UNIVERSITY OF TECHNOLOGY SYDNEY

Multifunctional cement-based sensors with integrated piezoresistivity and hydrophobicity toward smart infrastructure

by Wenkui Dong

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Under the supervision of

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Wenkui Dong declare that this thesis is submitted in fulfillment 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 ACRONYMS

SHM	Structure heath monitoring
AE	Acoustic emission
CNT	Carbon nanotube
MWCNT	Multi-walled carbon nanotube
CF	Carbon fibre
SF	Silica fume
CB	Carbon black
GNP	Graphene nanoplate
GNPC	Graphene nanoplate filled cementitious composite
GP	Graphite plate
GPC	Graphite plate filled cementitious composite
SCMs	Supplementary cementing materials
DC	Direct current
AC	Alternating current
SEM	Scanning electron microscope
CRC	Conductive rubber crumb
UDCC	Uniformly-dispersed CNT composites
PCP	Plain cement paste
LDCC	Layer-distributed CNT composite
LDCC1	CNT composite with 1 layer of undispersed CNT
LDCC2	CNT composite with 2 layers of undispersed CNT
DSC	Differential scanning calorimetry
TGA	Thermal-gravity analysis
PP	Polypropylene
FCR	Fractional changes of resistivity
C-S-H	Calcium silicate hydrate
XRD	X-Ray diffraction

EDX	Electron dispersion X-ray
CH	Calcium hydroxide
CAL	constant amplitude-loading
VAL	varied amplitude-loading
CBS	Cement-based sensors
NCB	Nano-carbon black
SL	Slaked lime
CP	Cement particles
SHP	Silane hydrophobic powder
CA	Contact angle
CBCS	CB filled cement-based sensor
CBCS05	CBCS with various CB contents of 0.5%
CBCS1	CBCS with various CB contents of 1.0%

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ABSTRACT

Concrete is the most widely used construction material for buildings, pavements, harbours and bridges. The piezoresistive cement-based sensor consists of the traditional cementitious composite and conductive fillers, thus the electrical conductivity is greatly improved and easily captured. Therefore, the cement-based sensors can be applied in concrete infrastructures to self-sense and monitor the damages and cracks through the measurements of concrete electrical resistivity, due to their low cost, easy manufacturing, high sensitivity and good durability compared to traditional sensors. However, several factors ranging from types and contents of conductive fillers, additives and environmental factors can affect the piezoresistivity and restrict the practical application of cement-based sensors.

In this study, the conventional cementitious materials with different conductive fillers including conductive rubber products (rubber crumbs and fibres) and carbon nanomaterials (carbon black, carbon nanotube, graphene and graphite) were developed to produce cement-based sensors, whose sensitivity was dozens or hundreds of times higher than the commercially available strain gauge. Later, the effects of additives such as rubber fibres, polypropylene fibres and silica fume on the electrical, mechanical, microstructural and piezoresistive properties of carbon black filled cement-based sensors were investigated. It was observed the enhanced durability and sensitivity of cement-based sensors containing these additives. Given working environment can significantly affect the piezoresistive performance of cement-based sensors, the effects of temperature, humidity, freeze-thaw cycles, acid erosion and drop impact on the cement-based sensors containing nanomaterials were explored regarding to the electrical resistivity and piezoresistivity. To reduce the interference from working environment, multifunctional cement-based sensors were developed with combined self-sensing, self-healing, self-cleaning and superhydrophobicity. These functions can hinder the penetration of water and ions inside of cement-based sensors, thus reduce the influences of working

environment on the piezoresistive performance of cement-based sensors. On the other hand, it provides the cement-based sensors with more functions to clean and heal themselves automatically.

In the end, this study carried out the piezoresistivity test on the small concrete beams and slabs with embedded cement-based sensors, to evaluate the sensing performance of cement-based sensors inside of concrete structures. Despite the inherent challenges, the multifunctional cement-based sensors have great potential for smart infrastructures. Overall, this study has comprehensively investigated the performance of cement-based sensors exposure to various conditions and taken a solid step forward for their practical application.