Experimental report

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Proposal: 1-07-4 **Council:** 10/2022

Title: Effect of carbonation on recycled concrete aggregates microstructure by Neutron and X-ray tomography

Research area: Materials

This proposal is a new proposal

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Samples: Recycled concrete aggregates

Instrument	Requested days	Allocated days	From	To
NEXT	3	3	01/09/2023	04/09/2023

Abstract:

Recycled concrete aggregates carbonation is one of the key solutions proposed since the last decade to trap the emitted CO2 back into the concrete, and to approach carbon-neutrality. This is a complex process, and depends on several factors, such as the CO2 transport within the material, the moisture content in the pore network and other environmental conditions. However, their effects are still poorly understood, and all current theories rely on point-wise, macroscopic measures, neglecting the intrinsically heterogeneous nature of the process. We seek instead, using the complementary of X-ray and Neutron tomography techniques, to quantify, in-situ, the spatio-temporal evolution of CO2 absorption and moisture profiles during carbonation over a range of conditions to understand the micro-scale processes underlying the macroscopic response. The uniquely high flux available will allow for testing the efficiency of the carbonation process over a matrix of conditions, which will bolster the ongoing development of improved numerical models.

Effect of carbonation on recycled concrete aggregates microstructure by Neutron and X-ray tomography

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1. Introduction

Recycled concrete aggregates, derived from crushing unused concrete structural elements, is one of the key solutions to sustainably tackle construction challenges. It substitutes natural aggregates and reduces the consumption of natural resources, which currently constitute 50% of all materials extracted from the environment. Aggregates are the main contributor to this consumption, constituting 70% of the total volume of concrete, and represent a corresponding fraction of the demolition wastes. Unfortunately, recycled concrete aggregates contain residual cement paste, mortar and impurities. Their reuse is hindered by their higher porosity, which increases their water absorption capacity. Recent studies have proven that adhered mortar can absorb CO2, a process called carbonation. CO2 from the atmosphere binds as insoluble calcium carbonate, which occupies the porosity because it is more voluminous than the primary reactant. This enhances their hydro-mechanical properties, making recycled aggregates viable while also balancing the net impact on CO2 emissions.

These recent developments rely on macroscopic or point-wise observations, but the highly heterogeneous nature of both the material and the process require full-field approaches. Factors such as relative humidity play a double role (both reducing the permeability to CO2 by occupying pores and enhancing its dissolution and carbonation reaction) and significantly vary in space.

Purpose of the experiment is to conduct an experimental campaign on cement paste samples, at different CO2 concentrations (20 and 100%) and different temperatures to characterize the diffusion-reaction kinetics by capturing the spatial distribution of moisture profile along with cracks developed due to carbonation shrinkage.

2. Experimental campaign

a. Material

The material selected for the experimental campaigns was OPC cement paste mixed with water at a ratio of W/B 0.5. Samples were cured for 28 days to obtain a complete hydration.

In term of water saturation, two values were retained: First is a 100% water saturation, where severe drying at 80 C will be coupled to carbonation. Second is 50% water saturation, an optimum value for the carbonation process.

b. Setup and Boundary conditions

The setup, a bespoke cell made of Teflon, allowed the full control over temperature, relative humidity and CO2 concentration.

Figure 1: Left: Designed carbonation chamber mounted on NeXT. Right: Complete setup controlling CO2 concentration and temperature inside the chamber.

In the scope of our study, we tested a total of 7 samples with a range of configuration:

Test number	Sample ID	CO2 Concentration	Relative Humidity %	Temperature C	Initial water saturation Sl %
1	N04	100	80	20	50
2	P04	0	0	80	100
3	P05	100	0	80	100
4	N06	0	80	20	50
5	P06	20	0	80	100
6	P07	100	0	80	100
7	N09	100	80	20	50

c. Tomography configuration

Tomography setting were similar throughout the entire beamtime.

A first tomography is acquired at the beginning to capture the initial state of the sample, then the boundary conditions are set and X-rays & Neutrons simultaneous tomographies are acquired. The voxel sizes are 14 microns and the acquisition time is 22 mins.

3. First results

- Cracks indued by carbonation shrinkage were visible in the carbonated area for all the conducted experiments with carbonation. They were not observed in the tests made at 0% CO2.
- At 80 C, bound water is released in the pores as free water due to portlandite dissolution. We were able to observe at 80 C the drying induced by carbonation, characterized by the decrease in attenuation coefficient in the dried areas. In this scope, a parametric study has been made to compare between the sample drying kinetics at different level of CO2 concentration (0, 20% and 100%).
- At 20 C 2 tests were conducted at different CO2 concentrations (0 and 100%) to assess the influence of carbonation on the drying laws.

4. Future developments

The data collected during this campaign is very useful, and will be further analyzed to validate and enhance our coupled chemo-hydro-mechanical model for carbonation.

Experiments on heterogeneous materials (Mortar/concrete) are to be considered to study the influence of spatial heterogeneity on both diffusion of CO2 and water.