UNIVERSITY OF TECHNOLOGY SYDNEY

Better Utilization of Fly Ash and other SCMs in Lean Concrete and Durable Concrete Pavements and Structural Concrete Applications

A thesis by

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Farzad Moghaddam

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Sincerely dedicated to

my lovely wife and son

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ABBREVIATIONS

AMBT	Accelerated Mortar Bar Test
AEA	Air Entraining Agent
ASR	Alkali-Silica Reactivity
ACI	American Concrete Institute
AVPV	Apparent Volume of Permeable Void
AS	Australian Standard
CH	Calcium Hydroxide
C-S-H	Calcium Silicate Hydrate
CCAA	Cement Concrete & Aggregate Australia organisation
CFA	Classified Fly Ash
ESP	Electrostatic Precipitators
FF	Fabric Filter
FA	Fly Ash
GGBFS	Ground Granulated Blast Furnace Slag
GRFA	Grounded Run-of-Station Fly Ash
HPC	High-Performance Concrete
HWR	High-range Water Reducer
LOI	Loss-Of-Ignition
MIP	Mercury Intrusion Porosimetry
MK	Metakaolin
MAU	Microstructural Analysis Unit
OFA	Original Fly Ash
PSA	Particle Size Analysis
PC	Portland Cement
RCPT	Rapid Chloride Permeability Test
RH	Relative Humidity
RMS	Road and Maritime Services
RFA	Run-of-the-Station Fly Ash
SSD	Saturated-Surface-Dry
SEM	Scanning Electron Microscopy
SL	Slag
SAI	Strength Activity Index Test
SCMs	Supplementary Cementitious Materials
C_3A	Tricalcium Aluminate

UNSW	University of New South Wales
UTS	University of Technology Sydney
WR	Water Reducer
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

ABSTRACT

The utilization of supplementary cementitious materials (SCMs) for the partial replacement of cement in concrete introduces several environmental and economical benefits. Some of the major benefits include the conservation of natural resources, the reduction of greenhouse gas emissions and a reduction in cement use. The use of SCMs in concrete also have technical merit and are multifaceted in their approach by enhancing the workability, strength and durability of concrete. In recent years, Australian road authorities have been increasingly concerned with the shortage of classified fly ash (CFA) predicted to occur in the near future with renewable energies finding their way into the market. Finding alternative SCMs is a critical issue due to a shortage of national resources available. Run-of-station fly ash (RFA) can be a possible alternative to CFA. However, the lack of enough information available in the literature hinders the use of RFA, and additional work needs to be carried out to investigate its efficiency in different concrete mixes.

In this investigation, an experimental study has been carried out to evaluate the effect of fineness of three fly ashes (ground run-of-station fly ash (GRFA), RFA and CFA) on the heat of hydration behaviour, flow and compressive strength properties of blended cement pastes. The study has been extended to also assess the influence of fineness, types and levels of SCMs (fly ash, slag or metakaolin) on the fresh and hardened properties of mortars. Finally, the effect of RFA and other SCMs on the fresh, hardened and durability properties of concretes for different applications such as lean, pavement and bridge work have also been studied.

Among all the SCMs investigated, metakaolin (MK) was found to have the highest fineness followed by slag (SL), GRFA, CFA and RFA. In addition, increasing the fineness of fly ash showed a reduction in the crystallinity of silica particles, which resulted in more reactivity suggesting possibly more amorphous silica particles present for pozzolanic reactivity. The presence of smaller quantities of crystalline silica particles in SL and MK also suggests a higher degree of pozzolanic reactivity may prevail. Results of the study on the blended pastes showed that the cumulative heat of hydration decreased by the incorporation of fly ash with different fineness (302, 368 and 495 m^2/kg), SL, or MK. This reduction was noted to increase with increasing SCM content. The finer grade fly ash (GRFA) generated higher heat of hydration compared to coarser grade fly ash (RFA). Furthermore, the consumption of portlandite increased with increasing fineness of fly ash at 28 days reflecting higher pozzolanic reactivity resulting in higher compressive strength than the blended pastes containing coarser grade fly ash.

Partially replacing cement with 20%, 30% and 40% fly ash of different fineness (CFA, RFA and GRFA), and 35%, 50% and 65% SL in mortars (using a fixed w/b ratio) improved the flow compared to control mortar (devoid of SCM addition). The inclusion of 5%, 10% and 15% MK in the same mortar decreased the flow compared to control mortar. Increasing the fineness of fly ash from 302 to 495 m^2/kg improved the 28-day compressive strength of the mortar even to a similar level to the control mortar. However, the 28-day compressive strength of mortars containing SL and MK were even higher than control mortar at all replacement levels evaluated. The 56-day drying shrinkage of mortars was also found to decrease considerably when partially replacing cement with SCMs. Compared to the control mortar, a reduction in drying shrinkage was noted with an increase in SCM replacement level.

Results from the study on lean concretes with 60% fly ash content revealed RFA is almost as effective as CFA in satisfying the strength and drying shrinkage requirements according to the RMS R82 specification despite having lower compressive strength development at all ages (up to 56 days) compared to the same concrete containing CFA. Replacing cement with 20% and 25% RFA in pavement and bridge concretes decreased 28-day compressive strength by about 11% and 11% respectively, compared to the same concretes containing CFA. In addition, there was a slight increase in drying shrinkage at all ages (up to 56 days) by replacing cement with RFA instead of CFA in all concretes investigated. It can be concluded that the concretes with RFA can achieve similar hardened properties to CFA concrete in pavement concrete and bridge applications by only adjusting the mix design such as lowering w/b ratio. This statement is based on the results of fineness level, crystaline phase indetification and oxide composition of CFA and RFA particles and also strength development from the pastes and mortars. Moreover, partially replacing cement with SL or MK could be another alternative to CFA in pavement concrete and bridge applications due to the high fineness confirmed by mortar and concrete results. However, only the relative performance of concrete used for bridge applications was assessed for durability properties.

According to the qualitative tests carried out on the bridge concretes containing SCMs, it was noted that the level of penetrability of chloride and sulfate ions into the concrete was reduced by replacing cement with 25% CFA or

RFA compared to the control concrete at 28 days. This reduction in penetrability level was significant for the concretes containing 50% SL or 15% MK. In addition, the results from the accelerated mortar bar test revealed that partially replacing cement with SCMs decreased the expansion of mortar bars due to alkali-silica reaction (ASR); the reduction in expansion increased with an increase in SCM content. For the reactive aggregate investigated in this study, incorporation of 25% CFA or 25% RFA or 50% SL or 15% MK is needed to control the expansion of mortar bars due to ASR.

This experimental investigation has demonstrated the value and benefits of using RFA as an alternative SCM in concrete. RFA has proven abilities to achieve the same level of performance as CFA when used in various concrete applications such as lean, pavement and bridge concrete mix designs. SL and MK could also be used as other alternatives to CFA in concrete.