as a highly compatible process (Delgado Rodrigues and Grossi 2007), suitable for delicate and valuable surfaces as an upscaling treatment (Delgado Rodrigues and Ferreira Pinto 2019).

ACKNOWLEDGEMENTS

The invaluable support and assistance in all project phases, as well as the permission to disseminate these results, are hereby gratefully acknowledged to the Parco Archeologico del Colosseo, and particularly Federica Rinaldi, Alessandro Lugari and Angelica Pujia. Further thanks are due to Enrico Montanelli, from Montanelli Restauri s.r.l. and to Marco Bartolini, from the Istituto Centrale per il Restauro, for their support; and to Pepe Cabello from KBYO Biological for the kind supplying of Myxostone-M3P©.

References

Delgado Rodrigues, J. and A.P. Ferreira Pinto. 2019 - "Stone consolidation by biomineralisation. Contribution for a new conceptual and practical approach to consolidate soft decayed limestones." *J. Cult. Herit.* 39: 82-92. doi:10.1016/j.culher.2019.04.022.

Delgado Rodrigues, J. and A. Grossi. 2007 - "Indicators and ratings for the compatibility assessment of conservation interventions." *J. Cult. Herit.* 8 (1): 32–43. doi:10.1016/j.culher.2006.04.007.

Drdácký, M., J. Lesak, S. Rescic, Z. Slızkova, P. Tiano, and J. Valach. 2012 - "Standardization of peeling tests for assessing the cohesion and consolidation characteristics of historic stone surfaces." *Mater Struct* 45 (4): 505–520. doi:10.1617/s11527-011-9778-x.

Ettenauer, J., G. Piñar, K. Sterflinger, M.T. Gonzalez-Muñoz, and F. Jroundi. 2011 - "Molecular monitoring of the microbial dynamics occurring on historical limestone buildings during and after the in situ application of different bio-consolidation treatments." *Sci. Total Environ.* 409 (24): 5337-5352. 10.1016/j.scitotenv.2011.08.063.

Jroundi, F., A. Fernández Vivas, C. Rodriguez-Navarro, E.J. Bedmar, and M.T. González-Muñoz. 2010 - "Bioconservation of deteriorated monumental calcarenite stone and identification of bacteria with carbonatogenic activity." *Microb. Ecol.* 60 (1): 39–54. doi:10.1007/s00248-010-9665-y.

Pardini, C., and P. Tiano. 2004 - "Valutazione in situ dei trattamenti protettivi per il materiale lapideo. Proposta di una nuova semplice metodologia." *ARKOS* 5: 32–38.

Rodriguez-Navarro, C., F. Jroundi, and M.T. Gonzalez-Muñoz. 2015 - "Stone consolidation by bacterial carbonatogenesis: Evaluation of *in situ* applications." *Restor. Build. Monum.* 21 (1): 9-20. doi:10.1515/rbm-2015-0002.

Rodriguez-Navarro, C., M. Rodriguez-Gallego, K. Ben Chekroun, and M.T. Gonzalez-Muñoz. 2003 - "Conservation of ornamental stone by Myxococcus Xanthus-induced carbonate biomineralization." *Appl. Environ. Microbiol.* 69 (4): 2182-2193. doi:10.1128/AEM.69.4.2182-2193.2003.