

The Combined Influence of Paste Volume and Volumetric Water-to-Powder Ratio on Robustness of Fresh Self-Compacting Concrete

Farid Van Der Vurst¹, Steffen Grünewald², Dimitri Feys³ and Geert De Schutter⁴

¹Ph.D. student, Ghent University

²Postdoctoral researcher, Ghent University and Delft University of Technology

³Assistant Professor Materials Engineering, Missouri University of Science and Technology

⁴Full Professor Concrete Technology, Ghent University

Abstract: In order to avoid durability problems caused by an inadequate consolidation of concrete, self-compacting concrete (SCC) has been developed. The mix design of SCC aims at balancing a minimum flowability allowing air bubbles to escape and a maximum flowability in order to avoid segregation. Because of the higher demands on mix design and additional requirements related to casting, SCC mixtures are in general more sensitive to small variations in its mix composition compared to conventional vibrated concrete. Besides improving the robustness of SCC with admixtures like Viscosity-Modifying Agents (VMAs), it is also important to find out why certain mixtures are more robust than others. This paper investigates the influence of the paste volume and the water-to-powder ratio (volumetric) on the robustness of fresh SCC mixtures. Nine SCC mixtures with a paste volume of 350, 375, and 400 l/m³ and a volumetric water-to-powder ratio of 0.75, 0.90, and 1.05 were subjected to a variation of ± 8 l/m³ water. The robustness of the produced mixtures was quantified measuring the slump flow, V-funnel time, L-box ratio, and sieve stability.

Keywords: Robustness, Self-Compacting Concrete, Rheology, Paste Volume, Water-to-Powder ratio

1. Introduction

1.1. Self-compacting concrete

After investigating many durability problems of post-war Japanese concrete structures, Okamura and his team found that a majority of problems originated in a poor consolidation of concrete during the casting process. As a solution to avoid similar problems, a new type of concrete was developed for which external vibration was no longer needed to assure a good compaction: self-compacting concrete (SCC) [1, 2]. In order to combine sufficient fluidity – allowing air-bubbles to escape and complete formwork filling – and sufficient stability to avoid segregation, the high fluidity concrete contains higher powder content compared to conventional vibrated concrete, superplasticizer(s), and sometimes a viscosity-modifying admixture (VMA). However, because the target range for sufficient fluidity, sufficient segregation resistance, and to avoid an excessive stickiness is much smaller than the optimum range of conventional vibrated concrete, self-compacting mixtures are generally more sensitive to small variations in the mix proportions, materials properties, and casting circumstances.

To counter this larger sensitivity to small variations, also referred to as reduced robustness, a more severe quality control and better trained workers are needed. The use of SCC is nowadays still limited to cases where all conditions are well-controlled and situations in which an external compaction would cause great difficulties. To facilitate the use of SCC in general and especially for applications with specific requirements for fresh concrete, it is necessary to investigate the origin of the robustness of concrete.

1.2. The origin of the robustness

Although many parameters such as material characteristics [3-11], temperature [12-14], and shear history [15-18] affect the fresh behaviour of self-compacting concrete, most robustness studies focus on the influence of small changes in the material proportions [11, 19-42]. Of all changes in material proportions, inaccuracies in the water amount are responsible for the largest variations of the fresh behaviour of SCC [43, 44]. Therefore, many studies on the robustness of fresh SCC focus on the influence of small variations of the water content (± 5 to 10 l/m³). According to these publications, the sensitivity to small variations of the water content decreases as:

- A surplus of fine aggregates is included in the aggregates grading curve, preventing the coarse aggregates from becoming dominant [19-21, 45].
- The powder content increases [20, 21, 23].
- Part of the cement is substituted by silica fume or fly ash [22, 24].
- A VMA is added to the mixture [20, 28-39, 46].
- Certain types of superplasticizers are used [25-27].
- Opposing conclusions are drawn about the influence of the water-to-cement and water-to-powder ratio [19, 38]

The mechanisms and combination of influences of the powder content, the water-to-powder ratio, mineral additions and admixtures on the robustness are still unknown. Some authors indicate the importance of the paste volume, the paste density, and the paste viscosity [20, 21, 23], while others focus on the excess water in the concrete mix design [38] or make a link between the thixotropy and robustness [47, 48]. This paper attempts to determine the causes behind the influence of paste volume and volumetric water-to-powder ratio on the robustness of SCC.

2. Experimental work

2.1. Materials and mixing sequence

All mixtures are made with the same raw materials: Rhine sand 0/5, river gravel 2/8 and 8/16 (with a density of respectively 2630 kg/m³, 2670 kg/m³, and 2660 kg/m³), Portland cement CEM I 52.5 N (with a density of 3126 kg/m³ and a Blaine fineness of 370 m²/kg), limestone filler (with a density of 2685 kg/m³ and a specific surface area of 424 m²/kg, based on the particle size distribution), and a PCE superplasticiser with a solid content of 35%. The grading curve of the aggregates is illustrated in

Figure 1 and the chemical composition of the cement as determined by an XRF analysis is given in Table 1. After premixing the cement, filler, and dry aggregates for one minute in a planetary pan mixer, water was added to the mixer and mixing continued for another minute. Finally, the superplasticizer was added and the concrete was mixed for two more minutes.

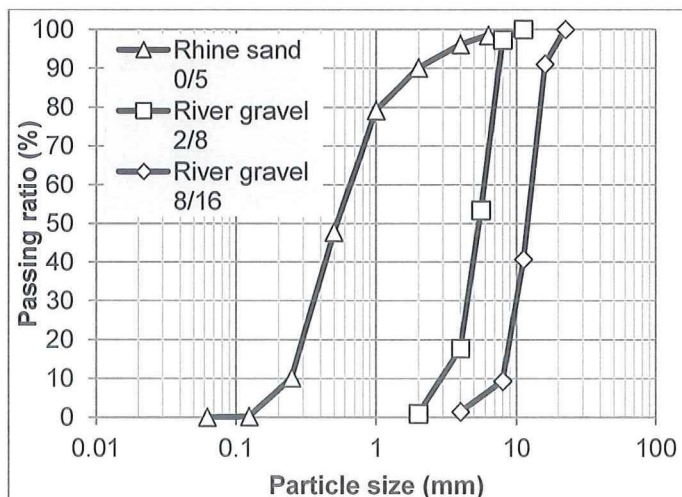


Figure 1. Grading curve of the aggregates

Table 1. Chemical composition of the cement

	Cement [%]
CaO	62.30
SiO ₂	18.77
Al ₂ O ₃	6.00
Fe ₂ O ₃	4.06
MgO	1.07
K ₂ O	0.58
Na ₂ O	0.51
CO ₂	0.60
SO ₃	3.35
Cl ²⁻	0.067
L.O.I.	1.82
Insoluble rest	0.41

2.2. Mixture compositions

The robustness of nine SCC mixtures was determined by measuring the slump flow, V-funnel time, L-box ratio, sieve stability, air content and density of the mixtures subjected to a variation of ± 8 l/m³ water. The mixtures, given in Table 2, have different paste volumes (350, 375, and 400 l/m³) and volumetric water-to-powder ratios (0.75, 0.90, and 1.05), keeping the water-to-cement ratio constant. These paste volumes and volumetric water-to-powder ratio's correspond with the 20%, 50%, and 80% fractals of a database summarizing the properties of SCC mixes used in more than 175 papers [49,

50]. The superplasticizer dosage was always determined such that the Sieve Stability Index (S.S.I., tested according to EN 12350-11) of the reference mixture is between 8 and 12%.

Table 2: Mix proportions of reference SCC mixes

Paste volume / water-to-powder ratio (by volume) [l/m ³] / [-]	Sand 0/5 [kg/m ³]	Gravel 2/8 [kg/m ³]	Gravel 8/16 [kg/m ³]	Cement I 52 N [kg/m ³]	Limestone filler [kg/m ³]	Water [kg/m ³]	SP dosage [l/m ³]
400 / 0.75	800	279	459	312	346	171	3.31
400 / 0.90	800	279	459	344	269	189	2.50
400 / 1.05	800	279	459	373	204	205	1.95
375 / 0.75	835	291	478	292	324	161	3.95
375 / 0.90	835	291	478	323	252	178	2.80
375 / 1.05	835	291	478	349	191	192	2.00
350 / 0.75	869	303	498	273	302	150	5.31
350 / 0.90	869	303	498	301	236	166	3.63
350 / 1.05	869	303	498	326	178	179	2.38

3. Experimental results

Table 3 and Table 4 summarize the fresh properties of the nine reference mixtures. In Table 4, for each workability test, the values for the reference mixtures are listed together with the change of the test response per liter water of the parameter (eg. $\Delta SF / 16 \text{ l/m}^3$) and the ratio of the interval divided by the mean value (eg. $\Delta SF / SF_{ref}$). All workability tests except the L-box ratio gave a good picture of the impact of fluctuations of the water content on the fresh behaviour of the mixtures.

