UNIVERSITY OF TECHNOLOGY SYDNEY

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

**by**

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Thesis submitted in fulfilment of the requirements for the degree of

**Doctor of Philosophy**

under the supervision of

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February 2021

# 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.

This research is supported by the Australian Government Research Training Program.

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# ACKNOWLEDGMENTS

Foremost, I wish to extend my deepest gratitude to my supervisors: Dr. Kirk Vessalas, Dr. Paul Thomas, and Professor Vute Sirivivatnanon. Words cannot express how much I appreciate the guidance and training you have given me throughout my doctoral study. I always count myself blessed for the opportunity to study under your supervision. ***Thank you!***

I would also like to acknowledge the support I have received throughout my research work from the UTS Science Technical Officers: Dr. Alex Angeloski, Dr. Mark Lockrey, and Dr. Herbert Yuan for their support with the analytical and characterisation studies carried out in their respective laboratory. I am also grateful to the FEIT Laboratory Technical Officers: Johir Mohammed, Rami Haddad, Mulugeta Hailu, and the UTS Service life facilities Techincal Support Assistant, Ann Yan. I truly appreciate all the assistance I have received from you. ***Dankie!***

I also acknowledge the assistance I have received from the School of Civil and Environmental Engineering Academic Officer, Van Le, for ensuring all the documentation surrounding my candidature is submitted to the university on time. ***Salamat!***

My gratitude also goes out to Muans Abdulnebe of Boral Materials and Technical Services for supplying the non-reactive Australian aggregates used, facilitating the work done in the initial stages of this study, and allowing my involvement in some industrial laboratory concrete mixing for essential training purposes. ***Mahalo!***

I sincerely thank ARC Nanocomm Hub for the financial support during my doctoral study. Similarly, I am grateful to Sue Freitag of WSP Opus and James Mackechnie of Concrete NZ for providing financial support and the New Zealand aggregates used in this study. I salute their very informative discussions on the codes of practice in New Zealand and their contribution to reviewing some of the published results from this study. ***Medaase!***

I am thankful to my family for their support and encouragement through this journey. I truly could not have done this without you. ***Merci!***

Finally, to my research mates, thank you for making this study a memorable one. ***Xièxiè!***

# LIST OF PUBLICATIONS

**E., Nsiah-Baafi**, K., Vessalas, P., Thomas and V., Sirivivatnanon, 2018, Mitigating Alkali-Silica Reactions in the Absence of SCMs: A Review of Empirical Studies. Proceedings, 5th International fib Congress, 7-11 October 2018, Melbourne, Australia.

**E.Nsiah-Baafi**, K., Vessalas, P., Thomas and V., Sirivivatnanon, 2019, Investigating Reactive Aggregate Combination for Alkali-Silica Reaction Risk-Free Concretes, Concrete Institute of Australia's Biennial National Conference, 8-11 September 2019, Sydney, Australia

**E., Nsiah-Baafi**, K., Vessalas, P., Thomas and V., Sirivivatnanon, 2019, Investigation of Alkali Threshold Limits and Blended Aggregate in ASR Risk-free Concretes, Concrete NZ conference, 10-12 October, Dunedin, New Zealand.

**E., Nsiah-Baafi**, K., Vessalas, P., Thomas and V., Sirivivatnanon, 2020, Protocols for Investigating Reactivity of Aggregates and Alkali thresholds for ASR Prevention, 16th International Conference on Alkali Aggregate Reaction in Concrete (ICAAR), October 2021, Lisboa, Portugal.

**E., Nsiah-Baafi**, K., Vessalas, P., Thomas and V., Sirivivatnanon, 2020, Mitigation of ASR using Aggregate Fines as Alternative for SCMs, 16th International Conference on Alkali Aggregate Reaction in Concrete (ICAAR), June 2021, Lisboa, Portugal.

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# 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% $Na_2O_e$ in cement and limiting the total alkali content in concrete to 2.5-2.8 kg/$m^3$ $Na_2O_e$; 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$^3$ $Na_2O_e$ 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.