

# **Investigation of Strategies for Risk Minimisation of Adverse Alkali-Silica Reaction in Concrete**

by

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the degree of

**Doctor of Philosophy**

under the supervision of

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# Certificate of Original Authorship

I, *Elsie Nsiah-Baafi* 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, Faculty of Engineering and Information Technology* 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

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# TABLE OF CONTENTS

<b>CERTIFICATE OF ORIGINAL AUTHORSHIP .....</b>	<b>II</b>
<b>ACKNOWLEDGMENTS .....</b>	<b>III</b>
<b>LIST OF PUBLICATIONS .....</b>	<b>V</b>
<b>TABLE OF CONTENTS .....</b>	<b>VI</b>
<b>LIST OF FIGURES .....</b>	<b>XI</b>
<b>LIST OF TABLES .....</b>	<b>XXII</b>
<b>ABSTRACT .....</b>	<b>XXV</b>
<b>CHAPTER 1. INTRODUCTION .....</b>	<b>1</b>
1.1 Research Aims .....	6
1.2 Research Objectives .....	6
1.3 Significance of Research .....	7
1.4 Organisation of Thesis .....	8
<b>CHAPTER 2. LITERATURE REVIEW .....</b>	<b>11</b>
2.1 Overview .....	11
2.2 Alkali-Silica Reaction (ASR) .....	11
2.3 Pre-requisites for ASR .....	13
2.3.1 Reactive Aggregates .....	14
2.3.2 Alkali content .....	16
2.3.2.1 Potential Internal Sources of Alkali .....	17
2.3.3 Moisture .....	19
2.4 Environmental Influence on ASR .....	21
2.5 Mechanism of ASR .....	23
2.5.1 Chemical Mechanism of ASR .....	23
2.5.1.1 Factors Affecting the Formation of Alkali-Silica Gel .....	25
2.5.2 Pore Solution Alkali Cations .....	26
2.5.2.1 Role of Calcium Hydroxide .....	28
2.5.3 Characteristics of Alkali-Silica Gel and Expansion Mechanism .....	30
2.5.3.1 Expansion Mechanism of Alkali-Silica Gel .....	32

2.6	Symptoms and Effects of ASR.....	35
2.7	Test Methods for Assessing ASR.....	41
2.7.1	Standard Test Methods for Assessing ASR.....	44
2.7.1.1	Petrography.....	45
2.7.1.2	Chemical Reactivity Test.....	47
2.7.1.3	Concrete Prism Test (CPT).....	50
2.7.1.4	Accelerated Concrete Prism Test (ACPT).....	51
2.7.2	Limitations of CPT.....	53
2.8	Mitigation and Control of ASR.....	55
2.8.1	Use of Non-Reactive Aggregates.....	56
2.8.2	Restricting Moisture Access.....	56
2.8.3	Limiting Alkali Content.....	57
2.8.3.1	Using Low Alkali Content Cement.....	58
2.8.3.2	Alkali Limits in Concrete.....	59
2.8.3.3	Addition of Supplementary Cementitious Materials (SCMs).....	61
2.8.4	Addition of Ground Siliceous Particles.....	67
2.8.5	Use of a Non-Expansive Aggregate Combination.....	71
	Chapter Summary.....	72
<b>CHAPTER 3. MATERIALS AND METHODS FOR ASSESSING AGGREGATE REACTIVITY AND ALKALI-SILICA REACTION.....</b>		<b>75</b>
3.1	Overview.....	75
3.2	Materials.....	75
3.2.1	Aggregates.....	75
3.2.2	Cement.....	76
3.2.3	Reagents.....	77
3.3	Methods.....	78
3.3.1	Physical Expansion Test Methods.....	78
3.3.1.1	Accelerated Mortar Bar Test (AMBT).....	78
3.3.1.2	Concrete Prism Tests.....	83
3.3.2	RILEM Recommended Methods for Determining Alkali Limits of Aggregates.....	88
3.3.3	Chemical Tests.....	90
3.3.3.1	ASTM C289.....	90
3.3.3.2	Dissolution Test.....	91
3.3.3.3	Ground Aggregate Slurry Test (GAST).....	92

3.3.3.4	Ground Aggregate Paste Test (GAP).....	94
3.3.4	Characterization Techniques.....	95
3.3.4.1	Petrography.....	95
3.3.4.2	Microstructural and Elemental Compositional Analysis.....	98
3.3.4.3	Sample Preparation.....	101
3.3.4.4	X-Ray Diffraction Analysis (XRD).....	104
3.3.4.5	X-Ray Fluorescence Spectroscopy (XRF).....	107
3.3.4.6	Thermogravimetric Analysis (TGA).....	108
3.3.5	Microwave Plasma Atomic Emission Spectroscopy (MP-AES).....	111
3.3.6	Laser Diffraction Particle Size Analysis.....	114
3.3.7	Compressive and Flexural Strength Tests.....	115
	Chapter Summary.....	116