Table 3: Fresh state properties of nine reference SCC mixes

Paste volume / water-to-powder ratio [l/m ³] / [-]	Slump flow [mm]	V-funnel time [s]	L-box ratio [-]	S.S.I. [%]	Density [kg/m ³]	Air content [%]
400 / 0.75	673	13.7	0.82	9.4	2475	2.5
400 / 0.90	680	6.3	0.85	12.2	2369	1.6
400 / 1.05	688	3.5	0.83	12.0	2369	1.2
375 / 0.75	705	17.6	0.96	11.2	2394	1.9
375 / 0.90	680	8.0	0.91	10.1	2375	1.8
375 / 1.05	680	4.0	0.86	12.3	2372	1.4
350 / 0.75	865	15.9	1.00	10.5	2406	0.9
350 / 0.90	750	10.5	0.98	9.4	2375	1.5
350 / 1.05	675	5.3	0.80	8.0	2369	1.5

Table 4: The robustness of nine SCC mixes

	400 / 0.75	400 / 0.90	400 / 1.05	375 / 0.75	375 / 0.90	375 / 1.05	350 / 0.75	350 / 0.90	350 / 1.05
Slump flow [mm]	673	680	688	705	680	680	865	750	675
ΔSF	260	163	210	155	138	133	90	130	148
$\Delta SF / 16 \text{ l/m}^3$	16.3	10.2	13.1	9.7	8.6	8.3	5.6	8.1	9.2
$\Delta SF / SF_{ref}$	0.39	0.24	0.31	0.22	0.20	0.19	0.10	0.17	0.22
V-funnel time [s]	13.7	6.3	3.5	17.6	8.0	4.0	15.9	10.5	5.3
ΔVF	11.4	3.8	3.8	18.4	5.4	2.2	21.8	5.4	2.8
$\Delta VF / 16 \text{ l/m}^3$	0.71	0.24	0.24	1.15	0.34	0.14	1.36	0.34	0.18
$\Delta VF / VF_{ref}$	0.83	0.60	1.07	1.04	0.68	0.56	1.37	0.51	0.53
L-box ratio [-]	0.82	0.85	0.83	0.96	0.91	0.86	1.00	0.98	0.8
ΔLB	0.78	0.19	0.35	0.06	0.27	0.15	0.02	0.02	0.19
$\Delta LB / 16 \text{ l/m}^3$	0.049	0.012	0.022	0.004	0.017	0.009	0.001	0.002	0.012
$\Delta LB / LB_{ref}$	0.95	0.22	0.41	0.06	0.29	0.17	0.02	0.02	0.23
S.S.I. [%]	9.4	12.2	12.0	11.2	10.1	12.3	10.5	9.4	8.0
ΔSSI	16.7	8.1	12.9	13.8	8.0	8.4	9.1	4.5	5.0
$\Delta SSI / 16 \text{ l/m}^3$	1.04	0.51	0.80	0.86	0.50	0.52	0.57	0.28	0.31

3.1. Variations of the slump flow

Because the superplasticizer dosage was always adjusted in order to have a S.S.I. of 10%±2%, the slump flow of the nine mixtures is not related to their paste volume or water-to-powder ratio (Table 3). However, as shown in Table 4 and Figure 2, the sensitivity of the slump flow to changes in the water content depends on the paste volume: the robustness of the flow decreases as the paste volume increases. Table 4 shows that the water-to-powder ratio of the mixtures has no clear influence on the robustness of the slump flow.

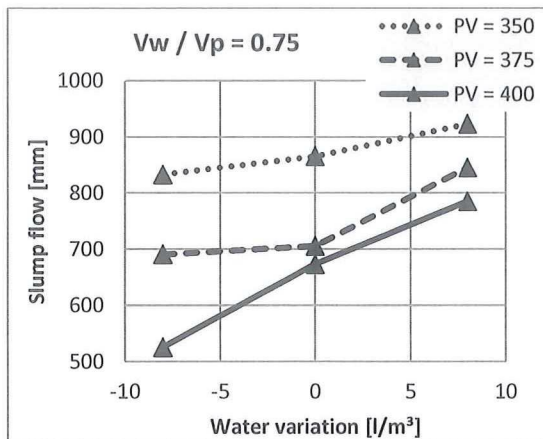


Figure 2a: Influence of the paste volume on the slump flow

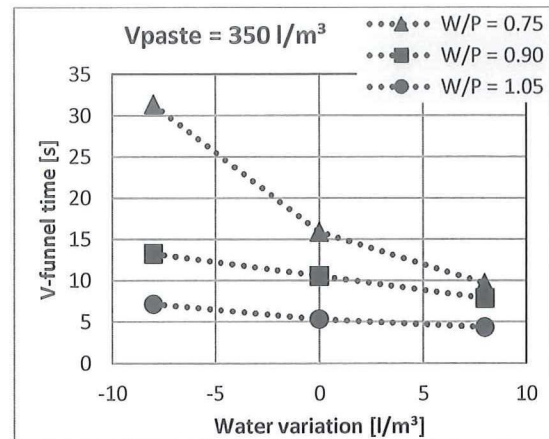


Figure 3a: Influence of the volumetric water-to-powder ratio on the V-funnel time

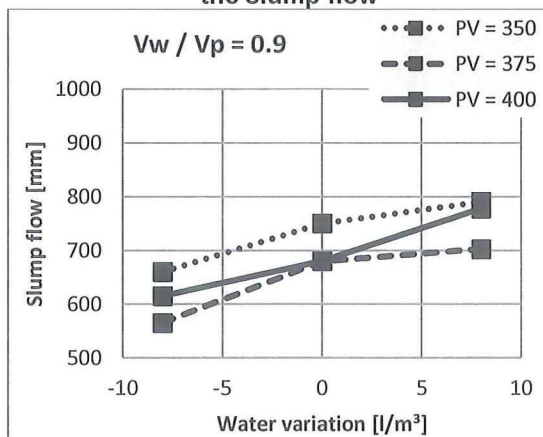


Figure 2b: Influence of the paste volume on the slump flow

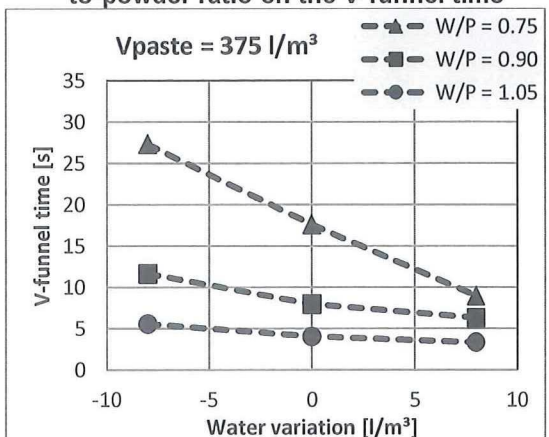


Figure 3b: Influence of the volumetric water-to-powder ratio on the V-funnel time

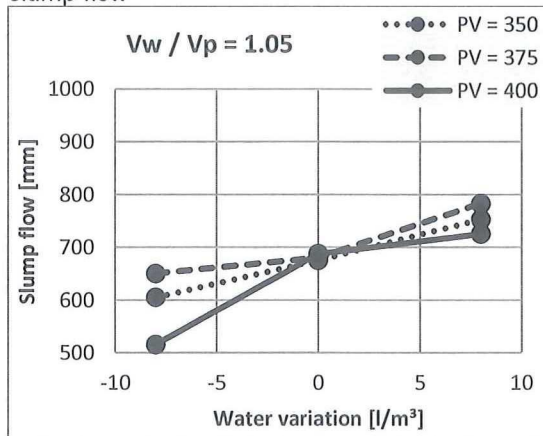


Figure 2c: Influence of the paste volume on

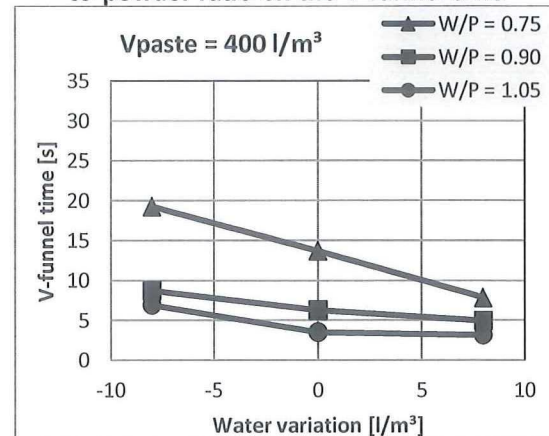


Figure 3c: Influence of the volumetric water-

3.2. Variations of the V-funnel time

When the paste volume increases, the V-funnel time of the mixtures decreases slightly (about 3 sec difference between 350 and 400 l/m³ for the same water-to-powder ratio); the sensitivity of the V-funnel time to variations in the water content also seems to be independent of the paste volume of the mixture. Mixtures with a higher water-to-powder ratio have a significant lower V-funnel time than mixtures with a lower water-to-powder ratio (see Tables 3 and 4). Especially, mixtures with a water-to-powder ratio of 0.75 are very sensitive to a decrease in the water content, making them very sticky and not easy to process. The robustness determined by changes in the V-funnel time therefore increases when the water-to-powder ratio increases (Figure 3).

