UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Design and Properties of Sustainable Geopolymeric Recycled Aggregate Concrete

by Zhuo TANG

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Doctor of Philosophy

under the supervision of
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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Zhuo Tang 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.

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LIST OF PUBLICATIONS

Journal Papers

Tang, Z., Hu, Y., Li, W. & Tam, V.W.Y. 2019, Uniaxial compressive behaviors of fly ash/slag-based geopolymeric concrete with RAs, *Cement and Concrete Composites*, 104, p. 103375.

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LIST OF ACRONYMS

CAC	Calcium aluminate cement
CFA	Coal-derived fly ash
CFRP	Carbon fiber-reinforced polymer
CG	Coal gangue
CSW	Construction solid waste
CWP	Ceramic waste powder
DCP	Dolomite-concrete powder
DIC	Digital image correlation
DIF	Dynamic increase factor
FRP	Fiber-reinforced polymer
GGBFS	Ground granulated blast furnace slag
GNAC	Geopolymeric natural aggregate concrete
GRAC	Geopolymeric recycled aggregate concrete
ITZ	Interfacial transition zone
LSCT	Linear strain conversion transducers
LOI	Loss on ignition
MIBA	Municipal solid waste incineration bottom ash
MIFA	Municipal solid waste incineration fly ash
MK	Metakaolin
MSW	Municipal solid waste
NA	Natural aggregate
NP	Natural pozzolana
nS	Nano-SiO_2
OPC	Ordinary Portland cement
RA	Recycled aggregate
RAC	Recycled aggregate concrete
RT	Room temperature
SEM	Scanning electron microscopic

SHPB	Splitting Hopkinson pressure bar
SSD	Saturated surface dry
S/S	Stabilization/solidification
SiMn	Silico-manganese
TMWM	Tungsten mining waste mud
WCB	Waste clay brick
WCP	Waste concrete powder
WGP	Waste glass powder
WPSA	Waste paper sludge ash

LIST OF NOTATIONS

Chapter 7

AAE	Average absolute error
c	Constant in the proposed strain enhancement expression
c_1	Constant in the strength enhancement expression
c_2	Constant in the strain enhancement expression
D	Diameter of concrete core (mm)
E_c	Elastic modulus of unconfined concrete (MPa)
E_l	Lateral confinement stiffness
f'_{co}	Peak axial compressive stress of unconfined concrete (MPa)
f^*_{cc}	Peak axial compressive stress of actively confined concrete (MPa)
f'_{cc}	Ultimate axial compressive stress of FRP-confined concrete (MPa)
f_{frp}	Ultimate tensile strength of FRP material
f^*_l	Lateral confining pressure of actively confined concrete (MPa)
f_{lo}	Threshold confining pressure (MPa) in the model proposed by Ozbakkaloglu & Lim (2013)
$f_{lu,a}$	Actual lateral confining pressure at ultimate (MPa)
k_1	Axial strength enhancement coefficient in the proposed model
k_2	Axial strain enhancement coefficient in the proposed model
LTS	Linear trend slope
MSE	Mean square error
n	Constant in proposed strength enhancement model
N	Number of data in the sample
SD	Standard deviation
t_{frp}	Total thickness of FRP jackets
ε^*_{cc}	Axial strain of actively confined concrete at f^*_{cc}

ε_c	Axial strain of concrete
ε_{co}	Axial strain of unconfined concrete at $f_{co}^{'}$
ε_{cu}	Ultimate axial strain of FRP-confined concrete
ε_{frp}	Ultimate tensile strain of FRP material
$\varepsilon_{h,rup}$	Hoop rupture strain of CFRP jackets
ε_l	Lateral strain of concrete
ε_o	Intercept strain of the axial strain axis of axial strain-lateral strain curve in model proposed by Xiao & Wu (2000)
ε_{vol}	Volumetric strain of concrete
ε_θ	Circumferential strain of concrete
μ_{tu}	Average tangent dilation rate of confined-concrete at ε_{cu} in model proposed by Xiao & Wu (2000)
α	Parameter in the proposed strain enhancement expression
β	Parameter in the proposed strain enhancement expression

