

DEVELOPMENT OF HIGH PERFORMANCE
SHRINKAGE RESISTANT CONCRETE, USING
NOVEL SHRINKAGE COMPENSATING
ADMIXTURES

by

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This thesis is submitted in fulfilment of the requirements for
the degree of Doctor of Philosophy

2012

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Certificate of Authorship / Originality

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 as fully acknowledged within the text.

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Pedram Hamedanimojarrad

Acknowledgments

My PhD candidature was one of the most memorable whilst challenging, in my professional life. For being beside me and leading me, I would like to express my gratitude to Prof. Abhi S. Ray, my principal supervisor, for his guidance, advice and encouragement throughout my candidature of this thesis. His invaluable experience and continuous support enhanced my motivation in my PhD journey. I would also like to thank Prof. Georgius Adam, who designed and produced most of the admixtures used in this dissertation, for his brilliant ideas, humble technical support on the chemistry side of admixtures and polymers and many weekly helpful meetings and discussions. The author would also like to thank Dr. Kirk Vessalas, my co-supervisor, for his efforts and time spent on training me throughout laboratory tasks and technical assistance. I would further convey my gratefulness to Dr. Paul Thomas, for his very useful comments and ideas during my PhD journey and his guidance on microstructural experiments and my research curriculum. A special appreciation is for Dr. Shami Nejadi, my co-supervisor, for his guidance, hands-on suggestions and his enthusiasm in this research project.

In allowing this research to progress, I would like to thank Prof. Bijan Samali, head of Centre for Built Infrastructure Research and head of School of Civil and Environmental Engineering, for the time and effort he spent for consultations and for his enduring support. Indeed his supports have helped many research students follow their will.

I wish to acknowledge and thank the support and technical assistance of the Faculty of Engineering and Information Technology Civil Laboratories staff especially Mr. Rami Haddad and Mr. David Hooper. Similarly, for the Faculty of Science staff, I would like to thank Mr. Jean-Pierre Guerbois for his technical support and training me during microstructural analysis.

For their technical and practical support and encouragements, I would like to thank all my fellow research students in Faculty of Engineering in University of Technology, Sydney, particularly Ms. Nicole Galea for her enthusiasm and high quality assistance.

An exceptional appreciation is held for Ms. Samaneh Mohammadi, my lovely wife. Her support and constant encouragement has made this study a memorable experience. I wish her luck with her PhD study.

Above all, I proudly take this moment to thank my parents who dreamed a successful life for me and devoted their lives and wishes to build me that dream.

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List of Abbreviations

| | |
|-------------------|--|
| APP | Ammonium Polyphosphates |
| AS | Australian Standards |
| ASTM | American Society for Testing and Materials |
| C ₂ S | Dicalcium Silicate |
| C ₃ A | Tricalcium Aluminate |
| C ₃ S | Tricalcium Silicate |
| C ₄ AF | Tetracalcium Aluminoferrite |
| CH | Calcium Hydroxide (Portlandite) |
| C-S-H | Calcium Silicate Hydrate |
| DTA | Differential Thermal Analysis |
| DTG | Differential Thermogravimetry |
| EnAPP | Encapsulated Ammonium Polyphosphates |
| HAp | Hydroxyapatite |
| HWR | High-range Water Reducer |
| ITZ | Interfacial Transition Zone |
| Ke | Keratin |
| LOI | Loss on Ignition |
| Me | Melamine |
| MePP | Melamine Polyphosphates |
| OPC | Ordinary Portland Cement |
| PE | Polyethylene |
| PVA | Polyvinyl Alcohol |

| | |
|-------|-----------------------------------|
| RH | Relative Humidity |
| SCA | Shrinkage Compensating Admixture |
| SDT | Simultaneous Differential Thermal |
| SEM | Scanning Electron Microscopy |
| SRA | Shrinkage Reducing Admixture |
| TG | Thermogravimetry |
| TGA | Thermogravimetric Analysis |
| Wo | Wollastonite |
| w/b | Water / binder |
| w/c | Water / Cement |
| wt. % | Weight Percent |

Abstract

Shrinkage in cementitious materials can bring about major durability issues, beginning with a crack in a restrained section. This phenomenon causes contraction and consequently tensile stresses in the sample, and since the concrete and all conventional cementitious materials are not capable enough to bear tensile stresses, they crack. In conventional concrete, the major contribution to shrinkage strain belongs to drying shrinkage. Therefore, reducing the amount of drying shrinkage in concrete and cement mortars can result in lower total shrinkage strain and therefore, lessen the risk of cracking and ion invasion into the sample.