3.3. Variations of the L-box ratio

Table 4 reveals no clear influence of the test responses on the L-box ratio results. The results are also difficult to interpret because of the poor flowability of the mixtures with 8 l/m³ less water, a paste volume of 400 l/m³ and volumetric water-to-powder ratios of 0.75 and 1.00, which have a slump flow of respectively 525 and 515 mm.

3.4. Variations of the sieve stability

As shown in Table 4 and Figure 4, an increase in the paste volume increases the sensitivity of the S.S.I. to variations in the water content. The paste volume has a larger effect than changes in the water-to-powder ratio.

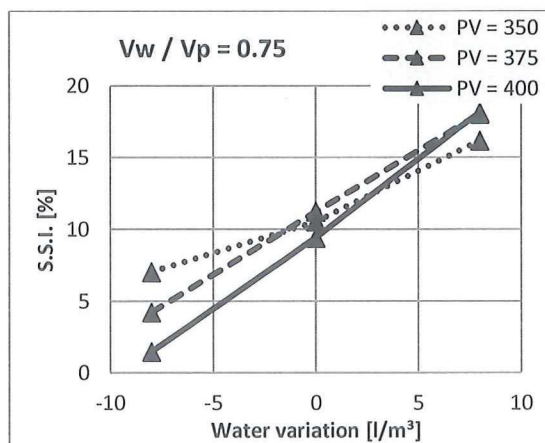


Figure 4a: Influence of the paste volume on the sieve stability

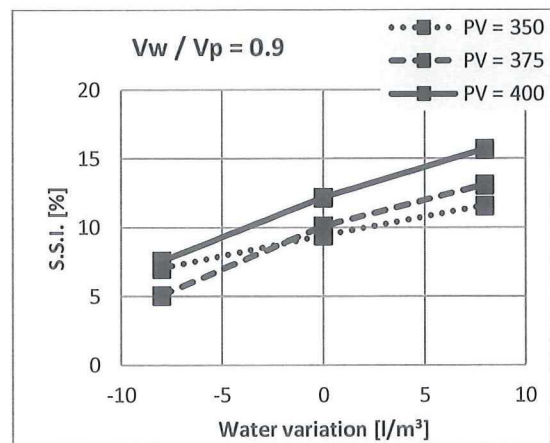


Figure 4b: Influence of the paste volume on the sieve stability

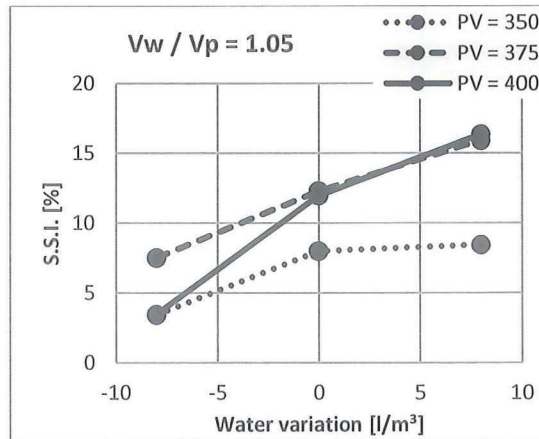


Figure 4c: Influence of the paste volume on the sieve stability

4. Discussion of influence parameters

Mixtures were designed to show a specific level of sieve stability, regardless of the fluidity of the mixture. As static segregation must be avoided in all cases, the S.S.I. was chosen as “reference mix design parameter”. The conclusions of this study may therefore deviate from other results in literature.

4.1. Workability tests for the robustness

Variations induced by changes in the water content affect the filling ability, the passing ability, and the segregation resistance and may result in a rejected mixture. Because a lack of robustness of an SCC mixture is most often not caused by the three key characteristics of SCC at the same time, it is not evident to grasp the variations of the slump flow, V-funnel time, L-box ratio, and sieve stability index into one global ‘robustness value’. A better approach is to judge robustness of each mixture based on its most critical parameter: a poor flowability or a too viscous and sticky mixture when the mixture contains 8 l/m³ less water; or a severe segregation of the coarse aggregates or extreme bleeding occurring when 8 l/m³ water in excess is added to the mixture.

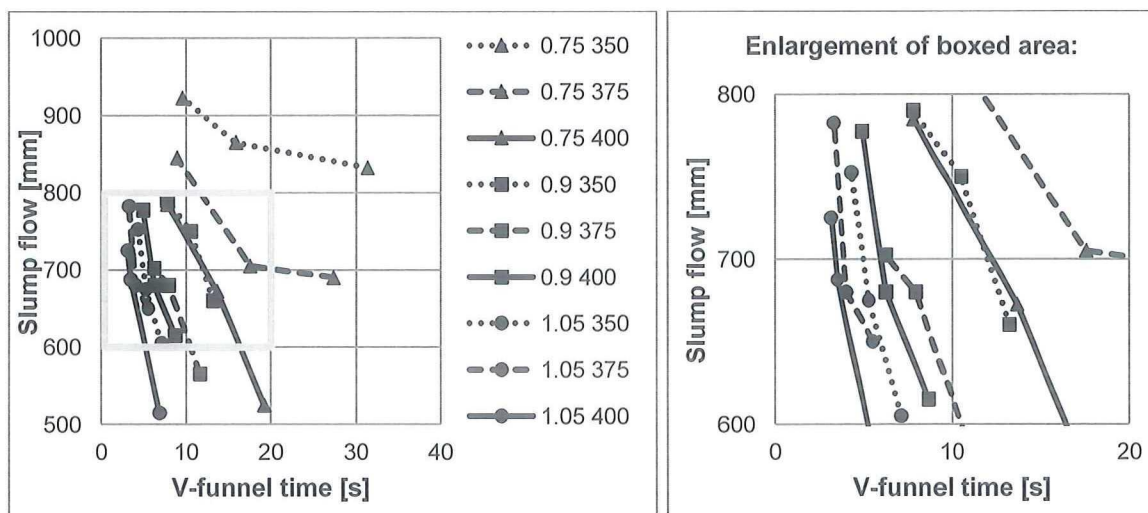


Figure 5: The robustness of all mixtures illustrated in a workability box

4.2. Influence of the paste volume

When the paste volume increases, the robustness to variations in the water content of the slump flow and S.S.I. decreases while the sensitivity of the V-funnel time is constant (Table 4 and Figure 3 to 5). As shown in Figure 5, the SCC mixtures with a higher paste volume (full lines) have a lower slump

flow to achieve similar stability and are thus more sensitive to a poor flowability when the water dosage is decreased by 8 l/m³ or have a more than proportional increase in S.S.I. when 8 l/m³ water is added to the mixture.

4.3. Influence of the volumetric water-to-powder ratio

The robustness determined by changes in the V-funnel time increases when the water-to-powder ratio increases (Table 4, Figure 3, and Figure 5, lines with circles). Because the superplasticizer dosage added to the mixtures decreases with a higher water-to-powder ratio to achieve similar stability, the resulting effect on the sensitivity of the slump flow and S.S.I. is rather limited. Mixtures with a higher water-to-powder ratio have a lower plastic viscosity, making them more dependent on the yield stress to assure a stable mix design. Therefore, the robustness of these mixtures should be assured by increasing the aggregates volume and thus reducing the paste volume. When the water-to-powder ratio of a mixture is rather low, the plastic viscosity might become too high when reducing water by 8 l/m³ and the robustness should be guaranteed by a larger paste volume. The paste volume, however, should also not be too high, since this increases the sensitivity of the slump flow of the mixture.

5. Recommendations

Every application of SCC imposes specific demands towards the mix design of the concrete [24]. In order to combine specific workability demands with a sufficient robustness, the following is recommended regarding the paste volume and water-to-powder volume combination while assuming the stability of the mixture, summarized in Table 5.

