Role of Supplementary Cementitious Materials in Mitigating Alkali-Silica Reaction

by

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Certificate of Original Authorship

I, *Marie Joshua Tapas,* 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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- Tapas, M.J., Brenner, J., Vessalas, K., Thomas, P. and Sirivivatnanon, V., "Effect of Limestone Content in Cement on Alkali-Silica Reaction Using Accelerated Mortar Bar Test" Concrete In Australia, Vol 44 (2): 41-47, June 2018

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- Tapas, M.J., Sofia, L., Vessalas, K., Thomas, P., Scrivener, K., “ The Ability of Supplementary Cementitious Materials to Mitigate Alkali-Silica Reaction (ASR) in Cements of Higher Alkali Contents and their Effect on ASR Gel Composition,” submitted to Cement and Concrete Research, October 2019 (under review)

- Tapas, M.J., Vessalas, K., Thomas, P., Sirivivatnanon, V., “Accelerated mortar bar test investigation of blended cements containing limestone mineral addition,” submitted to Cement and Concrete Research, October 2019 (under review)

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List of Abbreviations

AFm	aluminate ferrite monosulfate
AFt	Al_2O_3-Fe_2O_3-trisulfate
Al/Ca	aluminium/calcium
Al/Si	aluminium/silicon
Al_2O_3	alumina
AMBT	accelerated mortar bar test
AS	Australian standards
ASR	alkali silica reaction
C_2S	belite
C_3A	tricalcium aluminate
C_3S	alite
C_4AF	tetracalcium aluminoferrite
Ca/Si	calcium/silicon
$CaCO_3$	calcium carbonate
C-A-S-H	calcium aluminosilicate hydrate
CH	portlandite
CPT	concrete prism test
C-S-H	calcium silicate hydrate
EDS	energy dispersive spectroscopy
FA	fly ash
GGBFS	ground granulate blast furnace slag
GP	General Portland
ICP-MS	inductively coupled plasma mass spectrometry
ICP-OES	inductively coupled plasma - optical emission spectrometry
K	potassium

K_2O	potassium oxide
MK	metakaolin
Na	sodium
Na_2O	sodium oxide
Na_2O_{eq}	sodium equivalent
N-A-S-H	sodium aluminosilicate hydrates
PC	Portland cement
RH	relative humidity
SCM	supplementary cementitious material
SEM	scanning electron microscope
SF	silica fume
SiO_2	silica
SL	slag or ground granulated blast furnace slag
TG	thermogravimetry
XRD	X-ray diffraction

Abstract

Alkali-silica reaction (ASR) describes reactions between certain forms of silica and the high alkaline pore solution of concrete that form an ASR gel product that causes the concrete to expand and crack. ASR poses a threat to concrete stability particularly in cases where the formation of cracks leads to a loss in the mechanical performance and properties of the concrete. The addition of supplementary cementitious materials (SCMs) such as fly ash and slag for the partial replacement of Portland cement in concrete is considered to be the most economical option in mitigating the occurrence of ASR. However, the closure of coal-fired power stations and increased recycling of steel threaten the supply of fly ash and slag.

In order to be able to identify future SCMs for use in ASR mitigation, there is a need to understand the mechanisms by which conventional SCMs mitigate ASR. At present, the mitigation mechanisms are still poorly understood. Furthermore, the influence of other components of the binder system on the efficacy of SCMs in ASR mitigation such as limestone (which is a standard cement addition) and cement itself (the introduction of higher alkali contents) also warrant investigation. Currently, there is an ongoing interest in Australia to increase the limestone content in General Purpose (GP) cement from 7.5% to 12% in order to reduce CO_2 emissions associated with cement production. In addition, there is a requirement to increase the alkali limits in cement, which is currently set at 0.6% Na_2O_{eq} (sodium equivalent), in order to minimize the amount of raw materials thrown to waste. Sodium equivalent is equal to the sum of alkali oxides in the cement ($Na_2O + 0.658K_2O$).

In this study, the accelerated mortar bar test (AMBT) was carried out to assess the efficacy of traditional SCMs in mitigating ASR as a function of SCM type (fly ash, slag, metakaolin and silica fume) and dosage in binder systems with various limestone contents (0%, 8%, 12% and 17%). The effect of SCM type, SCM replacement level and limestone addition on the portlandite amount, the pore solution alkalinity and the composition of the calcium silicate hydrate (main cement hydration product) as well as the dissolution of SCMs in an alkali environment were investigated and compared with the expansion results. To be able to assess the effect of cement alkalinity on the efficacy of the SCMs in ASR mitigation, the expansion of concrete prisms was studied by immersion of concrete prisms in simulated pore solution derived from the 28-day pore solution of pastes with equivalent composition of the binder used in the concrete. This alternative testing method addresses the limitations of the conventional ASR testing methods of AMBT (excessive alkali) and CPT (alkali leaching) for assessing the effect of binder alkalinity on the level of ASR expansion.

The results demonstrate that SCMs at recommended dosages work effectively to mitigate ASR even in cements with effective alkali content of 1% Na_2O_{eq}. The efficacy of SCMs in reducing ASR expansion is related to their ability to release silicon and aluminium in solution, consume portlandite, reduce pore solution alkali concentration and modify the calcium silicate hydrate (C-S-H) composition. Thus, siliceous materials, aluminosilicates and even pure aluminium present a potential to mitigate ASR. Limestone (98% $CaCO_3$) does not aggravate ASR and has no detrimental effect on the efficacy of SCMs in mitigating ASR. Moreover, experimental findings indicate that limestone has no capability to actively mitigate ASR as it does not modify the C-S-H composition and does not actively reduce the pore solution alkali concentration like SCMs.