**CHAPTER 4. INVESTIGATING ALKALI LIMITS AND AGGREGATE BLENDS FOR MITIGATING DELETERIOUS ASR IN CONCRETES..... 117**

4.1	Overview.....	117
4.2	Experimental Plan.....	119
4.2.1	Materials.....	119
4.2.2	Methods.....	121
4.3	Results and Discussion.....	124
4.3.1	Petrographic Assessment of Aggregates.....	124
4.3.2	Chemical Tests.....	129
4.3.3	Expansion Tests.....	134
4.3.3.1	Accelerated Mortar Bar Test (AMBT).....	134
4.3.3.2	Concrete Prism Test (CPT).....	138
4.3.3.3	Accelerated Concrete Prism Test (ACPT).....	141
4.3.3.4	Potential Correlation between Test Methods.....	142
4.3.4	Determination of Alkali Limits.....	143
4.3.4.1	Determination of Alkali Limits at 24 Months.....	146
4.3.4.2	Minimizing the risk of ASR using sand blends (WT <sup>1</sup> and WT <sup>2</sup> ).....	149
4.3.5	Petrographic Analysis of Mortar and Concrete Samples.....	149
4.3.5.1	Mortar Bars.....	149
4.3.5.2	Concrete Prisms.....	157
	Chapter Summary.....	165

**CHAPTER 5. CORRELATIONS BETWEEN ASR TEST METHODS USED FOR ASSESSING POTENTIAL REACTIVITY OF AGGREGATES ..... 168**



5.1	Overview.....	168
5.2	Experimental Plan .....	169
5.2.1	Statistical Analysis .....	169
5.2.1.1	Pearson's Correlation Coefficient Method .....	169
5.2.1.2	Factorial Analysis .....	170
5.2.2	Leachate Assessment of CPT Expansion Tests .....	172
5.3	Results and Discussion .....	174
5.3.1	Reliability of Existing Test Methods for Aggregate Reactivity Determination .....	174
5.3.2	Correlation between Expansion Test Methods .....	178
5.3.2.1	Accelerated Mortar Bar Test (AMBT) and Concrete Prism Test (CPT).....	178
5.3.2.2	Concrete Prism Tests at 38°C (CPT) and 60°C (ACPT) .....	182
5.3.3	Leachate Assessment for Concrete Prism Expansion Tests.....	185
5.3.4	Assessment of Factors that Affect ASR Expansion.....	193
5.3.4.1	Principal Component Analysis (PCA).....	193
5.3.4.2	Analysis of Variance.....	195
	Chapter Summary .....	198

**CHAPTER 6. INVESTIGATING THE ASR MITIGATION POTENTIAL OF GROUND REACTIVE AGGREGATE FINES..... 200**

6.1	Overview.....	200
6.2	Experimental Plan .....	202
6.2.1	Materials .....	202
6.2.1.1	Ground Reactive Aggregate Fines (GRAFs) .....	202
6.2.1.2	Reference Aggregates.....	205
6.2.2	Methods.....	205
6.2.3	Chemical Tests.....	207
6.2.3.1	Dissolution of Silicon and Aluminium from GRAF in Alkaline Solution.....	207
6.2.3.2	Paste Studies .....	207
6.2.4	Expansion Tests .....	211
6.2.4.1	Accelerated Mortar Bar Test (AMBT) .....	211
6.2.4.2	Concrete Prism Tests (CPT) and Accelerated Concrete Prism Tests (ACPT).....	212
6.3	Results and Discussion .....	213
6.3.1	Determination of Silicon and Aluminium released from Ground Reactive Aggregate Fines (GRAFs) in Alkali solution .....	213
6.3.1.1	Characterisation of reaction products .....	216

6.3.2	Influence of Ground Reactive Aggregate Fines (GRAFs) on the Pore Solution Chemistry of Pastes.....	223
6.3.2.1	Alkalinity (pH) of Pore Solutions .....	223
6.3.2.2	Ion Concentration of Pore Solutions.....	226
6.3.3	Expansion Test Results .....	233
6.3.3.1	Effect of Ground Reactive Aggregate Fines on ASR Expansion of Mortar Bars ...	234
6.3.3.2	Effect of Ground Reactive Aggregate Fines on ASR Expansion of Concrete Prisms .....	241
6.3.4	Thermogravimetric Analysis (TGA) of Pastes containing GRAFs.....	244
6.3.5	Influence of Ground Reactive Aggregates on Mechanical Properties of Concrete .....	248
6.3.6	Evaluating ASR Mitigation Mechanism of Ground Reactive Aggregates through Post-Expansion Characterisation of Concrete Prisms .....	251
	Chapter Summary .....	265
	<b>CHAPTER 7. CONCLUSION.....</b>	<b>267</b>
7.1	Overview.....	267
7.2	Investigation of Alkali Limits and Aggregate Blends for Mitigating Deleterious ASR in Concretes (Chapter Four).....	267
7.3	Correlation between Test Methods for Assessing Potential ASR of Aggregates (Chapter Five) .....	272
7.4	Investigating the ASR Mitigating Potential of Ground Reactive Aggregate Fines (Chapter Six) .....	276
	<b>CHAPTER 8. RECOMMENDATION FOR FUTURE STUDIES.....</b>	<b>280</b>
	<b>REFERENCES.....</b>	<b>283</b>
	<b>APPENDIX A.....</b>	<b>321</b>
	<b>APPENDIX B.....</b>	<b>323</b>
	<b>APPENDIX C .....</b>	<b>330</b>

