UTS UNIVERSITY OF TECHNOLOGY SYDNEY

DEVELOPMENT OF SELF-SENSING CEMENTITIOUS COMPOSITES WITH MAGNETICALLY ALIGNED PARTICLES

by Zhuang Tian

Thesis submitted in fulfilment of the requirements

for the degree of

Doctor of Philosophy

under the supervision of Dr Yancheng Li,

Dr Wengui Li and Dr Jun Li

University of Technology Sydney
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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Zhuang Tian declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Civil and Environmental Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced 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.

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List of Publications during the candidature

1. **Tian, Z.**, et al., A state-of-the-art on self-sensing concrete: Materials, fabrication and properties. *Composites Part B: Engineering*, 2019. **177**: p. 107437.

2. **Tian, Z.**, Li, S., and Li, Y., Aligning conductive particles using magnetic field for enhanced piezoresistivity of cementitious composites. *Construction and Building Materials*, 2021. **313**: p. 125582.

3. **Tian, Z.**, et al., Influence of particle morphology and concentration on the piezoresistivity of cement-based sensors with magneto-aligned nickel fillers. *Measurement*, 2022. **187**: p. 110194.

4. **Tian, Z.**, Li, S., and Li, Y., Enhanced sensing performance of cement-based composites achieved via magnetically aligned nickel particle network. *Composites Communications,* 2021: p. 101106.

Contents

Abstract

Self-sensing cementitious composites as a type of smart material, have the ability to sense external loads and environmental changes through piezoresistive properties. They have the advantages of high sensitivity, good compatibility, low maintenance cost and hence great potential to be applied in structure health monitoring, weight in motion and traffic detection. The sensing function of the composites is achieved via the network formed of conductive particles which are randomly dispersed in the cement matrix. However, this isotropic network may not be used to its full capacity in a unidirectional loading scenario, and the composites with nickel powder share a disadvantage of high particle demand. This leads to a diminishment in mechanical strength and cement workability.

This study introduces an innovative method to align the nickel particles into chain patterns utilising the magnetic field in the fresh stage of cement and the structure is retained with the solidification process. Resistance measurement shows that resistivity declines significantly and the percolation threshold is advanced to a much smaller particle content when using the proposed method. Additionally, the anisotropic conductive chains exhibit enhanced piezoresistive performance and significant sensitivity with high gauge factor. Also investigated here are the influence of ferromagnetic particles morphology and magnetic parameters such as magnetic field strength and duration, the objective being to greatly improve the composites' piezoresistive performance. Finally, the embedment of proposed cement sensors in a beam signifies a further contribution to the possibility of using magnetically aligned nickel particles in practical situations.