Shrinkage reducing admixtures (SRA), expansive agents and fibres are currently used in research and industry, in order to reduce the amount of shrinkage in one or more aspects; or at least decrease the risk of shrinkage cracking. Having been used in industry, SRAs and many other shrinkage compensating admixtures have been showing adverse side effects on the physical and mechanical properties of concrete and cement mortars; such as strength reduction and change in rheology.

Therefore, this research project aimed to introduce, investigate and develop new drying shrinkage compensating admixtures with no or limited reduction in mechanical strength, in order to be used in mortar, concrete and cementing compounds. The methodology of current research project was based on examining engineering physical and mechanical properties of OPC mortar samples associated with the addition of these new admixtures. Cementitious material used in this research project was ordinary Portland cement (OPC) mortar instead of concrete samples, in which the coarse aggregates provide more resistant to any expansion or contraction.

Firstly, a novel chemical composition of polyphosphates, Ammonium Polyphosphates (APP) that was designed and produced in Science Faculty of UTS, was adopted in current research. Based on its unique composition, this agent was expected to produce a cementing product (binder) via reaction with calcium hydroxide in the mix, where can enhance mechanical characteristics of the cement mortar and at the same

time generate ammonia gas (or volatile amine, as an anti-corrosion product), and might end up in generating expansion in the mix.

APP was used as an admixture inside OPC mortar samples and resulted in less shrinkage strain and enhanced compressive strength and workability. However, after more investigation it was concluded that the shrinkage compensation of APP could not only be due to the ammonia agent, but it was mainly related to the robust structure of calcium polyphosphate as one of the primary products of APP and calcium hydroxide reaction. This assumption was tested by the means of expansion studies and microstructural tests, and then comprehensively explained in Chapter 4.

On the other hand, APP showed some undesirable aspects such as ammonia odour during mixing. This downside aspect of APP was firstly addressed by encapsulating APP with a superplasticiser, and then by changing the chemical composition of APP to melamine polyphosphate or even testing melamine as an admixture. Encapsulation did not eliminate the ammonia release from the mix completely, but remarkably reduced the rate of ammonia release. Other admixtures however, were subjected to different results, due to different behaviours involved in them, which were not similar to the mechanism of APP in cementitious materials.

As mentioned earlier, fibres are mainly known for their effects on crack resistance rather than their ability to limit the shrinkage. This dissertation has a close look at microfibres as shrinkage resistant admixtures, as expected to be more efficient for their micro-crack bridging. This micro-bridging parameter was supposed to lock in shrinkage immediately as soon as it begins due to moisture loss.

Therefore, polyethylene (PE) microfibre was tested and used as an addition to OPC mortar samples before mixing. Results showed reduction in drying shrinkage, workability and compressive strength. Reduction in moisture loss of PE reinforced specimens suggested that the hydrophobicity of PE microfibres make it a shrinkage reducing admixture, since with considering their dimensions, they can be located in a way to block capillary pores and accordingly avoid moisture loss. Whereas, loss in strength might reveal this phenomenon that PE microfibre could not be efficient in micro-bridging of particles under stress. Another conclusion was that micro-bridging is not the mechanism behind the shrinkage reduction of PE microfibre.

Another admixture used was microfibre of an inosilicate mineral, wollastonite. Its micro-bridging characteristics and its positive influence on some mechanical properties of concrete were the incentives for being used in this research. Wollastonite microfibre reduced the amount of drying shrinkage and for some concentrations; it even enhanced the compressive strength, with no adverse effect on workability. Behavioural test results showed that micro-bridging of wollastonite microfibre can possibly be a reason behind its shrinkage reduction.

Early age behaviour of these admixtures has also been investigated. Current early age experiments and the information that each can give, were studied. A simple experiment was adopted from the literature, and mortar specimens were cast using optimum concentrations of these admixtures. The specimens were stored in a controlled drying environment and monitored for 24 hours. The number of major cracks, the cracking time and the dimensions of cracks have been assessed and analysed. Based on these experiments, APP, PE microfibre and wollastonite microfibre can significantly reduce the number and the size of early age cracks in cementitious materials. APP modified mortar could also delay the cracking time significantly.

This dissertation concludes that APP, PE microfibre and wollastonite microfibre reduce the drying shrinkage and early age cracking potential. APP and wollastonite microfibre have no side effect in mechanical characteristics of OPC mortars. These admixtures not only reduce the drying shrinkage in a cementitious material, but also control the early age cracking. By examining some other chemical compositions of polyphosphates, this thesis concludes that there are still new shrinkage compensating admixtures and mechanisms, which need to be examined and introduced to the industry.

Throughout this PhD research project, a number of conference and journal articles were submitted and published, while there is also one article still under peer review. These publications have been listed under Appendix B of this dissertation and copies of published papers have been attached.