18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 180–181
Paper #312

APLICATION OF HIGH-RESOLUTION X-RAY RADIOGRAPHY FOR MONITORING THE PENETRATION DEPTH OF CONSOLIDANTS IN NATURAL BUILDING STONES

F. Krejci, J. Jakubek*, M. Slavikova, P. Kotlik**

Abstract: *For conservation of the built cultural heritage the application of conservation products like consolidants or water repellents is often used. A natural stone is, however, a complicated heterogeneous porous system making the process of consolidation dependent on many variables. The selection of a suitable consolidant and consolidation conditions therefore remains a complex issue. The impregnation depth is a key factor for the assessment of the treatment efficiency. So far, the methods used for monitoring the penetration depth usually require a cut of the investigated stone. These destructive approaches, however, significantly reduces the number and choice of the investigated cuts. The methods, furthermore, do not allow dynamical studies of the impregnation process. The combination of state-of-the-art hybrid pixel semiconductor detectors with newly available micro-focus X-ray sources makes X-ray radiography an ideal non-destructive tool for the penetration depth monitoring. In this contribution, we present results of high-resolution X-ray radiography applied for the penetration depth monitoring of polymer consolidants in the Opuka stone.*

Keywords: ***X-ray radiography, computed tomography, stone, consolidation, penetration depth, Opuka***

Cretaceous sandy marlstone, called in the Czech Republic and other eastern European countries "Opuka", was a common building stone in Bohemia from the beginning of stone architecture in the early mediaeval epoch. As the most ancient building stone in Prague, Opuka was used for historical monumental edifices such as churches, fortresses, castles, fortifications as well as burgher's houses. The consolidation of this stone thus plays a key role in preservation of the Czech building cultural heritage (Kotlik 2000).

Using the radiography technique, the visualization of the consolidant inside the stone depends on the contrast in X-ray absorption between the mineral constituents of the stone material and the consolidant itself. Besides the stone sample parameters, the quality of the resultant visualization is dependent on the CT configuration used given by the X-ray source parameters (used photon flux, tube spectrum) and in particular by the X-ray detector. In the case, when the total amount of the consolidation product applied is very small, the contrast between the treated and untreated part of the stone is very small and the exact localization of the penetration depth and the consolidant distribution in the stone remains very difficult to determine. A clear visualization of the consolidant is then often accomplished by doping these consolidation products with a contrast agent that causes a higher attenuation for X-rays (Cnudde et al. 2004, Slavikova et al. 2012).

By adding a product with higher attenuation for X-rays to the original conservation products, higher contrast can be created between the stone material and the conservation products. On the other hand, due to doping of the original products, the process of consolidation can be in certain characteristics significantly influenced (the penetration ability of consolidants is often not exactly the same as the penetration ability of commercial consolidation products). As these differences are reduced with decreasing concentration of the contrast agent, the application of X-ray radiography with high sensitivity enabling detection of very small variations in attenuation in the stone is desired.

* Ing. Frantisek Krejci, Ing. Jan Jakubek, Ph.D.: Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horska 3a/22, Prague 2, 12800, Czech Republic; CZ, e-mail: jan.jakubek@utef.cvut.cz, frantisek.krejci@utef.cvut.cz

** Ing. Monika Slavikova, Doc. Ing. Petr Kotlik, CSc. Institute of Chemical Technology, Department of Chemical Technology of Monuments Conservation, Technicka 5, Prague 6, 166 28, Czech Republic, e-mail: slavikom@vscht.cz, petr.kotlik@vscht.cz

Recent advances in semiconductor technology allow for the construction of hybrid planar pixelated detectors. The pixel detectors of Medipix type (X. Llopart et al. 2001) contain highly integrated signal electronics with a digital counter per pixel. Thus, each individual X-ray photon impinging on the detector is processed independently – the signal is amplified, discriminated and counted. Moreover, the counter is incremented without any dark current and with full suppression of electronic noise. Thanks to the digital integration, the result (e.g. radiograph) is absolutely linear and the dynamic range is virtually unlimited (in practice limited just by the number of detected photons, Jakůbek 2007). Such advantages do not exist in other types of detectors such as charge integrating devices (e.g. flat panels and CCDs) which suffer from limited dynamic range, limited linearity, noise integration and non-zero dark current. In this contribution, we present the application of Medipix detector technology for monitoring the penetration depth of consolidants in the Opuka by means of X-ray radiography.

