RILEM State-of-the-Art Reports

RILEM STATE-OF-THE-ART REPORTS

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Properties of Fresh and Hardened Concrete Containing Supplementary Cementitious Materials

State-of-the-Art Report of the RILEM Technical Committee 238-SCM, Working Group 4

Springer

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Preface

Supplementary cementitious materials (SCMs) are commonly used in concrete practice nowadays, either in blended cements or as separate additions into the concrete mixture. The use of hydraulic and pozzolanic by-products allows to reduce the carbon dioxide emissions related to Portland clinker production and hence provides a way to obtain a more sustainable binder for the construction industry. Furthermore, the use of by-products entails benefits related to costs and some durability aspects. In general, the effects of these supplementary cementitious materials on microstructure and durability have been widely studied over the last decades. Nevertheless, several aspects have been denoted to merit further attention:

- The interaction between Portland clinker hydration and SCM reaction is not yet fully understood. Determination of reaction degrees of SCM is difficult; this is even more so if ternary mixes are concerned.
- The interaction between SCM and commonly used admixtures is often not well documented.
- The quality of by-products such as fly ash is changing due to, for instance, co-combustion in the electrical power plants. The effect of changing composition on the clinker and SCM reactions, and on the resulting microstructure, should be elucidated.
- The ongoing move from Portland to blended cements, and the replacement of Portland cement by SCM in the mix design, will affect construction practices. The exact composition of blended cements, which is often unknown, will affect early age strength development. For the construction industry, it is important to know how the variability of SCM affects the properties of their concrete and curing requirements.

Hence, in July 2011, the RILEM technical committee TC 238-SCM was established with the aim to support the increasing utilisation of hydraulic and pozzolanic industrial by-products, natural resources and societal waste (fly ash, blast-furnace slag and other by-products and residues of thermal industrial processes, calcined clays, limestone, natural pozzolans, natural zeolites, …) to obtain more sustainable, less CO_2-intensive binders for the construction industry. It was decided that durability issues would not be a main focus of this TC. The TC was meant to serve as a knowledge platform where fundamental science and practical expertise are gathered to create a horizontal overview of the research area and to implement and promote the dissemination of more integrated generic approaches into the scientific community.

In one of their first meetings, TC 238-SCM defined a Supplementary Cementitious Material or SCM as *"an inorganic material that, when used in conjunction with Portland cement, contributes to the properties of the hardened concrete through chemical reaction e.g. hydraulic or pozzolanic activity"*.

The following subtopics were identified and studied in four different working groups with specific scope:

1. *SCM characterisation* (chairs: Maria Juenger, Jan Elsen)
   Quantitative characterisation of the physico-chemical properties of a wide range of traditional and potential SCMs. Identifying challenges on an expanding and evolving SCM market.
2. *SCM reaction kinetics* (chairs: Karen Scrivener, Nele De Belie)
   SCM reactivity and overall reaction kinetics in blended cements. Determination of reaction degrees of SCM, also in ternary mixes. Interaction between Portland clinker hydration and SCM reaction.
3. *Hydration product assemblage and microstructure of SCM-blended cements* (chairs: Barbara Lothenbach, Ruben Snellings)
   Hydrate reaction product assemblages and pore solution composition in SCM-blended cements, binary and ternary mixtures. Optimisation of sulphate additions. Effect of temperature and clinker replacement proportion. Effect of SCM incorporation on the microstructure. Linking microstructure to performance.
4. *Properties of concrete containing SCMs and interaction of SCMs and admixtures in concrete* (chairs: Marios Soutsos, Guang Ye)
   Effect of SCMs and mix proportioning on the properties of fresh and hardened concrete (e.g. early strength development, workability, shrinkage) and curing requirements (especially for in situ cast concrete in adverse weather conditions). Post-blending versus pre-blending. Implications of SCM variability. Interaction between SCM and commonly used admixtures (e.g. superplasticizers, air entrainers).

Over the period 2011–2017, the TC 238-SCM has convened 12 times and has published the outcome of their collaborative research and discussions in various articles, which are mentioned below for further reading. This book is the final outcome of working group 4 of the TC and provides an overview of the state of the art regarding the properties of fresh and hardened concrete containing supplementary cementitious materials. Each chapter was a joint effort of different co-authors and was reviewed by at least two other TC members.

Details of TC members are given after this Preface. I wish to acknowledge their contribution to meetings and discussions, their efforts in writing, reading and commenting on the various drafts of this book and of the other publications mentioned further. Special thanks go to the chairs of the working groups, which have given tremendous assistance to organise the activities within their group. Finally, I want to acknowledge my co-editors, Prof. Marios Soutsos and Dr. Elke Gruyaert, for ensuring that this STAR could be realised within the lifetime of the TC.

Ghent, Belgium

Prof. Nele De Belie
Chair of RILEM Technical Committee TC 238-SCM

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TC 238-SCM Publication List

WG1: Characterisation of SCMs

Juenger, M., Provis, J., Elsen, J., Matthes, W., Hooton, D., Duchesne, J., Courard, L., He, H., Michel, F., Snellings, R., De Belie, N. (2012). Supplementary Cementitious Materials for Concrete: Characterization Needs. International symposium on concrete with smart additives and supplementary cementitious materials, IMRC, 12–17 August 2012, Cancun, Mexico. Abstract on CD of abstracts. Full paper in MRS Online Proceedings Library—January 2012—VOLUME 1488 p imrc12-1488-7b-026.

