A method for examining water absorption in sand using fast neutron radiography

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Abstract. Water concentration in porous media is an important aspect when inferring the structural integrity of the building framework. A need has arisen to determine this water content. Experiments were conducted at the PTB cyclotron making use of a 6.6 MeV fast neutron beam and fast neutron radiography to follow the uptake of water through porous media. The observed benefit of fast neutrons is the ability to interrogate thicker samples. From the resulting radiographs, the presence of water absorbed as well as the rate of absorption is shown.

1. Introduction

The water content available in high strength concrete and sand is important in buildings where knowledge of the structural integrity is essential. Slowing of the cracking process in concrete can be better understood when the water content within dense mixtures is known[1]. Water content within the pores of a concrete structure has a direct relation to its strength and effective safe lifetime. Testing the sample for porosity, sorbtivity and water retention capability is a traditionally destructive processes and does not allow for quick testing on site [2].

Thermal neutron radiography has been used to examine the porosity and presence of water in a sample of prepared concrete and sand [3]. Due to the attenuation of thermal neutrons by hydrogen, thermal neutron radiography was used to determined the amount of water absorbed [4].

Sample thickness limits the thermal neutron radiography technique, due to the penetration depth of the thermal neutrons and compromises the achievable contrast as the sample thickness grows. Fast neutrons have a higher penetration capability through dense materials than thermal neutrons but a lower attenuation for lighter elements (hydrogen and oxygen). Fast neutron radiography has been used in this investigation to examine the water absorption in thick samples of a porous sand medium in order to infer the volume of water absorbed.

2. Experiment

The investigation was carried out at Physikalisch-Technishe Bundesanstalt (PTB) in Brausnschwieg, Germany, making use of the PTB cyclotron which produces a 6.6 MeV fast neutron beam via the D(^{9}Be,n) reaction. The beam flux was approximately 10^8 neutrons

$s^{-1}cm^{-2}$ with the sample and detector placed 1.2 m away from the source of neutrons. The TRION fast neutron radiography system [6] was used to conduct the radiography.
Figure 1 shows the experimental setup for the sample, with regular dehydratded sand placed in a water tray. The sandl was dehydrated in a microwave oven and placed in the setup shown. Water was allowed to drip into the tray folowing the path indicated in Figure 1, subsequently being absorbed by the sand, this process was imaged via fast neutron radiography.

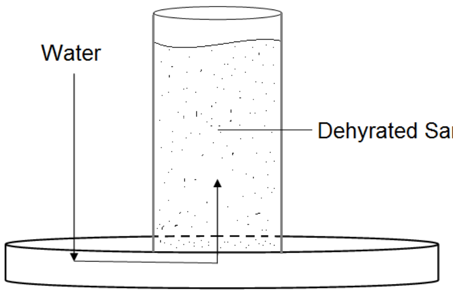

Figure 1. Experimental setup of water absorption experiment

The sample has a cross sectional thickness of 8.7 cm. To qualify the amount of water absorbed, the mass of the sand is recorded before and after being placed in water. The images where acquired in intervals of 12s during absorption.

3. Results

The radiographs in Figure 2 shows the absorption of water and areas of stratification forming. The fast neutrons can examine thicker samples, yielding different information about the bulk with a higher resolution over this thickness. Using the measured radiographs, Figure 2, a method of comparing the attenuation coefficient of the dry and wet areas is applied to infer the presence of water. Three regions of interest (RoI) are defined on the radiographs, highlighted in Figure.2, with the attenuation coefficient being calculated at these regions.

The attenuation coefficient for a single attenuating sample is calculated using Beers Law adapted for radiography [7], represented by equation 1,

$$I = I_0 e^{-\mu x} \tag{1}$$

where I_0 is the flat field radiograph taken without the investigating sample present, I is the radiograph with the investigating sample present, μ and x being the attenuation coefficient and thickness of the sample, respectively. For each RoI in Figure 2 we apply equation 1, to obtain the attenuation coefficient of the water sand mixture (sand alone is also calculated in this manner). Each image is corrected for the effects of dark current and read-out noise [8][9]. As fast neutrons have a higher probability of interaction with lighter elements (low Z materials), than heavier elements (high Z materials) [10], an increase in μ for the water sand mixture, compared to that of sand, illustrates an increased presence of water in the RoIs. This is illustrated in Figure 3 for each RoI, as a function of time.

Figure 3 shows the moving water front through the sample by the increased presence of water in the RoI's.

