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**Application of micro X-ray fluorescence and micro computed tomography to the study of laser cleaning efficiency on limestone monuments covered by black crusts**

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**Abstract**

Laser cleaning is widely used to remove black crusts from weathered limestone monuments. The cleaning efficiency is commonly tested using conventional analytical techniques, which do not allow to analyze the same sample before and after the treatment. In this paper, micro computed tomography ( $\mu$ -CT) and micro X-ray fluorescence spectroscopy ( $\mu$ -XRF) techniques were used for the first time to evaluate the laser cleaning efficiency on two different encrusted quoins collected from a limestone monument. Analyses were carried out non-destructively on the same portion of the two lithotypes before and after the treatment.  $\mu$ -XRF confirmed the presence of gypsum in the black crust, and showed a marked decrease of S and other typical elements after laser cleaning of both samples.  $\mu$ -CT clearly showed the different structure of limestone before and after cleaning and the crust portion removed by the laser. The combination of the two techniques allowed to assess that, even if the two samples had a similar chemical composition, their response to laser cleaning was different on dependence of their different fabric/structure. In fact, in one sample calcium sulphate was still partially retained also after the black crust removal, whereas in the other sample the sulphate layer was almost completely ablated due to its more compact structure. In both cases, laser cleaning operation was shown not to cause any structural modification or mechanical damage

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