Performance of Sustainable and Low-Carbon Cementitious Composites under Aggressive Environmental Conditions

by Fulin Qu

Thesis submitted in fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

under the supervision of
Dr. Wengui Li (Principal supervisor)
Prof. John Zhou (Co-supervisor)

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, ***Fulin Qu***, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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LIST OF RESEARCH PAPERS

Journal Papers

- Fulin Qu, Wengui Li*, Wang Kejin, Vivian W. Y. Tam, Zhang Shishun. "Effects of seawater and undesalted sea sand on the hydration products, mechanical properties and microstructure of cement mortar", Construction & Building Materials, 310 (2021): 125229.
- Fulin Qu, Wengui Li*, Wang Kejin, Shishun Zhang, and Sheng Daichao. "Performance deterioration of fly ash/slag-based geopolymer composites subjected to coupled cyclic preloading and sulfuric acid attacks." Journal of Cleaner Production (2021): 128942.
- Fulin Qu, Wengui Li*, Zhuo Tang, and Kejin Wang (2021). "Property degradation of seawater sea sand cementitious mortar with GGBFS and glass fiber subjected to elevated temperatures". Journal of Materials Research and Technology, 13, 366-384.
- Fulin Qu, Wengui Li*, Zhong Tao, Arnaud Castel, and Kejin Wang. "High temperature resistance of fly ash/GGBFS-based geopolymer mortar with load-induced damage." Materials and structures 53, no. 4 (2020): 1-21.
- Fulin Qu, Wengui Li*, Xiaohui Zeng, Zhiyu Luo, Kejin Wang, and Daichao Sheng. "Effect of microlimestone on properties of self-consolidating concrete with manufactured sand and mineral admixture." Frontiers of Structural and Civil Engineering (2020): 1-16.
- Fulin Qu, Wengui Li*, Wenkui Dong, Vivian WY Tam, and Tao Yu. "Durability performance deterioration of concrete under marine environment from material to structure: A critical review." Journal of Building Engineering (2020): 102074.
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- Fulin Qu, Wengui Li*, Yipu Guo, Shishun Zhang, John L. Zhou, and Kejin Wang. "Chloride-binding capacity of cement-GGBFS-nanosilica composites under seawater chloride-rich environment." Construction & Building Materials 342 (2022): 127890.

Conference Paper

- Fulin Qu, Wengui Li*, Xinyu Zhao."Characterization of Fly Ash Based Geopolymer Mortar Exposed to High Temperatures after Load-induced Damage", PROTECT 2019: 7th International Colloquium on Performance, Protection and Strengthening of Structures Under Extreme Loading and Events, Whistler, BC, Canada, September 16-17, 2019.

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ABSTRACT

Pozzolanic materials, like fly ash (FA) and ground granulated blast-furnace slag (GGBFS), are considered promising binder materials as they are industrial by-products, helping to decrease ordinary Portland cement (OPC) demands and further lessen greenhouse emissions. Therefore, the total or partial replacement of pozzolanic materials for OPC to fabricate sustainable and low-carbon cementitious composites (LCC) has garnered extensive attention for providing enormous environmental benefits for infrastructure and offshore construction. In addition, the durability of LCC under aggressive environmental deterioration (such as fire, acid, and marine environments) is a progressively significant property for concrete structures due to the increasing demand for extended service life and less maintenance.

For total pozzolanic materials replacement for OPC, this work has estimated the performance of fly ash/GGBFS-based geopolymer under combined mechanical loads and aggressive environmental conditions (fire and sulfuric acid attack). For partial pozzolanic materials replacement for OPC, this work has also assessed the performance of cementitious composites with GGBFS under the marine environment. The synergistic effects of seawater and undesalted sea sand on the properties of cementitious composites have been firstly analyzed. And then, the fire resistance of GGBFS-based cementitious composites with seawater and undesalted sea sand has been examined. Finally, the chloride-binding capacity of GGBFS-based cementitious composites in seawater and chloride solutions has also been observed.

The results showed that fly ash/GGBFS-based geopolymer with 20 wt.% GGBFS could be regarded as a remarkable alternative for OPC to achieve extraordinary fire resistance by considering the strength and compatibility variations. The fly ash/GGBFS-based geopolymer with cyclic preloading was also confirmed to exhibit less severe performance deterioration even after 18-month exposure to sulfuric acid attacks. In addition, the results illustrated that the chloride, sulphate, and magnesium ions in

seawater and/or undesalted sea sand were assessed to lead to the phase changes of cementitious composites, including the formation of Friedel's/Kuzel's salts, magnesium hydroxide, and magnesium silicate hydrate, etc. The addition of 30 wt.% GGBFS and 1.0 wt.% glass fibers was also supposed to improve cementitious the fire resistance of cementitious composite with seawater and undesalted sea sand. Additionally, the cementitious composite with 30 wt.% GGBFS and 1.0 wt.% NS having the highest value of chloride-binding ratio was expected to enhance the long-term chloride-binding capacity.

Overall, this thesis improves the current understanding of the performance of low-carbon cementitious composites under aggressive environmental environments to produce more reliable data and ensure the reliability and sustainability of LCC-based construction.