Table 5: The recommended paste volume and water-to-powder ratio depended on the application

Application	Recommended paste volume	Recommended volumetric water-to-powder ratio
Large horizontal elements (floors and plates)	Low	High
Long horizontal elements (reinforced beams)	Low	Intermediate
Long vertical elements (walls)	Intermediate	Low
Slender vertical elements (columns)	High	Low

5.1. Large horizontal elements (floors and plates)

To facilitate the casting of large horizontal elements, SCC mixtures with high volumetric water-to-powder ratios should be used. Because the stability of such a mixture is provided by its high yield stress, the robustness can be improved by decreasing the paste volume of the mixture.

5.2. Long horizontal elements (reinforced beams)

A slow, but far flowing SCC mixture with a low paste volume and low water-to-paste ratio should be applied. In such a mixture, the stability is achieved by the high plastic viscosity. With a sufficiently high but not too high volumetric water-to-powder ratio, the needed robustness concerning changes in the water content is achieved.

5.3. Long vertical elements (walls)

In order to flow slowly and without segregation in between the reinforcement of long vertical elements, mixtures should have a low yield stress and a high plastic viscosity for its segregation resistance. The high plastic viscosity can be achieved with a low volumetric water-to-powder ratio. A maximum robustness is achieved by a higher paste volume, which should not be too high preventing the yield stress from becoming dominant and thus increasing the sensitivity to an too low flowability.

5.4. Slender vertical elements (columns)

In columns and slender walls, the mixture should have a high plastic viscosity and without specific demands towards the yield stress. Because the stability to segregation can be provided by a combination of an intermediate plastic viscosity and yield stress, the mixture needs a low volumetric water-to-powder ratio to obtain the required plastic viscosity and a relatively high paste volume.

6. Conclusions

An experimental program including nine SCC mix compositions with different paste volumes and volumetric water-to-powder ratio's demonstrates that the robustness of SCC should be tested with several workability parameters in order to determine the most critical parameter of the mixture for a specific application. Because the L-box ratio does not always provide clear trends, the analysis in this experimental program is based on the slump flow, V-funnel, and sieve stability measurements. For all mixtures, the superplasticizer dosage was adjusted to achieve a specific stability level (S.S.I. = $10 \pm 2\%$).

The robustness of the slump flow increases when the paste volume decreases, because mixtures with a lower paste volume depend mainly on their larger aggregate volume in order to obtain sufficient segregation resistance. The paste volume only has a minor influence on the V-funnel time and its sensitivity. A lower volumetric water-to-powder ratio increases the V-funnel time and increases the risk for the mixture of becoming too viscous when a small decrease of the water content occurs. The limited influence of the water-to-powder ratio on variations of the slump flow is probably caused by the lower superplasticizer dosage of the mixtures with a higher water-to-powder ratio.

7. Acknowledgements

The authors would like to thank the Science Foundation Flanders (FWO) for their financial support, and Tom Stulemeijer and Nathan Lampens for their assistance during the experimental work.

8. References

- [1] De Schutter G, Bartos PJM, Domone P, Gibbs J. Self-compacting concrete. Dunbeath, Scotland, UK: Whittles Publishing 2008.
- [2] Ozawa K, Maekawa K, Kunishima M, Okamura H. Development of high performance concrete based on the durability design of concrete structures. In: Okamura H, Shima H, eds. *Second East-Asia and Pacific Conference on Structural Engineering and Construction*. Chiang-Mai, Thailand 1989.
- [3] Nunes S, Milheiro-Oliveira P, Sousa Coutinho J, Figueiras J. Rheological characterization of SCC mortars and pastes with changes induced by cement delivery. *Cement & Concrete Composites*. 2011;33(1):103-15.
- [4] Kubens S. Interaction of cement and admixtures and its effect on rheological properties. Göttingen: Bauhaus-Universität Weimar 2010: Doctoral thesis.
- [5] Kubens S, Peng H, Oesterheld S, Wallevik OH. Some effects of silica fume on variations in rheology of mortar due to production date of cement. *Annual Transactions of the Nordic Rheology Society*. 2008;16:4.
- [6] Wallevik OH, Kubens S, Müller F. Influence of cement-admixture interaction on the stability of production properties of SCC. In: De Schutter G, Boel V, eds. *5th International RILEM Symposium on Self-Compacting Concrete*. Ghent, Belgium: RILEM Publications SARL 2007:211-6.
- [7] Nunes S, Oliveira PM, Coutinho JS, Figueiras J. Rheological characterization of SCC mortars and pastes with changes induced by cement delivery. *Cement & Concrete Composites*. 2011;33(1).
- [8] Juvas K, Käppi A, Salo K, Nordenswan E. The effects of cement variations on concrete workability. *Nordic Concrete Research*. 2001;26:39-46.
- [9] Westerholm M, Lagerblad B, Silfwerbrand J, Forssberg E. Influence of fine aggregate characteristics on the rheological properties of mortars. *Cement & Concrete Composites*. 2008;30(4):274-82.
- [10] Kristensen LF. Influence of different Danish glacial deposited sands on SCC properties. In: Wang K, Shah SP, eds. *Fifth North American Conference on the Design and Use of Self-Consolidating Concrete*. Chicago, IL, USA 2013.
- [11] Yurugi M, Sakai G. A Proven QA System for Flowable Concrete. *Concrete International*. 1998;20(10):44-8.

- [12] Yamada K, Yanagisawa T, Hanehara S. Influence of temperature on the dispersibility of polycarboxylate type superplasticizer for highly fluid concrete. In: Skarendahl A, Petersson Ö, eds. *First International RILEM Symposium on Self-Compacting Concrete*. Stockholm, Sweden: RILEM Publications 1999:437-48.
- [13] Jolicoeur C, Simard M-A. Chemical admixture-cement interactions: phenomenology and physico-chemical concepts. *Cement and Concrete Composites*. 1998;20(2):87-101.
- [14] Schmidt W. Design concepts for the robustness improvement of self-compacting concrete - Effects of admixtures and mixture components on the rheology and early hydration at varying temperatures. Eindhoven, The Netherlands: Eindhoven University of Technology 2014: Doctoral thesis.
- [15] Van Der Vurst F, Ghafari E, Feys D, De Schutter G. Influence of addition sequence of materials on rheological properties of self-compacting concrete. *The 23rd Nordic Concrete Research Symposium*. Reykjavik, Iceland: Norsk betongforening 2014:399-402.
- [16] Ng IYT, Ng PL, Fung WWS, Kwan AKH. Optimizing mixing sequence and mixing time for SCC. In: Shi C, Yu Z, Khayat KH, Yan P, eds. *Second International Symposium on Design, Performance and Use of Self-Consolidating Concrete*. Beijing, China: RILEM 2009:105-13.
- [17] Mazanec O, Schiessl P. Mixing Time Optimisation for UHPC. In: Fehling E, Schmidt M, Stürwald S, eds. *Second International Symposium on Ultra High Performance Concrete*. Kassel, Germany: Kassel University Press 2008:401-8.
- [18] Schiessl P, Mazanec O, Lowke D. SCC and UHPC - Effect of mixing technology on fresh concrete properties. In: Grosse CU, ed. *Advances in Construction Materials*. Heidelberg, Germany: Springer 2007:513-22.
- [19] Kwan AKH, Ng IYT. Optimum superplasticiser dosage and aggregate proportions for SCC. *Magazine of Concrete Research*. 2009;61(4):281-92.
- [20] Bonen D, Deshpande Y, Olek J, Shen L, Struble L, Lange DA, et al. Robustness of self-consolidating concrete. In: De Schutter G, Boel V, eds. *5th International RILEM Symposium on Self-Compacting Concrete*. Ghent, Belgium: RILEM Publications SARL 2007:33-42.
- [21] Jonasson J-E, Nilsson M, Utsi S, Simonsson P, Emborg M. Designing robust SCC for industrial construction with cast in place concrete. In: Shah SP, ed. *Second North American Conference on the Design and Use of Self-Consolidating Concrete; Fourth International RILEM Symposium on Self-Compacting Concrete*. Chicago, IL, USA: Hanley Wood, LLC 2005:1251-7.
- [22] Kwan AKH, Ng IYT. Improving performance and robustness of SCC by adding supplementary cementitious materials. *Construction and Building Materials*. 2010;24(11):2260-6.
- [23] Nunes S, Oliveira PM, Coutinho JS, Figueiras J. Evaluation of SCC Mixture Robustness. In: De Schutter G, Boel V, eds. *5th International RILEM Symposium on Self-Compacting Concrete*. Ghent, Belgium: RILEM Publications SARL 2007:131-6.
- [24] BIBM - CEMBUREAU - EFCA - EFNARC - ERMCO. The European Guidelines for Self-Compacting Concrete - Specification, Production and Use. 2005.
- [25] Haldenwang R, Fester VG. The influence of different superplasticisers on the flowability and reproducibility of a SCC mix. In: Wallevik O, Khrapko M, eds. *9th International Symposium on High Performance Concrete*. Rotorua, New Zealand: New Zealand Concrete Society 2011.
- [26] Bosiljkov VB, Gasperic N, Zevnik L. New type of superplasticizer for SCC mixtures with increased robustness. In: Roussel N, Bessaies H, eds. *7th International RILEM Symposium on Self-Compacting Concrete*. Paris, France 2013.
- [27] Naji S, Hwang S-D, Khayat KH. Robustness of self-consolidating concrete incorporating different viscosity-enhancing admixtures. *ACI Materials Journal*. 2011;108(4):432-8.
- [28] Billberg P, Westerholm M. Robustness of fresh VMA-modified SCC to varying aggregate moisture. *NCR Journal*. 2008;38(7):103-19.
- [29] Grünewald S, Walraven JC. Robust flowable concrete with viscosity agents. In: Mechtcherine V, Schroefl C, eds. *International RILEM Conference on Application of superabsorbent polymers and other new admixtures in concrete construction*. Dresden, Germany: RILEM Publications 2014:385-94.
- [30] Sakata N, Yanai S, Yoshizaki M, Phyfferoen A, Monty H. Evaluation of S-657 Biopolymer as a new viscosity-modifying admixture for self-compacting concrete. In: Ozawa K, Ouchi M, eds. *Second International Symposium on Self-Compacting Concrete*. Tokyo, Japan 2001:229-36.
- [31] Phyfferoen A, Monty H, Skags B, Sakata N, Yanai S, Yoshizaki M. Evaluation of the biopolymer, diutan gum, for use in self-compacting concrete. In: Shah SP, Daczko JA, Lingscheit JN, eds. *First North American Conference on the Design and Use of Self-Consolidating Concrete*. Evanston, IL, USA 2002:147-52.
- [32] Grünewald S, Walraven JC. The effect of viscosity agents on the characteristics of self-compacting concrete. In: Shah SP, ed. *Second North American Conference on the Design and Use of*