The water/sand system has a mix of attenuataing material, each one effecting the complexity in the calculation of the attenution coefficient. Using the technique by Anderson *et a*l [11], the increase in the water thickness (designated by α) is calculated using equation 2,

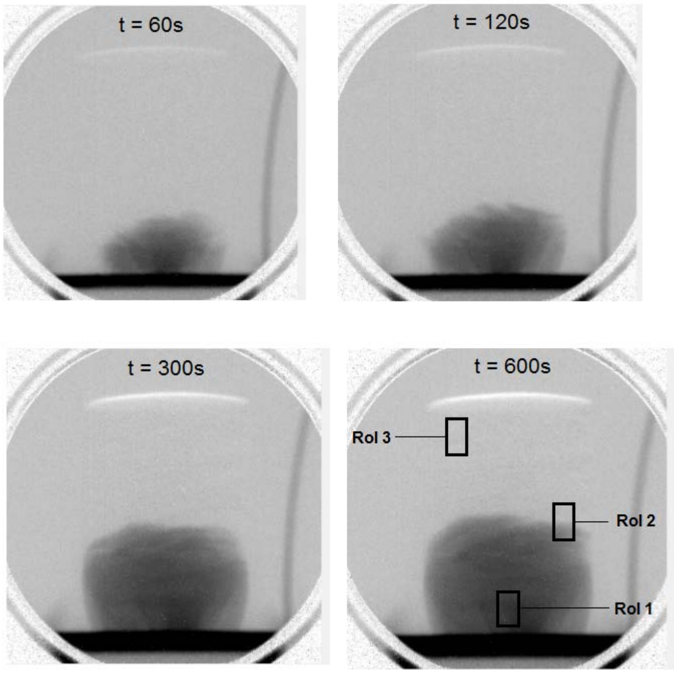

Figure 2. Fast neutron radiographs of the absorption of water in a column of sand taken at specified times.

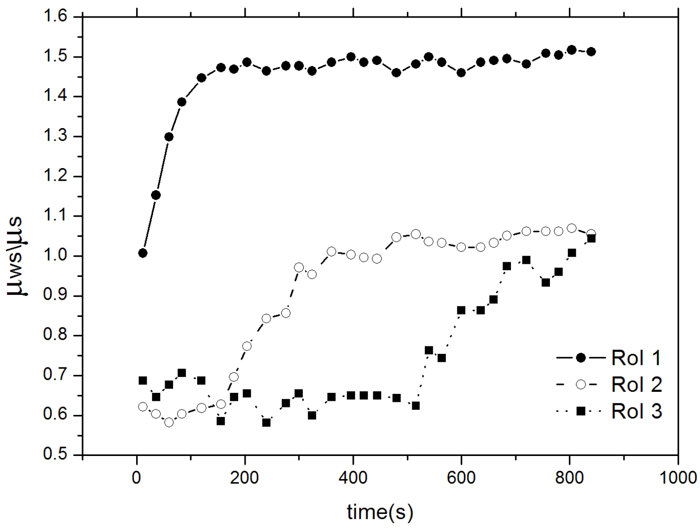

Figure 3. Attenuation coefficient of the water sand mixture μ_{ws} relative to the attenuation coefficient of sand , μ_s, as a function of time.

$$\alpha = \frac{\log \frac{I_{ws}}{I_s}}{\log \frac{I_w}{I_s}} \tag{2}$$

where I_{ws} is the intensity from the composite water/sand radiograph with I_w and I_s being the intensitites from the water alone and sand alone, respectively. The results for the 3 RoI's are plotted in Figure 4.

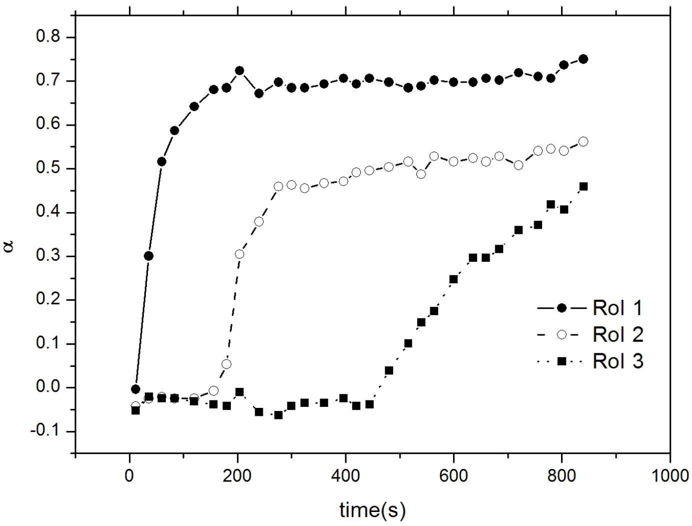

Figure 4. Water thickness as a factor of sand thickness over time.

Similarly to the results achieved and respresented in Figure 3, the trend of the water contribution (α) increases faster in RoI 1 than the other contributing regions. There is a clear relation in the data represented in Figure 3 and Figure 4 with a fast initial growth, indicative of a fast absorption rate that plateaus after around 240s as the RoI's begin to saturate.

4. Conclusions

The results respresented in Figure 3 and Figure 4, assist in inferring the amount of water absorbed and the amount of water present in a structure, at a given time, when compared to the dry sample. The water being absorbed through the sand and the different thicknesses of water due to the increase in α, is calculated from the resulting fast neutron radiographs, which enables one to analyse thicker samples.

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