Arvaniti, E.C., Juenger, M.C.G., Bernal, S.A., Duchesne, J., Courard, L., Leroy, S., Provis, J.L., Klemm, A., De Belie, N. (2015). Physical Characterization Methods for Supplementary Cementitious Materials. Materials and Structures, 48, (11), 3675–3686.

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WG2: SCM reaction kinetics

Scrivener, K.L., Lothenbach, B., De Belie, N., Gruyaert, E., Skibsted, J., Snellings, R., Vollpracht, A. TC 238-SCM: Hydration and microstructure of concrete with SCMs. State of the art on methods to determine degree of reaction of SCMs. Materials and Structures, 48 (4), 835-862 (invited paper)

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Durdzinski, P., Ben Haha, M., Bernal, S., De Belie, N., Gruyaert, E., Lothenbach, B., Menendez-Mendez, E., Provis, J.L., Schöler, A., Stabler, C., Tan, Z., Villagran Zaccardi, Y., Vollpracht, A., Winnefeld, F., Zajac, M., Scrivener, K. (2017). Outcomes of the RILEM round robin on degree of reaction of slag and fly ash in blended cements. Materials and Structures, 50, (135), 15 p.

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WG3: Hydration product assemblage and microstructure

Vollpracht, A., Lothenbach, B., Snellings, R., Haufe, J. (2016) The pore solution of blended cements: a review. Materials and Structures, 49, (8), 3341-3367.

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WG4: SCMs in concrete

Vollpracht, A., Soutsos, M., Kanavaris, A. Strength development of GGBS and fly ash concretes and applicability of fib model code’s maturity function – a critical review. Construction and Building Materials, submitted.

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Contents

1 **Ground Granulated Blast-Furnace Slag** 1
Winnie Matthes, Anya Vollpracht, Yury Villagrán, Siham Kamali-Bernard, Doug Hooton, Elke Gruyaert, Marios Soutsos and Nele De Belie

2 **Fly Ash** 55
Kosmas Sideris, Harald Justnes, Marios Soutsos and Tongbo Sui

3 **Silica Fume** 99
Robert C. Lewis

4 **Limestone Powder** 123
Luc Courard, Duncan Herfort and Yury Villagrán

5 **Metakaolin** 153
F. Wang, K. Kovler, J. L. Provis, A. Buchwald, M. Cyr, C. Patapy, S. Kamali-Bernard, L. Courard and K. Sideris

6 **Natural Pozzolans** 181
Christos Dedeloudis, Monika Zervaki, Kosmas Sideris, Maria Juenger, Natalia Alderete, Siham Kamali-Bernard, Yury Villagrán and Ruben Snellings

7 **Alternative Supplementary Cementitious Materials** 233
Konstantin Sobolev, Marina Kozhukhova, Kosmas Sideris, Esperanza Menéndez and Manu Santhanam

8 **Rice Husk Ash** 283
Guang Ye, Hao Huang and Nguyen Van Tuan

9 **Ternary Blends** 303
R. Doug Hooton, Semion Zhutovsky and Siham Kamali-Bernard

Introduction

Supplementary cementitious materials (SCMs) have become a common ingredient of the concrete mix design nowadays. Many studies have focused on the effects of SCMs on reaction kinetics, microstructure and concrete properties. This state-of-the-art book aims to focus particularly on the properties of concrete containing supplementary cementitious materials, in the fresh and hardened state.

The SCMs identified include the most commonly used ones, like ground granulated blast-furnace slag, fly ash and silica fume, but also others that may not have attracted as much attention but nonetheless show promise for use in concrete. Dedicated chapters for each SCM were considered necessary, and thus, the chapters are as follows:

- Chapter 1. Ground Granulated Blast-furnace Slag
- Chapter 2. Fly Ash
- Chapter 3. Silica Fume
- Chapter 4. Limestone Powder
- Chapter 5. Metakaolin
- Chapter 6. Natural Pozzolans
- Chapter 7. Alternative Supplementary Cementitious Materials
- Chapter 8. Rice Husk Ash
- Chapter 9. Ternary Blends

The following points have been in general addressed:

- Overview/production of SCMs, pre- and post-blending, uses in concrete (historical perspective),
- Relevant standards,
- Health and safety issues,
- Environmental sustainability,
- Fresh properties, workability, water demand, rheology, bleeding, etc.,
- Chemical admixture interaction,
- Setting times, plastic settlement, (chemical) shrinkage, curing,
- Early age strength development,

- Heat of hydration, rate of reaction (influence of temperature and curing, maturity functions),
- Compressive strength,
- Tensile strength,
- Flexural strength,
- Modulus of elasticity,
- Fatigue,
- Transport properties.

We hope this book will contribute to a better understanding of the effects of SCMs on concrete properties, and that it will stimulate appropriate use of these valuable materials.

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