## LIST OF FIGURES

<b>Figure 2.1</b> Schematic representation of ASR and Thomas Stanton in 1940 with a bridge parapet wall showing evidence of ASR (Thomas, Fournier & Folliard 2013) .....	12
<b>Figure 2.2</b> A typical two dimensional schematic of the silicate structure showing (a) crystalline silica and (b) amorphous silica (Brown 2012) .....	15
<b>Figure 2.3</b> A typical example of alkali (sodium) within an amorphous silica structure (Callister & Rethwisch 2014) .....	19
<b>Figure 2.4</b> Effects of water-to-cement ratio on ASR expansion of concrete specimens (Stark 1995).....	20
<b>Figure 2.5</b> Schematic representation of (a)-(b) the hydrolisation of silica and to form silanol (c) alkali charge balancing resulting in the formation of alkali silicate (Pignatelli, Comi & Monteiro 2013) .....	25
<b>Figure 2.6</b> Effect of solution alkalinity (pH) on the concentration of silica dissolved (Cs) (Vogelsberger, Seidel & Rudakoff 1992) .....	26
<b>Figure 2.7</b> Changes in the expansion of mortar bars in 0.05M NaOH solution as a function of SiO <sub>2</sub> /Na <sub>2</sub> O ratio of the ASR gel formed (Glasser & Kataoka 1981).....	28
<b>Figure 2.8</b> Schematic molecular model of a typical ASR gel (Vayghan, Rajabipour & Rosenberger 2016) .....	30
<b>Figure 2.9</b> Schematic diagram of DDLs mechanism of ASR gel expansion (reconstructed from(Pignatelli, Comi & Monteiro 2013)).....	34
<b>Figure 2.10</b> Symptoms of ASR. (a) map cracking (b) efflorescence and exudation of ASR gel from concrete cracks (c) aggregate pop-out (d) surface discoloration and ASR gel exudation from map cracks (Thomas, Fournier & Folliard 2013).....	36

<b>Figure 2.11</b> The Chickamauga lock and dam showing extensive cracking due to ASR (dominating mechanism) and ACR (Smith et al. 2017).....	37
<b>Figure 2.12</b> ASR affected concrete showing (a) cracks, exudation, efflorescence, and discoloration on a bridge beam, (b) longitudinal crack on a concrete beam, and (c and d) misalignment of concrete members (Thomas, Fournier & Folliard 2013) .....	39
<b>Figure 2.13</b> The Los Angeles sixth street viaduct showing signs of significant ASR (Muscato 2017) .....	40
<b>Figure 2.14</b> Recommended protocol for assessing the reactivity of aggregates to minimize the risk of ASR. (Standards Australia 2015) .....	42
<b>Figure 2.15</b> (a) Examples of SCMs. <i>From left to right</i> ; fly ash (Class C), metakaolin, silica fume, fly ash (Class F), slag and calcined clay, and (b) image of the Nant-y-Moch Dam (a 60-year-old bridge) containing reactive aggregates and 50% fly ash (Thomas, Fournier & Folliard 2013).....	62
<b>Figure 2.16</b> Effects of (a) SCM addition on the expansion of mortar bars (Tapas et al. 2019) and (b) SCM composition on dosage requirement for effective ASR mitigation in concrete(Thomas 2011).....	64
<b>Figure 2.17</b> Effect of SCM fineness and dosage on the compressive strength. Data from (Chindaprasirt, Jaturapitakkul & Sinsiri 2005).....	66
<b>Figure 2.18</b> Linear distribution of elements (Ca, Si and Na) along a partly reacted finely ground glass grain, showing evidence of a pozzolanic reaction to form (Na-C-S-H) ASR gel(Afshinnia & Rangaraju 2015b).....	68
<b>Figure 2.19</b> SEM micrographs of concrete sample containing (a) 100% cement and (b) 30% glass powder. <i>Note: 1= Aggregate; 2= ASR gel</i> (Afshinnia & Rangaraju 2015b)	69
<b>Figure 2.20</b> Influence of particle size on the reactivity of reactive silica (Thomas 2011) .....	70

