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Corrosion of Steel in Concrete Seen through Neutron and X-Ray Tomography

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In a recent study, corrosion of reinforcement steel within reinforced concrete samples was observed and quantified non-destructively. This is one of the first successful attempts at employing multimodal neutron and X-ray tomography for the identification of corrosion products in reinforced concrete.

What makes the use of imaging techniques uniquely powerful in the context of reinforced concrete is their nondestructive nature: the chemical composition of corrosion products rapidly changes when exposed to air, thus making it difficult to assess both their composition and distributions with the more traditional, yet destructive, tests. Additionally, the use of X-rays alone is very detrimentally affected by the high attenuation of the reinforcement bar embedded in the concrete.

The distribution of the corrosion products and their expansion coefficients are two fundamental parameters when modeling the corrosion process in concrete structures. Corrosion products occupy a volume larger than the steel they come from, but the ratio between the original steel volume and one of the corrosion products may vary between 2.2 and 6.4 [1], depending on the availability of hydrogen and oxygen. Additionally, the distribution of corrosion products, and their expansion coefficient, is expected to be influenced by the presence of voids and defects in the concrete surrounding the reinforcement bar.

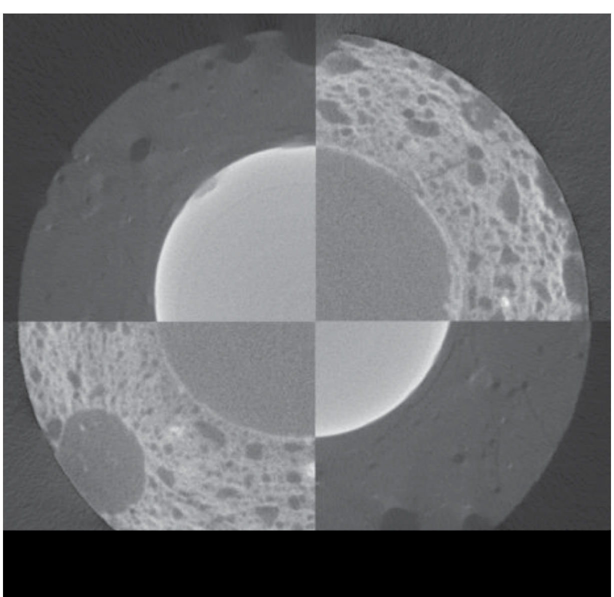

Figure 1. A cross section of a corroded reinforced concrete sample is shown. Neutron and X-ray data are superimposed, thus the complimentary nature of the two techniques can be observed.

It is in this context that neutron imaging, combined with X-ray tomography, proves to be extremely valuable. Since corrosion products are a combination of iron, hydrogen and oxygen, the high absorption coefficient of hydrogen makes neutron imaging an ideal probe to assess the corrosion products in concrete. However, other aspects of the composition of the concrete are harder to capture with neutron imaging alone. A reinforced concrete sample usually comprises steel, cement paste, aggregates, air voids, and corrosion products, when present. Of these, aggregates and pores are hard to distinguish from neutron imaging data alone. Nevertheless, the use of X-rays, to which voids are almost transparent, is pivotal in providing all the information necessary for rigorously segmenting the image, that is, for discerning the individual components of the concrete to assess the interplay between corrosion, porosity and overall sample geometry. Figure 1 shows a cross-sectional view of a reinforced concrete sample, after neutron and X-ray data were aligned and superimposed.

The identification of the different phases of the image in Figure 1 allows to quantify the corrosion products in the sample and thus, to estimate the expansion coefficient of the corrosion products.

The presented study focuses on two corroded reinforced concrete samples, clearly showing the applicability of multimodal neutron and X-ray tomography for the identification of key metrics for understanding and modeling the corrosion process in reinforced concrete structures.

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