Self-consolidating Concrete / 4th International RILEM Symposium on Self-Compacting Concrete. Addison, IL, USA: Hanley Wood 2005:9-15.

[33] Domone PL. Self-compacting concrete: An analysis of 11 years of case studies. *Cement & Concrete Composites*. 2006;28(2):197-208.

[34] Berke NS, Cornman CR, Jeknavorian AA, Knight GF, Wallevik O. The effective use of superplasticizers and viscosity-modifying agents in self-consolidating concrete. In: Shah SP, Daczko JA, Lingscheit JN, eds. *First North American Conference on the Design and Use of Self-Consolidating Concrete*. Evanston, IL, USA: North Western University 2002:173-8.

[35] Sakata N, Yanai S, Yokozeki K, Maruyama K. Study on new viscosity agent for combination use type of self-compacting concrete. *Journal of Advanced Concrete Technology*. 2003;1(1):37-41.

[36] Garcia L, Valcuende M, Balasch S, Fernández-Lebrez J. Study of robustness of self-compacting concretes made with low fines content. *Journal of Materials in Civil Engineering*. 2013;25(4):497-503.

[37] Gettu R, Shareef SN, Ernest KJD. Evaluation of the robustness of SCC. *The Indian Concrete Journal*. 2009;83(6):13-9.

[38] Billberg PH. Influence of powder type and VMA combination on certain key fresh properties of SCC. In: Wallevik O, Khrapko M, eds. *9th International Symposium on High Performance Concrete*. Rotorua, New Zealand: New Zealand Concrete Society 2011.

[39] Höveling H. Robustheit von selbstverdichtendem Beton (SVB) - Robustness of self-compacting concrete (SCC), in German. *Faculty of Civil Engineering and Geodesy*. Hannover, Germany: University of Hannover 2006:Doctoral thesis.

[40] Leemann A, Winnefeld F. The effect of viscosity modifying agents on mortar and concrete. *Cement & Concrete Composites*. 2007;29(5):341-9.

[41] Van Der Vurst F, De Schutter G. Improving the robustness of fresh self-compacting concrete using small quantities of fine additions. In: Shi C, Ou Z, Khayat KH, eds. *Third International Symposium on Design, Performance and Use of Self-Consolidating Concrete*. Xiamen, China: RILEM 2014.

[42] Georgiadis AS, Sideris KK, Anagnostopoulos NS. Properties of SCC produced with limestone filler or viscosity modifying admixture. *Journal of Materials in Civil Engineering*. 2010;22(4):352-60.

[43] Rigueira JW, García-Taengua E, Serna-Ros P. Robustness of SCC dosages and its implications on large-scale production. In: De Schutter G, Boel V, eds. *5th International RILEM Symposium on Self-Compacting Concrete*. Ghent, Belgium: RILEM Publications SARL 2007:95-101.

[44] Rigueira JW, García-Taengua E, Serna-Ros P. Self-consolidating concrete robustness in continuous production regarding fresh and hardened state properties. *ACI Materials Journal*. 2009;106(3):301-7.

[45] Lohaus L, Ramge P. Robustness of UHPC - A new approach for mixture proportioning. In: Fehling E, Schmidt M, Stürwald S, eds. *2nd International Symposium on Ultra High Performance Concrete*. Kassel, Germany: Kassel University Press 2008:113-20.

[46] Phan TH. Thixotropic behaviour of self-compacting pastes (in french). *XXIVèmes Rencontres Universitaires de Génie Civil 2006* 2006.

[47] Bonen D, Deshpande Y, Olek J, Shen L, Struble L, Lange DA, et al. Robustness of SCC. In: Lange DA, ed. *Self-consolidating concrete*. Urbana, IL, U.S.A.: The Center for Advanced Cement Based Materials (ACBM) 2007.

[48] Bouras R, Chaouche M, Kaci S. Influence of viscosity-modifying admixtures on the thixotropic behaviour of cement pastes. *Applied Rheology*. 2008;18(4):45604-1 - -8.

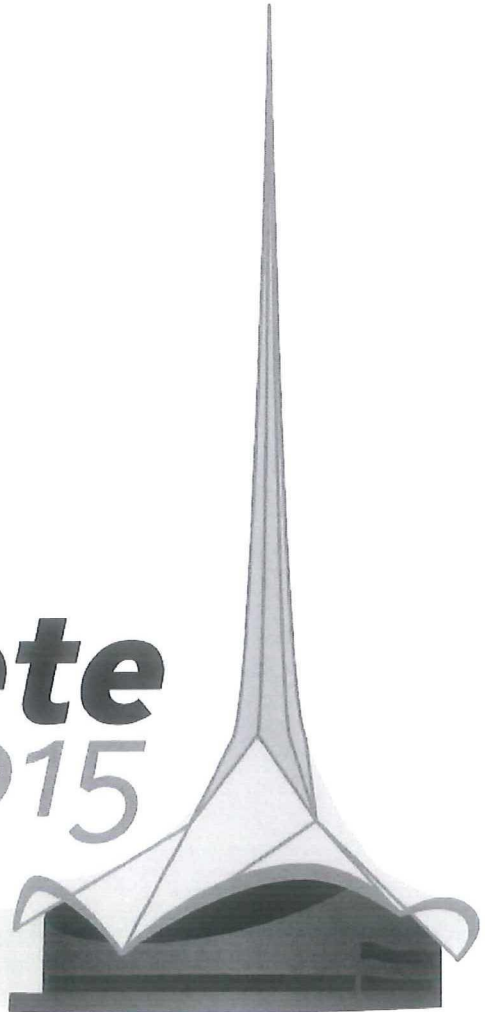
[49] Desnerck P, Van Itterbeeck P, Boel V, Craeye B, De Schutter G. Survey on the mechanical properties of SCC: 20 years of research. In: Tam CT, Ong KCG, Teng S, Zhang MH, eds. *36th Conference on Our World in Concrete & Structures : 'Recent Advances in the Technology of Fresh Concrete'*. Singapore, Singapore: Ghent University, Department of Structural engineering 2011:231-9.

[50] Craeye B, Van Itterbeeck P, Desnerck P, Boel V, De Schutter G. Modulus of elasticity and tensile strength of self-compacting concrete: Survey of experimental data and structural design codes. *Cement and Concrete Composites*. 2014;in press.

**27th Biennial National Conference of the
Concrete Institute of Australia in conjunction with
the 69th RILEM Week**

concrete
30 August – 2 September
Melbourne, Australia **2015**

construction innovations:
RESEARCH INTO PRACTICE



Chair's Preface

The proceedings contain 171 papers across 14 themes. All the papers included in the proceedings have been selected on the basis of least two peer reviews which were provided by independent reviewers (referees), who were experts in the subject field of the paper. We are grateful to the independent reviewers for their time and effort in reviewing the papers and providing reviews in a timely manner.