<b>Figure 3.1</b> AMBT procedure showing (a) Horbat mixer (b) AMBT moulds (c) initial curing of mortar bars in a humidity cabinet (d) water curing of mortar bars at 80°C (e) ageing in 1M NaOH hot bath at 80°C, and (f) horizontal comparator for measuring expansion at respective ages .....	80
<b>Figure 3.2</b> Concrete mixing procedure.....	85
<b>Figure 3.3</b> Concrete mixing with principal supervisor and laboratory technicians, for CPT and ACPT, and schematic and photograph of prism storage method (showing absorbent polypropylene rope) during curing for CPT and ACPT.....	86
<b>Figure 3.4</b> 38°C environmental chamber for CPT and the horizontal comparator for CPT and ACPT prism expansion measurements carried out in this study.....	87
<b>Figure 3.5</b> ASTM C289 standard curve for identifying reactivity of aggregates .....	91
<b>Figure 3.6</b> Procedure for GAST method (a) ring mill for grinding aggregates to micron-sized powders (b) ground aggregate slurries in 80°C oven and (c) ground aggregate slurry after day 1 of testing.....	93
<b>Figure 3.7</b> Petrographic slides for mortar bars studied .....	96
<b>Figure 3.8</b> SEM-EDS instrument used in this study .....	98
<b>Figure 3.9</b> Electron interactions and resulting emissions during SEM. <i>Modified image from</i> (Mazumder et al. 2018) .....	99
<b>Figure 3.10</b> Labotom15 cutting machine for mortar and concrete sectioning .....	102
<b>Figure 3.11</b> Set-up for mounting and polishing specimens for SEM-EDS analysis....	103
<b>Figure 3.12</b> Prepared powder samples for XRD analysis .....	105
<b>Figure 3.13</b> Schematic of $\theta$ - $\theta$ Bragg-Brentano configuration and Burker X-ray diffraction instrument used in this study.....	106
<b>Figure 3.14</b> Atomic model explaining the principle of XRF analysis (Francisco; 2018) .....	107

<b>Figure 3.15</b> General TGA curve for hydrated cement (Singh et al. 2015).....	109
<b>Figure 3.16</b> Thermal analyser used for TGA in this study.....	110
<b>Figure 3.17</b> 4200 Agilent Technologies MP-AES instrument with an autosampler....	113
<b>Figure 3.18</b> Malvern MasterSizer 3000 laser diffraction particle size analyser.....	114
<b>Figure 4.1</b> Plane polarised petrographic images of aggregate (a) aggregate WT, (b) GW, (C) RT, and (d) PR. Note: Q= Quartz; Q''= Quartz veining through aggregate particle; F= Feldspar; G= Indurated greywacke in aggregate RT (notice the resemblance to aggregate GW); P= Pumice, and epidote vein cutting across the meta-greywacke fragment of aggregate GW .....	128
<b>Figure 4.2</b> Classification of aggregates according to the dissolution test (as per ASTM C289).....	130
<b>Figure 4.3</b> Compiled dissolution test from (Freitag 2003) for aggregate AS (x). Modified from (Black 2009).....	132
<b>Figure 4.4</b> TG-DTG results of 28 days GAST test on aggregates .....	133
<b>Figure 4.5</b> AMBT expansion results for aggregates at (a) 0.6 M, (b) 0.8 M and (c) 1.0 M NaOH alkali concentration.....	136
<b>Figure 4.6</b> 12 months CPT expansion results for the selected aggregates (a) including aggregate AS and (b) excluding aggregate AS at 38°C and 5.25 kg/m <sup>3</sup> Na <sub>2</sub> O <sub>e</sub> alkali content. <i>Note: Initial expansion (Day 0/Month 0) is 0.00%. Graphs represent expansion measurements from Day 7 (Month 0.25)</i> .....	139
<b>Figure 4.7</b> 6 months ACPT expansion results for aggregates at 60°C and 5.25 kg/m <sup>3</sup> Na <sub>2</sub> O <sub>e</sub> alkali content. <i>Note: Initial expansion (Day 0/Month 0) is 0.00%. Graphs represent expansion measurements from Day 7 (Month 0.25)</i> .....	142
<b>Figure 4.8</b> 12-month CPT expansion of aggregates at varying alkali content (Na <sub>2</sub> O <sub>e</sub> )	145
<b>Figure 4.9</b> 24-month CPT expansion of aggregates at varying alkali content (Na <sub>2</sub> O <sub>e</sub> )	146

**Figure 4.10** Petrographic images of mortar bar WT showing (a) photograph of cut-off dyed block surface (*image width= approx. 20mm*), (b) fine crack joining two acid volcanic fragments and showing porosity in a glassy shard and acid volcanics, (c) ASR induced open crack passing through an acid volcanic and porous depleted glassy shard, as well as through quartz grains and (d) ASR gel lining an air bubble leading from micro-cracks within a beta-form quartz grain (*Note: SCALE= 200µm*) ..... 152