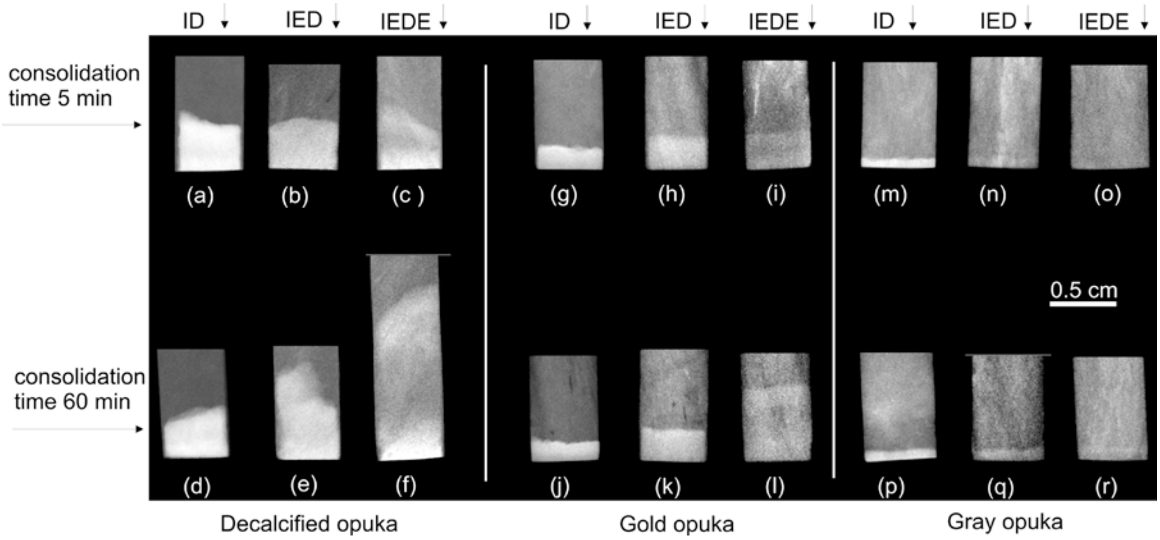

Fig. 1 X-ray radiographs of three different Opuka stone samples impregnated for 5 min (above) and 60 min (below) with consolidation mixtures containing 97 % (ID), 48 % (IED) and 4 % (IEDE) of the contrast agent. The penetration of consolidants is visualized in white. Besides the penetration depth monitoring it is also possible to visualize Opuka stone sedimentary layers (nicely visible in radiograms (h),(n) and (e)) or consolidant distribution inhomogenities – for example, the consolidants flow is divided into two fronts in radiograms (c), (f), and (i)) (Slavikova et al. 2012).

We demonstrate that the application of X-ray radiography utilizing semiconductor particle-counting detectors stands out as a powerful tool in research of consolidants inside natural building stones (see Fig. 1). The capabilities of this technique are demonstrated on simple projections X-ray radiography as well as computed tomography used for monitoring of consolidant in Opuka. The study can provide not only a basic step for additional knowledge on the suitability of investigated products for the treatment of the Opuka stone type, but also the study can serve as an instrumental and methodological work applicable for treatment of other stone types.

References

Bayer, K. (2008), Možnosti hodnocení efektivity konsolidace porézních anorganických materiálů, in: Padesát let používání organokřemičitanů na území České republiky, *Proceedings of ICOMOS* (in Czech), Národní muzeum, Národní památkový ústav, 35–42.

Cnudde, V. et al. (2004), X-ray micro-CT used for the localization of water repellents and consolidants imide natural building stones, *Material Characterization*, 53, 259-271.

Jakůbek, J. (2007), Data processing and image reconstruction methods for pixel detectors, *Nuclear Instruments and Methods in Physics Research A*, 576, 223-234.

Kotlík, P. (2000), Opuka, STOP (Society for Technology protection of monuments), (in Czech), Praha.

Llopart, X., et al. (2001), *IEEE Transactions on Nuclear Science* , 49, 2279-2283.

Slavikova, M. et al. (2012), X-ray radiography and tomography for monitoring the penetration depth of consolidants in Opuka – the building stone of Prague monuments, *Journal of Cultural Heritage*, in print.