Professor Jay Sanjayan

Swinburne University of Technology

Conference Chair

Concrete 2015

Proceedings of the 27th Biennial National Conference of the Concrete Institute of Australia
in conjunction with the 69th RILEM Week

"Construction Innovations, Research into Practice"

30 August – 2 September 2015, Melbourne, Australia

Published by the Concrete Institute of Australia

Suite 401, Level 4, 53 Walker Street, North Sydney NSW 2060, Australia

Tel: (02) 9955 1744

Fax: (02) 9966 1871

Email: admin@concreteinstitute.com.au

Publication Date: 30 August 2015

ISBN: 978-1-943847-70-9

Table of Contents

Keynote Presentations

Ultra High Performance Ductile Concrete: The Delivery from Research into Practice Stephen Foster and Yen Lei Voo	1
Low Carbon Emission Geopolymer Concrete: from Research into Practice Jannie S.J. van Deventer and John L. Provis	12
Creep and Shrinkage of Concrete – from Theoretical Background and Experimental Characteristics to Practical Prediction Models Harald S. Müller Raphael Breiner and Vladislav Kvitsel	13

Construction Methods

Concrete Hinges at Legacy Way Peter Boesch, Chin Cheah and Peter Miller	33
Challenges, Opportunities and Design Impacts for Different Construction Methods on Curtis Island LNG Jetties Jesper Jensen and Peter Kastrup	44
A Bond-Slip Modelling Approach for the Transfer Length of Pre-tensioned Concrete Rik Steensels, Lucie Vandewalle and Hervé Degée	55
Design for Construction Cockburn Gateway Stage 3 Case Study Bassam Matty	63
An Innovative Solution for Temporary Movement Joints in Concrete Floors Lance Rogers	73
Officer South Sewage Pumping Station – A Diaphragm Walling Case Study Marc Peril and Jaya Weerasinghe	83
Expansion and Mechanical Properties of Reactive Concrete incorporating Fused Thamer Kubat, Ahmad Shayan and Riadh Al-Mahaidi	94
Construction 3D Printing Laurie Edwards, Camille Holt, Louise Keyte, and Redmond Lloyd	101
The Application of Scattering-filling Stone Concrete on Highway Pavement Weiguo Shen, Xing Cheng, Liu Cao, Xinling Li, Chaochao Li and Guiming Wang	111
Preparation and Application of 3D Printing Materials in Construction Xiqiang Lin, Tao Zhang, Liang Huo, Guoyou Li, Nan Zhang, Baohua Wang	118

Repair and Retrofitting

The restoration and repairs of the Sir William Goodman Bridge designed by Sir John Monash, Adelaide John Woodside and Leo Noicos	128
Condition Assessment and Structural Repair Solutions for the Renovation of the Sheraton Hotel at Doha, Qatar Satyajit Datar and Sajeev Kumar Krishnan	138
Adelaide Railway Station Façade Conservation Works Structural Engineering Aspects David Kennedy	147
A Variety of Remediation, Maintenance and Serviceability in its 15 Year Life Peter Kastrup and Andrew Turnbull	152
Design of FRP retrofitted concrete structures using AS5100 Part 8 Binh Pham	161
Investigation of Corrosion, Repair Assessment and Quality Assurance of a Basement subject to Saline Water Ingress Jonathon Dyson, Marton Marosszeky and Frank Papworth	167
Experimental Study on Anchorage Behaviour of the CFRP Grid in Mortar Bo Wang, Kimitaka Uji, Junlei Zhang, Atsushi Ueno, Kentaro Ohno and Tran Vu	177
Influence of Fiber Net Reinforced Mortar Repair Coating on the Crack Opening Resistance of Concrete Yoshinori Kitsutaka and Yukihiro Oyama	187
Performance of Fire-damaged Concrete Members Strengthened with NSM Laminates Embedded in Epoxy Adhesive Awad Jadooe, Riadh Al-Mahaidi and Kamiran Abdouka	193
Behavior of Squat Columns Strengthened with Fiber Reinforced Concrete Jacket Reza Hassanli and Minoru Kunieda	203

Failure Mode and Risk Analysis

A Review of Limit State Design Principles and Practice Douglas Jenkins	218
Fasteners to Concrete: Failures and Solutions D. J. Heath, E. F. Gad and J. Lee	228
AEFAC Anchor Installer Certification Program Jessey Lee, David Heath and Emad Gad	238
Guide to Seismic Design & Detailing of Reinforced Concrete Buildings in Australia Scott Munter, John Woodside and Peter McBean	248

Structures Research and Applications

Assessment of the Performance of a 24 Year Old Coating Applied to Concrete Bridge Piers Since Construction in a Saline Tidal Environment Fred Andrews-Phaedonos, Ahmad Shayan and Aimin Xu	259
Behaviour of Concrete Filled Steel Stub Columns During and After Fire Exposure Zhong Tao, Xing-Qiang Wang, Tian-Yi Song and Lin-Hai Han	268
Dynamic Performance Criteria for Suspended Courts at the National Tennis Centre Mark Sheldon and Benjamin Delaney	278
Flexural Response of GFRP-Reinforced Geopolymer Concrete Beams Ginghis B. Maranan, Allan C. Manalo, Warna Karunasena, Brahim Benmokrane and Priyan Mendis	287
An Experimental Study on the Long-Term Behaviour of Simply-Supported and Continuous Reinforced Concrete Slabs Md Mahfuzur Rahman, Gianluca Ranzi, Daniel Dias-da-Costa, Arnaud Castel and Raymond Ian Gilbert	297
Influence of environmental temperature and moisture conditions on the fatigue resistance of concrete Yasuhiro Koda, Shohei Minakawa and Ichiro Iwaki	307
An Approach for the Quantification of Ductility and Robustness of Reinforced Concrete Beams and Slabs R. Ian Gilbert, Stephen Foster and Ankit Agarwal	313
Experimental study of the mechanical behavior of shear-critical prestressed and reinforced concrete beams Kristof De Wilder, Guido De Roeck and Lucie Vandewalle	322
Development of a New Design Expression for the In-Plane Shear Capacity of the Partially Grouted Concrete Masonry Walls. Thangarajah Janaraj and Manicka Dhanasekar	332
Transient Heat Transfer Analysis of Reinforced Concrete Members Using a Discrete Crack Approach D. Dias-da-Costa, L. Godinho and G. Ranzi	343
In-Plane Behavior of Unbonded Post-Tensioned Concrete Walls Reza Hassanli	353
Concrete Slab and Footing Systems for Large Industrial Buildings. A Critical Overview of Current Design Methods for Reactive Clay Sites Anthony J Davis and Brian Ims	362

Fibres FRP Research and Applications

Creep of Cracked Polymer Fiber Reinforced Concrete Rutger Vrijdaghs, Lucie Vandewalle and Marco di Prisco	373
Using FRP as Reinforcement in Precast Concrete Panels for Soil-Concrete Bridges Sameh Salib	382
Torsional Strengthening of Concrete Members Using Near-Surface Mounted CFRP Composites G. Al-Bayati, R. Al-Mahaidi and Robin Kalfat	390
Flexural Testing of Concrete Filled Fibre Reinforced Polymer Tubes (CFFT) with and without Internal Fibre Reinforced Polymer (FRP) Reinforcement Qasim S. Khan, Josiah S. Strong, M. Neaz Sheikh and M.N.S. Hadi	400
Durability Study of Textile Fibre Reinforcement Natalie Williams Portal, Nelson Silva, Katarina Malaga, Urs Mueller, Peter Billberg	408
Mechanical Properties and Post-crack Behaviours of Recycled PP Fibre Reinforced Concrete Shi Yin, Rabin Tuladhar, Tony Collister, Mark Combe and Nagaratnam Sivakugan	414
A Novel Ultra High Performance Fibre Reinforced Concrete Spandrel Cladding Panel Raafat El-Hacha, David Pesta, Gamal Ghoneim and Don Zakariasen	422
Upgrading the Dundas Point Boardwalk, Applecross with the use of GFRP Bar Reinforced Concrete Columns and Footings Joel Brown	433
A Design Methodology for Fibre Reinforced Concrete Slabs-on-grade Ravindra Gettu and Sunitha K Nayar	443
FRP Anchors for FRP-Strengthened Concrete Structures: Numerical Modelling Scott T. Smith, Jia-Qi Yang and Zhen-yu Wang	453
Joint Free Restrained Slabs – SFRC combined with mesh Alan Ross	459