**Figure 4.11** Petrographic images of mortar bar GW<sub>F</sub> showing (a) polished and dyed cut-off blocks from the mortar bars (*image width= approx. 20mm*), (b) ASR gel lining air bubbles and open micro-cracking in greywacke clast, (c) micro-cracks pass through and connecting greywacke clasts and, (d) an ASR-filled crack passing through a greywacke fragment (*Note: SCALE= 200µm*) ..... 154

**Figure 4.12** Petrographic images of mortar bars containing aggregate WT<sup>1</sup> showing (a) cut-off block from the mortar bar with fine porosity and micro-cracks occurring in and around WT grains and in the cement matrix (*image width= approx. 20mm*), (b) micro-cracks passing through silica depleted (porous) acid volcanic and glassy shard fragments (c) a crack passing through acid volcanic fragment. *Note the remnants of ASR gel in the cracks* and, (d) ASR gel lining an air bubble and, many micro-cracks emanating from the edge of the air bubble into the cement matrix (*Note: SCALE= 200µm*)..... 156

**Figure 4.13** Petrographic images of the mortar bars containing aggregate WT<sup>2</sup> showing (a) dyed cut-off mortar blocks (*image width= approx. 20mm*), (b) conspicuous ASR-filled crack passing through an acid volcanic fragment and a silica-depleted (porous) acid volcanic fragment, (c) a micro-crack through a greywacke fragment and along an ovoid air bubble lined with ASR gel and (d) ASR gel lining air bubbles with associated micro-

cracks passing into cement matrix. *Note the internal cracking and depletion-induced porosity in a glassy acid volcanic clast (Note: SCALE= 200µm)* ..... 157

**Figure 4.14** Plane and cross-polarized transmission light images of WT<sup>1</sup> CPT prism showing (a) ASR gel lining an air bubble (inner rim), outlined by fibrous ettringite (outer rim) and micro-crack passing through glassy acid volcanic clasts and, (b) ASR gel lining an air bubble replaced by fibrous ettringite. *Note micro-cracks passing through cement matrix and alongside a quartz grain into the gel lined air bubble. (Note: SCALE= 200µm)* ..... 159

**Figure 4.15** Plane and cross-polarized transmission light images of WT<sup>1</sup> ACPT prism showing (a) an air bubble lined with fibrous ettringite and ASR gel in micro-cracks passing through cement paste and quartz grain and (b) ASR gel lining an air bubble that is thinly outlined by low birefringent ettringite. Basaltic PR<sub>C</sub> can also be seen (*Note: SCALE= 200µm*) ..... 160

**Figure 4.16** Plane and cross-polarized transmission light images of WT<sup>2</sup> CPT prism showing (a) fine cracking running alongside meta-greywacke fragments suspected to be bleeding gaps, (b) micro-crack joining two quartz grains and running alongside a glassy volcanic clast (c) an air void (pore) lined by remnants of a clear ASR gel and associated micro cracks around the air bubble and, (d) a micro-crack joining a glassy fragment and a meta-greywacke fragment (*Note: SCALE= 200µm*) ..... 162

**Figure 5.1** Selected variables for factorial analysis..... 171

**Figure 5.2** (a) Filtration and (b) dilution of sampled CPT and ACPT storage water for MP-AES analysis ..... 174

**Figure 5.3** Relationship between GAST after 56 days and 12 months CPT expansion test ..... 177



<b>Figure 5.4</b> Relationship between AS 1141.60.1 AMBT and AS 1141.60.2 CPT test methods .....	180
<b>Figure 5.5</b> Related studies on the comparison of AMBT and CPT results for several aggregates from various projects .....	181
<b>Figure 5.6</b> Correlation between AMBT and CPT for different aggregates assessed under AS 1141.60.1 and AS 1141.60.2 test methods.....	182
<b>Figure 5.7</b> Correlation between 12 months CPT and 3 months ACPT expansion tests. ....	184
<b>Figure 5.8</b> Alkali leaching from prisms tested under CPT condition (38°C). <i>Note: All concrete prisms have initial alkali content of 5.25 kg/m<sup>3</sup> Na<sub>2</sub>O<sub>e</sub></i> .....	186
<b>Figure 5.9</b> Alkali leaching from prisms tested under ACPT condition (60°C). <i>Note: All concrete prisms have initial alkali content of 5.25 kg/m<sup>3</sup> Na<sub>2</sub>O<sub>e</sub></i> .....	186
<b>Figure 5.10</b> Alkali leaching from prisms containing only cement, tested under CPT and ACPT. <i>Note: All concrete prisms have initial alkali content of 5.25 kg/m<sup>3</sup> Na<sub>2</sub>O<sub>e</sub></i> .....	188
<b>Figure 5.11</b> Alkali leaching for one prism tested under standard CPT condition at varying alkali contents (total alkali measured divided by three).....	191
<b>Figure 5.12</b> Scree plot of extracted principal components and related eigenvalues ....	194
<b>Figure 5.13</b> Loading plot for variables in principal component analysis.....	195
<b>Figure 5.14</b> Effect of varying alkali and temperature on measured expansion.....	197
<b>Figure 6.1</b> A typical example of GRAFs used and the particle size distribution of cement, GRAFs, and FA.....	204
<b>Figure 6.2</b> SEM micrograph and elemental mapping of fractured hardened paste surface showing (a) GRAFs in paste and (b-c) well-dispersed GRAFs (Si) in paste ( <i>Note: Paste contains 25% RH<sub>G</sub></i> ) .....	208