Chapter 8

AAE	Average absolute error
a	Parameter in the model proposed by Lim & Ozbakkaloglu (2014)
c_1	Parameter in the model proposed by Ozbakkaloglu & Lim (2013)
c_2	Parameter in the model proposed by Ozbakkaloglu & Lim (2013)
D	Diameter of concrete core
E_1	Slope of the initial branch of axial stress-strain curve
E_2	Slope of the second branch of axial stress-strain curve
E_c	Elastic modulus of unconfined concrete
E_{frp}	Elastic modulus of FRP material
E_l	Lateral confinement stiffness

E_{re}	Reloading modulus
$E_{\sec u}$	Unloading secant modulus
$E_{un,0}$	Residual modulus
$f_{co}^{'}$	Peak axial compressive stress of unconfined concrete
f_{cc}^{*}	Peak axial compressive stress of actively confined concrete
$f_{cc}^{'}$	Ultimate axial compressive stress of FRP-confined concrete
f_{frp}	Ultimate tensile strength of FRP material
f_{l}^{*}	Lateral confining pressure of actively confined concrete
f_{lo}	Threshold confining pressure in the model proposed by Ozbakkaloglu & Lim (2013)
$f_{lu,a}$	Actual lateral confining pressure at ultimate condition
f_{new}	New stress
f_{un}	Unloading stress
k_1	Axial strength enhancement coefficient
k_2	Axial strain enhancement coefficient
MSE	Mean square error
N	Number of data in sample
SD	Standard deviation
t_{frp}	Thickness of FRP jackets
ε_{cc}^{*}	Axial strain of actively confined concrete at f_{cc}^{*}
ε_{c}	Axial strain of concrete
ε_{co}	Axial strain of unconfined concrete at $f_{co}^{'}$
ε_{cu}	Ultimate axial strain of FRP-confined concrete
ε_{frp}	Ultimate tensile strain of FRP material
$\varepsilon_{h,rup}$	Hoop rupture strain of CFRP jackets

ε_l	Lateral strain of concrete
ε_{new}	Strain of reloading curve at stress f_{new}
ε_{un}	Unloading strain
ε_o	Intercept strain of the axial strain axis of axial strain-lateral strain curve in the model proposed by Xiao & Wu (2000)
ε_{pl}	Plastic strain
μ_{tu}	Average tangent dilation rate of confined-concrete at ε_{cu} in model proposed by Xiao & Wu (2000)
ρ	Confinement stiffness ratio
ϕ_1	Stress deterioration ratio

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ABSTRACT

Geopolymeric recycled aggregate concrete (GRAC) is a type of geopolymeric concrete that recycled aggregate (RA) was utilized to replace the virgin aggregate. Thus, GRAC can provide the environmental benefits of both geopolymeric concrete and recycled aggregate concrete (RAC). Specifically, geopolymeric concrete offers a valuable method for recycling industrial by-products and reducing greenhouse gas emissions associated with the production of ordinary Portland cement. As for the RAC, the merits consist of, but not limited to, the avoidance of natural resource extraction, reduced landfills of construction and demolition waste (C&DW), and diminished transportation of wastes. Accordingly, GRAC suggests a route with a high degree of environmental friendliness for concrete materials.

In this study, fly ash and ground granulated blast furnace slag combination based geopolymeric concrete incorporating C&DW based RA was developed and evaluated. Firstly, the engineering properties of GRAC were studied. Subsequently, quasi-static and dynamic compressive tests were conducted on GRAC, respectively, by using a high-force servo-hydraulic test system and a Ø80-mm split Hopkinson pressure bar apparatus. Special attention was devoted to the failure patterns, stress-strain curves, and energy absorption capacity. Moreover, the failure process and mechanism of GRAC under compression was investigated with the help of a digital image correlation system.

Existing studies have validated that external confinement by confining materials is an effective strategy to enhance the mechanical and long-term performance of RAC or even to qualify RAC with structural purposes. Therefore, carbon fiber-reinforced polymer (CFRP) material was utilized in this study to provide external confinement for GRAC. Experimental studies on the mechanical behaviors of CFRP-confined GRAC under monotonic and cyclic compression were carried out. The failure model, stress-strain relationship, and axial-lateral strain relationship were investigated. Further, the results were compared with the predictions by existing models to evaluate these models' applicability to CFRP-confined GRAC.

Overall, this study could support the producers of C&DW to gain considerable interest by applying the C&DW-based RA into geopolymeric concrete and can benefit the stakeholders of geopolymeric material industries who seek more sustainability in their products.