Doctoral Dissertation
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Testing and characterization of innovative cementitious materials:
addressing a CO_2 circular economy in the cement industry

By

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Summary

Concrete is the most used construction material worldwide, used extensively in buildings and infrastructure, as it provides numerous benefits, including versatility, durability, strength, low cost, and energy efficiency. However, the production of traditional cement, i.e. Portland cement, is responsible for 2–3% of energy use and 8–9% of global CO_2 emissions, contributing significantly to global warming. Around half of these emissions are process emissions that involve the chemical reaction of the calcination of limestone to produce Portland clinker, the intermediate product in cement manufacturing, thus making decarbonization of cement production difficult.

Some evolutionary strategies have been adopted by the cement industry to address this challenge, including energy-efficient production technologies, the use of alternative fuels (including biomass), the development of new cement chemistries with low lime content, the reduction of the clinker factor and carbon capture and storage (CCS) technologies. This thesis investigates the incorporation into cementitious materials of the $CaCO_3$ nanoparticles synthesized from CO_2 conversion with the intention of creating innovative cement-based materials with improved mechanical properties.

Much of the present work was developed in the framework of the European Union Project "RECODE" related to the topic SPIRE-08-2017 that is "Carbon dioxide utilization to produce added value chemicals". This project aims to exploit the CO_2 present in the flue gases from the cement industry to produce added-value chemicals, which can be used to improve the cement quality (cement additives, concrete nanofillers), reduce the energy intensity of cement production itself (grinding aids,

accelerators, fillers) and favor effective CO_2 purification from the flue gases (amine-integrated ionic liquids for CO_2 sorption-desorption). By these means, CO_2 can be re-used within the cement plant itself in a sustainable and synergistic manner.

Another significant portion of the current research focuses on innovative biochar cement-based materials with the intention of obtaining an overall enhancement of mechanical properties of cementitious materials as well as the valorization of industry waste or by-products. Biochar is the solid residue rich in carbon which results from pyrolysis, i.e. the thermochemical decomposition which converts biomass waste into energy in a low-zero oxygen environment. In the current study a standardized biochar, Softwood Biochar, was used as a filler in the cement paste. The material was obtained from pyrolyzed feedstock at a nominal peak temperature of 700°C and with a carbon content of 90.21 wt%. Mechanical testing in the study showed a general enhancement in terms of flexural strength and fracture energy in specimens with biochar addition, although some parameters of the biochar process, (e.g. production, temperature, heating rate or pressure), as well as some biochar features (e.g. carbon content, particle size distribution or porosity) could influence the performance of cementitious composites.

The improved mechanical properties of the innovative cementitious materials are promising compared to ordinary cement-based materials, including flexural strength anf fracture toughness. These properties are particularly suited to structural applications under severe dynamic loading conditions (earthquake, impact, blast). An experimental set-up for uniaxial cyclic loading testing of cementitious materials was developed in this work. Cyclic alternate compression/tension tests were performed to investigate their behavior in the transition from the compression to tension phases. This preliminary study provides insights for future research on the evaluation of the strength, deformability, and energy dissipation capacity of innovative cementitious composites.