<b>Figure 6.3</b> Photographs of paste specimens during curing phase for pore solution analysis .....	209
<b>Figure 6.4</b> Illustration of pore solution extraction device .....	210
<b>Figure 6.5</b> Photograph of (a) concrete specimens cast for the various tests and (b) concrete cylinder during 28 days compressive strength testing.....	213
<b>Figure 6.6</b> Concentration of silicon released by GRAFs and FA in 1M NaOH at 80°C .....	214
<b>Figure 6.7</b> Concentration of aluminium released by GRAFs and FA in 1M NaOH at 80°C .....	216
<b>Figure 6.8</b> Microstructure of (a) unreacted FA and (b-d) FA treated in 1M NaOH alkali solution at 80°C after 28 days .....	217
<b>Figure 6.9</b> Schematic showing the zeolitization process of FA (Fansuri, Pritchard & Zhang 2008) .....	218
<b>Figure 6.10</b> Microstructure of (a) unreacted WT <sub>G</sub> and (b-d) WT <sub>G</sub> treated in 1M NaOH alkali solution at 80°C after 28 days .....	219
<b>Figure 6.11</b> Microstructure of (a) unreacted GW <sub>G</sub> and (b-d) GW <sub>G</sub> treated in 1M NaOH alkali solution at 80°C after 28 days .....	220
<b>Figure 6.12</b> Microstructure of (a) unreacted RH <sub>G</sub> and (b-d) RH <sub>G</sub> treated in 1M NaOH alkali solution at 80°C after 28 days .....	221
<b>Figure 6.13</b> XRD diffraction patterns of GRAFs and FA (a) untreated and (b) treated in 1M NaOH at 80°C after 28 days.....	222
<b>Figure 6.14</b> Effect of temperature on the measured pH of pore solutions of pastes containing GRAFs after 28 days.....	224
<b>Figure 6.15</b> Effect of age on the measured pH of pore solutions of pastes containing GRAFs at 38°C .....	225

<b>Figure 6.16</b> Total alkali concentration of the pore solution after 28 days and varying temperatures .....	227
<b>Figure 6.17</b> Total alkali concentration of the pore solution at 38°C and varying ages	229
<b>Figure 6.18</b> Ca/Si ratio of the pore solution of pastes after 28 days and varying temperatures .....	230
<b>Figure 6.19</b> Concentration of Al in the pore solution of pastes after 28 days and varying temperatures .....	230
<b>Figure 6.20</b> AMBT expansion results of aggregates used as GRAFs.....	234
<b>Figure 6.21</b> Effect of GRAFs on AMBT expansion of mortar bars with reactive test aggregates WT (a-c) and RT (d-f).....	237
<b>Figure 6.22</b> AMBT results of mortar bars containing GRAFs and FA at 25% cement replacement level .....	238
<b>Figure 6.23</b> AMBT expansion results for mortar bars containing reference aggregate WT and ground non-reactive aggregate PR (PR <sub>G</sub> ).....	239
<b>Figure 6.24</b> Mortar bar expansions as related to three cement alkali contents in 1M NaOH 80°C test solution (Islam et al. 2016) .....	240
<b>Figure 6.25</b> Expansion results of 12 months CPT at 38°C for concrete prisms containing GRAFs and FA. <i>Note: Initial expansion (Day 0/Month 0) is 0.00%. Graphs represent expansion measurements from Day 7 (Month 0.25)</i> .....	241
<b>Figure 6.26</b> Expansion results of ACPT (CPT at 60°C) for concrete prisms containing GRAFs and FA. <i>Note: Initial expansion (Day 0/Month 0) is 0.00%. Graphs represent expansion measurements from Day 7 (Month 0.25)</i> .....	243
<b>Figure 6.27</b> Microstructure of fractured paste samples containing (a) FA (2000x) and GRAFs (WT <sub>G</sub> ) (1000x) cured at 60°C after 28 days ( <i>Note the presence of ettringite (Ett)</i> ,	