Concrete Materials and Performance

Neutron Pair Distribution Function Analysis of Synthetic Calcium-Silicate-Hydrate Claire E. White	471
Using Conventional Materials as Concrete Confinement Hua Zhao and Muhammad N.S. Hadi	476
Behaviour of Crumb Rubber Concrete Columns under Seismic Loading Osama Youssf, Mohamed A. ElGawady, Julie E. Mills, Xing Ma and Tom Benn	482
Sulfate Resistance Testing in Germany - Critical Review Johannes Haufe, Anya Vollpracht and Wolfgang Brameshuber	492

Linking New Australian Alkali Silica Reactivity Tests to World-Wide Performance Paul Rocker, James Mohammadi, Vute Sirivivatnanon and Warren South	502
Mechanical Properties of Mortar with Oil Contaminated Sand Rajab M. Abousnina, Allan Manalo and Weena Lokuge	514
Investigation into the Structural Properties of an Innovative Modified Concrete Negin Sharifi and Bijan Samali	523
Twisted Steel Micro-Reinforcement: Proactive Micro-Composite Concrete Reinforcement Luke Pinkerton, Kevin Fuller and Jeff Novak	533
Design of UHPFRC Mixtures to be used in Structures Subjected to Impact Loads Michael F. Petrou, Konstantinos G. Trezos and Anna L. Mina	543
Effect Rubberised Aggregates from Tyres on the Engineering Performance of M. Sonebi, R. Summerville and S. Taylor	552
The Effectiveness of Mineral Admixtures and Low Water to Cement Ratio in Concrete for Immobilizing Cesium, Sodium and Iodide from Radioactive Waste Irfan Prasetya and Kazuyuki Torii	559
Challenges contemporizing Australian Standards: Supplementary Cementitious Craig Heidrich	568
Effects of Chemical Admixtures and Aggregate Particles on Spatial Distribution of Cement Particles and Capillary Pores in Mortars Takuma Nakagawa and Shin-ichi Igarashi	578
The Effect of Type of Fly Ash on Mechanical Properties of Geopolymer Concrete M.P.C.M.Gunasekara, David W.Law and Sujeeva Setunge	586
Towards a More Sustainable Australian Cement and Concrete Industry James Mohammadi, Warren South and Des Chalmers	596
Steel, Concrete or Plastic? Support your Reinforcement! Scott Munter and Mark Turner	604
Performance of Architectural Concrete: New Approach Vyacheslav Falikman, Vyacheslav Deniskin and Alexander Vainer	611
Torsional Behaviour of Reinforced Concrete T-Beam Sections Douglas Anabalon	619
Effect of Ultraviolet Radiation on the Physical and Mechanical Properties of Polymer Matrix Wahid Ferdous, Allan Manalo, Thiru Aravinthan and Gerard Van Erp	630
Self-healing of Cementitious Composites via Coated Magnesium Oxide/Silica Fume Based Pellets Rami Alghamri and Abir Al-Tabbaa	637
Impact of Pore Structure of Lightweight Aggregates on Internal Curing Pietro Lura, Mateusz Wyrzykowski, Sadegh Ghourchian, Sakprayut Sinthupinyo and Clarence Tang	646

Reinforcing ordinary Portland Cement Mortar using Carbon Nanotubes Shu Jian Chen, Xiang Yu Li, Tong Bo Sui and Wen Hui Duan	652
The Significance of the Alkali Aggregate Reactivity Provisions in the VicRoads Structural Concrete Specification Section 610 Fred Andrews-Phaedonos, Ahmad Shayan and Aimin Xu	657
Long-term Experiments of Composite Slabs Using Recycled Coarse Aggregate Qinghe Wang, Gianluca Ranz, Yue Geng and Yuyin Wang	669
Implications of Alkali-Aggregate Reaction for three Concrete Bridges Ahmad Shayan, Aimin Xu and Fred Andrews-Phaedonos	679
Effectiveness of Traditional and Alternative Supplementary Cementitious Materials in Mitigating Alkali-Silica Reactivity Daniel Pospischil, Vute Sirivivatnanon, Uthayakumar Sivathasan and Kevin Cheney	694
The Use of Reaction Kinetics in Classifying Alkali Silica Reactivity Potential of Bob Bornstein, David Hocking, Johwelvic Bacolod and Vute Sirivivatnanon	704
Fresh and Early-Age Properties of Cement Pastes and Mortars Blended with Nickel Muhammad Ashiqur Rahman, Prabir Kumar Sarker and Faiz Ahmed Shaikh	712
Thermo-mechanical Behaviour of Epoxy Based Polymer Matrix Wahid Ferdous, Allan Manalo, Thiru Aravinthan and Gerard Van Erp	720
Development of an Acid Resistant Concrete Shamila Salek, Bijan Samali, Vute Sirivivatnanon and Georgius Adam	727
Effect of the Chemical Composition of Building Materials on Algal Biofouling Philippe Grosseau, Estelle Dalod, Alexandre Govin, Christine Lors, René Guyonnet and Denis Damidot	735
Expansive Behavior of Mortars - Containing Surf Clam Shell Powder at Early Age Akio Watanabe, Kazumi Hirokawa and Takashi Kondo	745
The use of Cementitious Coatings to Reinstate Low Nominal Cover on Reinforced Concrete Structures Neil Wilds	751
Behavior of Concrete after Exposure to Elevated Temperatures Yaman S. S. Al-Kamaki, Riadh Al-Mahaidi and Ian Bennetts	761
A Discussion on Service Life Prediction of Fly Ash Concrete Structures based on DuraCrete Methodology Zhuqing Yu and Guang Ye	770
Effect of Combined Fibres on Fire Resistance of Large Specimens Youngsun Heo and Byungyeol Min	779
Mechanical Properties of Fibre Reinforced High Volume Fly Ash Concretes Yashar Shafaei, Faiz Shaikh, Prabir Sarker and Salim Barbhuiya	788

Admixtures and Polymers

- Improving the Rheology of High Strength, very low W/C Ratio Concrete. 799
Gary Boon and Tony Thomas
- The Effects of Superabsorbent Polymers on the Water Vapour Sorption Properties of Cementitious Materials 805
D.Snoeck, L.F.Velasco, A.Mignon, C.Vervaeet, S.Van Vlierberghe, P.Dubruel, P.Lodewyckx and N.De Belie
- Benefits of Water-Resisting Admixtures to Watertight Concrete 814
Mohammadreza Hassani, Kirk Vessalas, Daksh Baweja and Zoe Schmidt
- The Effect on Expansion of Wrapping Concrete Prisms with Cloth Saturated with Alkali Hydroxide 822
Yasutaka Sagawa, Kazuo Yamada, Shoichi Ogawa, Yuichiro Kawabata and Masahiro Osako
- Innovations in Admixtures for Piling Concrete 832
Bruno D'Souza and Hairul Sarwono
- Properties of Ultra-lightweight Concrete based on Protein and Surfactant foaming Agent 837
Patrick Hartwich, Thomas Adams, Ali Shams, Anya Vollpracht and Wolfgang Brameshuber
- Effect of Guar Gum Derivatives on Fresh State Properties of Portland Cement-Based Mortars 848
Alexandre Govin, Marie-Claude Bartholin, Barbara Biasotti, Max Giudici, Valentina Langella and Philippe Grosseau
- The Effect of Superplasticisers and Viscosity Modifiers on the Rheological Properties of Super Workable Concrete 858
Greg Langton and Gary Boon

Durability and Serviceability

- Concrete Durability Performance Testing – The Approach Adopted in a Concrete Institute of Australia Recommended Practice 864
W. Green and F. Papworth
- A Discussion on the Autogenous Shrinkage Interpretation from the Experimental Shrinkage Measurement Based on the Australian Testing Procedure AS1012.13 875
William A. Thomas, James Mohammadi and Warren South
- Performance Test for Hydrophobic Impregnations for Protection against Chloride Ingress in Concrete 884
Nelson Silva, Elisabeth Helsing, Katarina Malaga, Eva Rodum, Minna Torkkeli and Arvid Hejll
- Durability of Concrete Caissons Made in Floating Docks 894
Jose Vera-Agullo, Francisco Manuel Castro-Visos, Francisco Javier Larraz-Bordanaba, Claudio Troncone-Cusati, Juan Pedro Asencio-Varela, Nelson Silva, Urs Mueller and Katarina Malaga

