Use of GGBS as a cement substitute and carbonation for reducing CO2-emissions

Study and experiments to improve the bonding and ITZ between two mortars

Graduate

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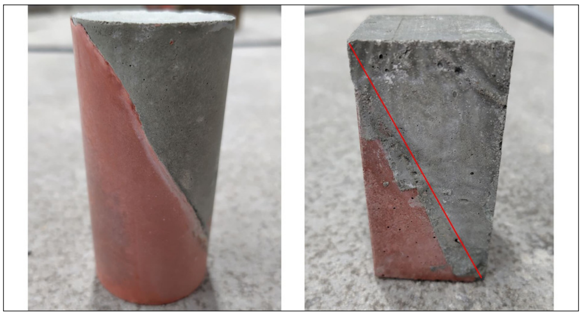
Introduction: The cement industry is one of the largest CO2 emitters worldwide, responsible for around 8–10% of global emissions from clinker production and limestone calcination. One way to reduce this footprint is by partially replacing cement with additives such as ground granulated blast-furnace slag (GGBS). GGBS is a waste product from the steel making industry and has similar chemical and physical properties to cement. In addition, technologies like carbon capture, storage, and utilization (CCUS) are increasingly explored to capture CO2 and reintegrate it into the material cycle. This work examines the combination of GGBS and CCUS, focusing on their mechanical and chemical effects.
Mortar mixtures with different GGBS contents (0%, 50%, 70%) were produced, with two mortars being concreted together to form the desired specimens. The focus was on investigating the bonding behaviour of the mortars, which may be the case in practice with existing structures when they need to be repaired or reinforced. Furthermore, the Interfacial Transitions Zone (ITZ) between the mortars were analyzed to understand the interaction on the microlevel between the materials and carbonation.

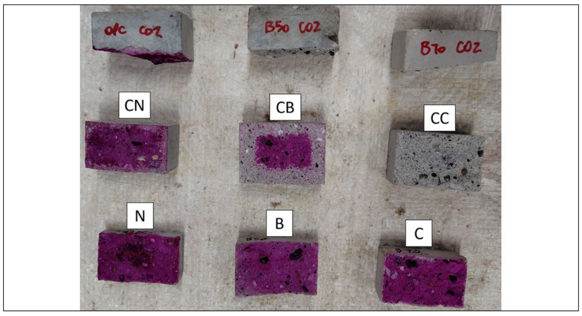
Approach: Following a literature review, experiments were conducted to develop suitable methods for manufacturing test specimens that would allow analysis about their mechanical properties and the ITZs. It was decided to produce modified small cylinders (D=50 mm, H=100 mm) and rectangular prisms (S=40 mm, H=70 mm), so that the mortars were applied to each other at a shear angle of 30° to the vertical axis and then subjected to axial compressive stress. Additionaly, bending beams (160x40x40mm) were produced in order to test the flexural strength and subsequently the compressive strength of the mixtures. The first mortar was poured and left to harden for 28 days, with half of the first mortar pour being carbonated. The second mortar was then applied and left to harden for another 28 days.
Chemical material analyses such as XRD and TGA, as well as Vickers hardness (VH) testing, were conducted to analyze the ITZ in a more targeted manner. In addition to the extensive laboratory tests, the test specimens were reproduced in the ATENA software and analyzed for their fracture behavior.

Result: The experiments showed that the modified test specimens could largely be produced and tested as expected. The tests indicated that carbonation generally increased the shearing and compressive properties, as the pores of the mortars were reduced by the formation of calcium carbonates. The flexural strength was reduced, because of microcracks, possibly caused by carbonation shrinkage. With increasing use of GGBS, the mechanical properties generally decreased, which could be explained its slow hydration speed.
XRD and TGA analyses clearly showed carbonation effects on all mixtures. The VH test, however, could not be carried out as the ITZ separated during specimen preparation. In ATENA the models and fracture patterns could be reproduced, but the lack of laboratory data was noticeable. Still, the results provided useful insights and a basis for future improvements.

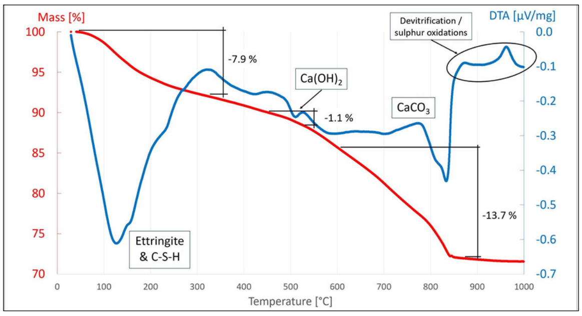
Finished cylindrical and rectangular specimen, with shearing angle between mortars of 30° to the vertical axis.
Own presentment



Mortars sprayed with phenolphthalein to analyze the carbonation depth.
Own presentment



TGA evaluation of a cement paste, consisting of 50% cement and 50% GGBS after carbonation.
Own presentment



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