<i>portlandite (CH), calcium silicate hydrate (C-S-H), calcium aluminium silicate hydrate (C-A-S-H), and aluminate ferrite monosulfate (AFm)</i> .....	244
<b>Figure 6.28</b> Portlandite content in pastes containing GRAFs at different dosages after 28 days curing at 80°C .....	245
<b>Figure 6.29</b> (a) Full range DTG curves and (b) partial range DTG curves showing portlandite content in pastes with 25% cement replacement after 28 days at CPT temperature (38°C) <i>Note: Area under portlandite curve represents the amount of portlandite present in the system</i> .....	247
<b>Figure 6.30</b> (a) Full range DTG curves and (b) partial range DTG curves showing portlandite content in pastes with 25% cement replacement after 28 days at ACPT temperature (60°C) <i>Note: Area under portlandite curve represents the amount of portlandite present in the system</i> .....	247
<b>Figure 6.31</b> Effect of GRAFs and FA on the compressive and flexural strengths of concrete after 28 days.....	249
<b>Figure 6.32</b> Appearance of concrete prisms after 8 months ACPT ( <i>Note micro-cracks (within red squares) and map cracking on the surface of control samples (OPC)</i> ) .....	252
<b>Figure 6.33</b> SEM-BSE micrograph and elemental mapping of ASR gel found in the control sample (WT- control) after 8 months (242x) ( <i>Note: aggregate has higher Na alkali content</i> ) .....	254
<b>Figure 6.34</b> Morphology of crystalline ASR gel after 8 months (a) forming on the surface of the aggregate particle in the control prisms (5000x) (b) ASR gel at a higher magnification (10000x).....	256
<b>Figure 6.35</b> SEM-SEI micrograph and elemental mapping of ASR gel found in concrete prism containing 25% WT <sub>G</sub> after 8 months (400x) .....	257

**Figure 6.36** SEM-SEI micrographs of the concrete prisms containing 25% GW<sub>G</sub> showing ASR gel in cracks after 8 months (a) along the aggregate-paste interface (500x) and (b) within the paste (250x).....260

**Figure 6.37** SEM-SEI micrograph and elemental mapping of ASR gel found in concrete prism containing 25% GW<sub>G</sub> after 8 months (1000x) .....261

**Figure 6.38** SEM-SEI micrographs of concrete prisms containing 25% RH<sub>G</sub> at (a) 200x (b) 200x (c) 250x and (d) 500x, showing extensive cracking and presence of ASR gel after 8 months (*Note red arrows in (c) indicate the reaction rim of aggregate*) .....263

## LIST OF TABLES

<b>Table 2.1</b> Composition of ASR gel identified in different studies .....	31
<b>Table 2.2</b> Examples of concrete structures around the world that have suffered effects ASR.....	39
<b>Table 2.3</b> Laboratory Test methods for ASR assessment.....	44
<b>Table 2.4</b> ASR susceptible minerals in aggregates (Islam & Akhtar 2013).....	47
<b>Table 2.5</b> Variations in adopted AMBT test methods (Golmakani 2013) .....	49
<b>Table 2.6</b> Expansion limits and reactivity classification as per the different current CPT methods .....	51
<b>Table 2.7</b> Alkali limits specified in CSA A23.2-27A (Canadian Standards Association 2000) .....	60
<b>Table 3.1</b> Description of all the aggregates used in this study .....	76
<b>Table 3.2</b> The chemical composition of the cement used, as determined by XRF analysis .....	77
<b>Table 3.3</b> Grading requirement for manufactured fine aggregates in AMBT according to AS 1141.60.1.....	79
<b>Table 3.4</b> AMBT aggregate reactivity classification by AS1141.60.1 test method .....	82
<b>Table 3.5</b> Coarse aggregate grading requirement for CPT and ACPT under AS 1141.60.2 .....	84
<b>Table 3.6</b> Classifications of aggregate reactivity levels in accordance with RILEM AAR 3.2.....	89
<b>Table 3.7</b> Selected wavelengths of the desired elements for MP-AES analysis .....	113
<b>Table 4.1</b> Aggregates and sand blends selected for investigating alkali limits .....	119

<b>Table 4.2</b> Summary of the test program showing the different test methods used, the sample description and test conditions.....	122
<b>Table 4.3</b> Mortar bars and concrete prisms selected for post-expansion petrographic assessment.....	124
<b>Table 4.4</b> Mineralogical composition and reactivity classification of aggregates selected for investigating alkali limits, as determined by petrography.....	125
<b>Table 4.5</b> ASTM C1778 Classification of Aggregate Reactivity.....	138
<b>Table 4.6</b> RILEM AAR-3.2 reactivity categories and recommended alkali limits as per RILEM AAR-7.1 .....	148
<b>Table 4.7</b> Summary of aggregate reactivity classifications based on various expansion tests and suggested alkali limits .....	148
<b>Table 4.8</b> ASR causative minerals in the respective aggregates and their mortar bars	151
<b>Table 5.1</b> Comparison of reactivity classification by various test methods .....	175
<b>Table 5.2</b> Correlation between 12 months CPT results and ACPT results at different ages .....	183
<b>Table 5.3</b> Alkali leaching ( $\text{Na}_2\text{O}_e$ ) for three concrete mixes, during CPT and ACPT expansion tests .....	187
<b>Table 5.4</b> Effect of alkali content on alkali leaching during CPT per prism (total alkali measured divided by three).....	190
<b>Table 5.5</b> Percentage of alkali in safety margin and leached alkali per prism at alkali content of $4.0 \text{ kg/m}^3 \text{ Na}_2\text{O}_e$ .....	192
<b>Table 6.1</b> Details of the ground reactive aggregates used in this study determined by petrography .....	203
<b>Table 6.2</b> Chemical composition of GRAFs, FA, and cement determined by XRF ....	203
<b>Table 6.3</b> Particle Size distribution of GRAFs, cement, and FA .....	204