Prescriptive versus Performance-based Design Approaches for Concrete Durability Hans Beushausen, Mark Alexander, Manuel Wieland and Stefan Linsel	904
Durability Performance of Crystalline-Modified Concrete Exposed to Severe Environment Farhad Nabavi	914
ISO 16204 and the Correct Solution to Fick Norwood Harrison	924
K-value for Carbonation of Concretes with Supplementary Cementitious Materials Christina Nobis and Anya Vollpracht	931
Feasibility of Digital Image Correlation Technique to Determine Mechanical Properties of Corroded Steel Rebars Ranjitha Rajagopal, Sameer Sharma, Radhakrishna G. Pillai and Sankara J.	939
Determination of Chloride Diffusion Coefficient of Concrete: Comparison of Bulk Diffusion and Electrical Field Method Aimin Xu and Ahmad Shayan	950
Frost Test and the Significant Influence of Small Amounts of Ions Dissolved in Surface Water Max J. Setzer	960
Durability Planning – a Formalised Approach in Concrete Institute of Australia Recommended Practice Rodney Paull and Frank Papworth	970
Time-dependent Stiffness of Concrete Members under Cyclic Loading Angus Murray, Raymond Ian Gilbert and Arnaud Castel	980
Role of Ettringite in Expansion and Cracking Potential in Steam Cured Precast Concrete Elements Johnson Mak, Paul Thomas, Kirk Vessalas and Daksh Baweja	990
Improved Sustainability by Design for Concrete Durability R. Doug Hooton	996
Exp-Ref: A Simple, Realistic and Robust Method to Assess Service Life of Reinforced Concrete Structures Roberto Torrent	1006
Durability Assessment of Concrete Immersed Tube Tunnel in Hong Kong-Zhuhai-Macau Sea Link Project Kefei Li, Quanwang Li, Pianpian Wang and Zhihong Fan	1016

Geopolymers and Non-traditional Binder Concrete

Effect of MgO Incorporation on the Structure of Synthetic Alkali-activated Calcium Aluminosilicate Binders Brant Walkley, Rackel San Nicolas, Susan A. Bernal, John L. Provis and Jannie van Deventer	1026
Use of Geopolymer Concrete in Column Applications Weena Lokuge, Jay Sanjayan and Sujeeva Setunge	1033
Influence of Matrix Related Parameters on Strain Hardening Behavior of Engineered Geopolymer Composite (EGC) Behzad Nematollahi, Jay Sanjayan and Faiz Uddin Ahmed Shaikh	1041
EFC Geopolymer Concrete Aircraft Pavements at Brisbane West Wellcamp Airport Tom Glasby, John Day, Russell Genrich and James Aldred	1051
On Fly Ash Based Geopolymer Concrete and its Behaviour at Elevated Temperature Tian Sing Ng, Stephen J. Foster and Samantha Milojevic	1060
Development of Sugarcane Bagasse Ash Blended Geopolymer for use in Concrete Deepika S, Madhuri G, Bahurudeen A and Manu Santhanam	1070
Behaviour of Granulated Lead Smelter Slag-Based Geopolymer Concrete M. Albitar, M.S. Mohamed Ali, P. Visintin and M. Drechsler	1080
Influence of Binder on Alkali Reactivity of Aggregates in Geopolymer Concrete Chandani Tennakoon, Ahmad Shayan and Jay G. Sanjayan	1089
Rheological Properties of Sodium Carbonate Alkali-Activated Fly Ash/Slag pastes with Different Superplasticisers Ahmed Abdalqader and Abir Al-Tabbaa	1105
Direct Electric Curing of Alkali-Activated Concretes. Preliminary Study Maxim Kovtun, Julia Shekhovtsova and Elsabe Kearsley	1116
Investigation on Engineering Properties of Powder-activated Geopolymer Concrete Kamal Neupane, Daksh Baweja, Rijun Shrestha, Des Chalmers and Paul Kidd	1125
Alkali-Activated Foamed Concrete Elsabe Kearsley and Maxim Kovtun	1139
Alternative Concrete Materials from Industrial Waste Valle Chozas, Ignacio del Val, José Vera and Íñigo Larraza	1146
Progress Towards a Handbook for Geopolymer Concrete Marita Allan Berndt, Jay Sanjayan, Stephen Foster, Arnaud Castel, Pathmanatham Rajeev and Craig Heidrich	1156
Development of Low Shrinkage Water Repelling Foamed Concrete Kai Tai Wan, Honggang Zhu, Binmeng Chen and Chuanlin Hu	1166
A Resistivity-Based Approach to Indicate Chloride Permeability of Geopolymer Amin Noushini and Arnaud Castel	1172
Chloride induced Corrosion of reinforcing bars in Geopolymer concrete M. Babae and A. Castel	1182
Specifying Fly Ash for Use in Geopolymer: A Conception of Reactivity Index Hao Wang, Zuhua Zhang, John L. Provis and Jin Zou	1188

Structural Monitoring and Assessment

Evaluation of the Level of Damage of Concretes Affected by Expansive Reactions at Meso and Microstructural Scale. Relationship between Alkali-aggregate Reaction and Internal Sulfate Attack Esperanza Menéndez, Ricardo García Rovés and Nicanor Prendes	1197
The Impacts of Temperature and Salinity Variance on Service Life Modeling as a Result of Climate Change. Andrew Hunting, Sujeeva Setunge and David Law	1207
In situ and Laboratory Testing of Different Repair Materials. Lukovic, M., Gellweiler, W.A., Sierra Beltran, M.G., Blom, C.B.M., Savija, B., Zanten, van, D.C. Schlangen, E. , Ye, G. and Taffijn, E.	1217
Acid-soluble and Water-soluble Chloride – Testing Proficiency and Specification Warren South, Tony Thomas and Vute Sirivivatnanon	1225
Integrated Fracture-based Model for the Analysis of Cracked Reinforced Concrete Beams Tahreer M. Fayyad and Janet M. Lees	1233
Predicting Fire Induced Spalling in Concrete Structural Elements James M. de Burgh, Stephen J. Foster and Hamid R. Valipour	1243
In-situ Concrete Strength Assessment based on Ultrasonic (UPV), Rebound, Cores and the SONREB Method Frank Papworth, David Corbett, Reuben Barnes, Joseph Wyche and Jonathon Dyson	1253
Full Scale Concentric Punching Shear Testing of Two-way Floor with Bonded Post-tensioning and Studrails Fariborz Moeinaddini, Kamiran Abdouka and Andrew Barraclough	1263
Experimental Study on Carbon Fiber Reinforced Concrete for Strain Measurement of RC Portal Frame Fang-Yao Yeh, Kuo-Chun Chang and Wen-Cheng Liao	1273
Early-age Concrete and Cracking	
Temperature Monitoring of Concrete Elements for Insitu Strength Measurement and Prevention of Damage from Heat of Hydration Reuben Barnes, Frank Papworth, William Ward and Jim O'Daniel	1284
The Role of Dilation in Shrinkage Cracking of Concrete Suhaila Mattar and R.S. Al-Rawi	1295
High-absorptive Normal-weight Aggregates used as Internal Curing Agent Pericles A. Savva and Michael F. Petrou	1305
Tensile Properties of Early-Age Concrete Duy NGUYEN and Vinh T.N. DAO	1314
Experimental Study of Creep and Shrinkage in Early-age Concrete Inamullah Khan, Angus Murray, Arnaud Castel and Raymond Ian Gilbert	1325

Self-Compacting Concrete

The Combined Influence of Paste Volume and Volumetric Water-to-Powder Ratio on Robustness of Fresh Self-Compacting Concrete 1335
Farid Van Der Vurst, Steffen Grünewald, Dimitri Feys and Geert De Schutter

Instantaneous and Time-Dependent Behaviour of Reinforced Self-Compacting Concrete Slabs 1345
Farhad Aslani, Shami Nejadi and Bijan Samali

Foam Concrete-aerogel Composite for Thermal Insulation in Lightweight Sandwich Facade Elements 1355
Nelson Silva, Urs Mueller, Katarina Malaga, Per Hallingberg and Christer Cederqvist

Fib-C6

Prefabricating in Unusual Environments 1364
Marco Menegotto and Luciano Marcaccioli

Paddington Rail Station 1374
George Jones

PCI Design Awards Program 1382
Jason Krohn, Daniel Roman and Karla Vazquez

Sustainability of Structures with Precast Elements 1391
D. Fernández-Ordóñez, B. González-Rodrigo, J. Ramírez and R. Valdivielso

Major Projects Case Studies

Christchurch Art Gallery Foundation Strengthening and Building Re-Level 1400
James O'Grady, William Lindsay and Russell Deller

Design of Berthing Dolphins on Curtis Island LNG Jetties 1408
Jesper Jensen, Peter Kastrup and Matt Hodder

Lady Cilento Children's Hospital 1418
Ken Gallie and Darryl Feodoroff

Documentation of Bridge Deck Construction Using Industrially Produced Internally Cured, High Performance Concrete 1430
Timothy J. Barrett Albert E. Miller and W. Jason Weiss