<b>Table 6.4</b> Summary of the test program for investigating the ASR mitigation potential of GRAFs .....	206
<b>Table 6.5</b> Sodium and potassium ion concentration in the pore solution of pastes after 28 days as a function of temperature .....	228
<b>Table 6.6</b> MP-AES results of pore solution of pastes containing GRAFs and FA at different ages.....	233
<b>Table 6.7</b> EDS Analysis of ASR gels in concrete prisms after eight months (Atomic weight percentages have been normalized relative to oxygen).....	259



## ABSTRACT

In recent decades, many structures worldwide have suffered damage due to alkali-silica reaction (ASR). This reaction is one of the most recognised chemical reactions leading to the deterioration of concrete. ASR is largely an alkali-activated process that causes the concrete to expand with time. To minimise the risk of expansion, a large focus has been placed on reducing the alkali content in the concrete when non-reactive aggregates are not available to use as part of the mix design. Restricting the alkali content can be achieved by: (i) imposing a generalised alkali limit of 0.6%  $\text{Na}_2\text{O}_e$  in cement and limiting the total alkali content in concrete to 2.5-2.8  $\text{kg/m}^3$   $\text{Na}_2\text{O}_e$ ; and (ii) adding supplementary cementitious materials (SCMs) for partial replacement of the cement to limit and bind the amount of alkali available. While these practices have shown desired outcomes in the past, recent challenges surround the implementation of these practices, such as a shortage of SCM supply in the foreseeable future and the economic cost associated with using such solutions.

In addition, owed to the several limitations identified, the validity of classifying the reactivity status of aggregates against current short-term laboratory test methods employed for assessing ASR is under conjecture by researchers. This has left the concrete and cement industry with the inconvenient option of performing long-term tests extending up to 24 months to obtain a reliable prediction of an aggregate's reactivity. As a consequence, a delay in decision-making leading to a decrease in productivity is likely.

For these reasons, this study has been undertaken to explore sustainable and novel techniques for mitigating ASR that also encourage the conservation of natural

resources. Aggregates of different mineralogical compositions and reactivity potentials sourced from Australia and New Zealand were studied using a suite of test methods comprised of petrography, chemical tests, expansion tests, and analytical techniques.

The effect of varying alkali content on the expansion behaviour of selected aggregates was investigated via accelerated mortar bar test (AMBT), concrete prism test (CPT), and accelerated concrete prism test (ACPT) to establish specific alkali limits respective to the mineralogical composition and reactivity classification of the aggregate. Subsequently, the potential of using ground reactive aggregate fines (GRAFs) as alternative additives for mitigating ASR was evaluated. Pastes, mortar, and concrete specimens containing varying cement replacement levels of GRAFs were studied and compared against control and fly specimens using expansion tests, thermogravimetric analysis (TGA), and microwave plasma atomic emission spectroscopy (MP-AES) analysis carried out on extracted pore solutions. The effect of GRAFs on some mechanical properties of concrete was also measured. Furthermore, the correlation between the various test methods was investigated via a statistical approach involving the use of Person's correlation coefficient method and a modified factorial analysis approach to assess the validity of the different test methods and to determine the effects and interactions of ASR factors on expansion.

The results showed that a generalised alkali limit imposed on all aggregate types may not be necessary. It is further illustrated that the current alkali limits could be relaxed to accommodate the use of cement containing slightly higher alkali content with aggregates that are compatible, or revised from the current 2.5 to 2.8 kg/m<sup>3</sup> Na<sub>2</sub>O<sub>e</sub> set in concrete. The efficacy of GRAFs in mitigating ASR as potential SCMs was

established as pozzolanicity was identified from the GRAFs investigated. Although the mechanical properties of concretes containing GRAFs were found to be lower than control concrete strength after 28 days, the GRAFs satisfied the ASTM C618 strength requirement for natural pozzolans revealing pozzolanicity for the coarser particle-sized GRAFs compared to fly ash and cement particle fineness. The findings also showed consistency in the reactivity prediction by the different methods. A positive correlation was found between CPT, chemical tests, and AMBT. Moreover, a correlation coefficient of  $r= 0.9$  was found between 12 months CPT and three months ACPT, indicating that ACPT could be used as a reliable short-term test method for early predictions of the reactivity potential of aggregates.