Latest Updates and Developments on Self-Compacting Concrete. Report of Rilem Symposium 2016

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Abstract
The present paper focuses on interesting features influencing the behavior of self-compacting concrete in terms of its related properties. Based on selected peer reviewed and non-peer reviewed conference articles, authors briefly highlight exciting recent developments and changes influencing SCC properties. Information was collected from the eighth International RILEM Symposium on SCC held in Washington, D.C. Topics include mix design, materials, test methods, durability and others. They reflect on the most recent advancement in research, design and application of SCC worldwide.
Keywords: durability, self-compacting concrete, sustainability, optimization

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1. Introduction

To tackle rough obstacles in the construction industry, development of self-compacting concrete (SCC) was essential to overcome several problems associated with concrete placement. Thank to mostly Japanese researchers, the concept of SCC was introduced and progressed with time [1]. Superior and iconic structures require advanced concrete properties. These properties combine high deformability, adequate pumpability, very high strength, low drying shrinkage and others [2]. To join all these together is a crucial challenge especially when it comes to produce SCC. In the last 20 years, SCC has been used in the construction field due to its unique properties in comparison with conventional vibrated concrete. Hence, a lot of research and development have been reported. According to *Fig. 1*, a statistical study done by *Desnerck* et al. illustrates geographically where most of the research were performed and publications were published on SCC. For the sake of providing a general view, this study aimed to collect all database related to SCC fresh and hardened properties from RILEM committee work, conferences and journal papers [3].

2. Mix design for SCC

Several proportioning methods of mix design for SCC are available in the literature. Micro-Proportioning of SCC with crushed aggregate is a new method based on optimization of crushed aggregates. According to *Cepuritis* et al., flow resistance of separated group mixes were presented in function of specific surface area in order to understand the response of micro-proportioning to the rheological behavior [4]. Hence the dosages of the crushed fines and particle size distribution of the fines can be applied to control and modify the rheological properties of concrete. Also, leaner and more economic SCC mixtures (C20/25 or C25/30) can be reached with an optimized grading of fines taking into consideration a balanced water demand, desired flowability, stability and robustness of the mix.

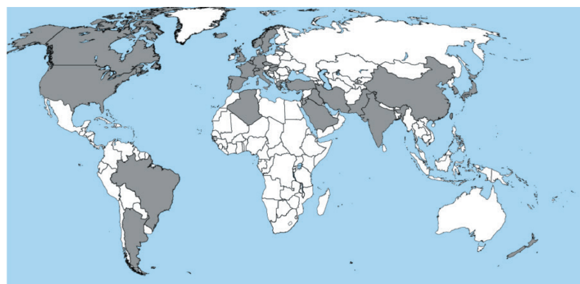

Fig. 1. Geographical distribution of the analyzed papers [3]
1. ábra Az értékelt cikkek földrajzi megoszlása [3]

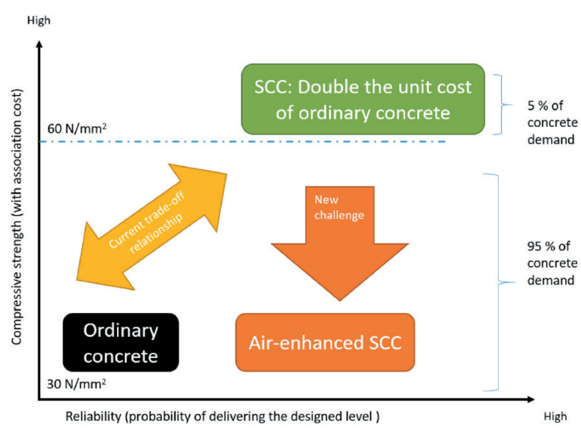

Fig. 2. Concept of development of air-enhanced SCC [5].
2. ábra Légpórusos ömtömörödő beton fejlesztésének koncepciója [5].

According to *Fig. 2*, most concrete structures do not require strength over 60 N/mm^2, hence a remarkable air enhanced SCC mixing method have been developed by *Ouchi* et al.

which applies the use of the ball-bearing effect of entrained air bubbles. This bubble-lubricated SCC mixture with low cement unit and air content of approximately 10% has been achieved. Small entrained bubbles were efficient in enhancing SCC compatibility in comparison with larger ones which could be entrained by making mortar portion soft before injecting air entraining agent into the fresh mix. For further details about the mixing procedure, the reader can refer to the article "Development of air enhanced Self-compacting concrete" in the relevant proceedings [5].

3. Materials for SCC

Filler materials are essential in order to obtain the required rheological properties that characterize SCC. With a higher amount of clay and implementation of calcium sulfoaluminate cement, self-compacted clay concrete is obtained. The novelty of this approach is to reach a more sustainable SCC with less CO_2 emission. For more details, *Plamondon* et al. showed an extensive study about the related rheological properties and the field of application [6]. The application of CSA instead of cement is encouraging because the ability of to remove water faster and lower drying shrinkage results. In case of superplasticizers, a new generation of high range water reducing admixtures of comb polymers holding phosphate instead of the carboxylate groups was synthesized and tested. The key idea about this approach is the high affinity of phosphate groups towards calcium ions. Hence a strong interaction with cement is expected. Results clarified that phosphate groups can insure different product characteristics to concrete with high range water reducing admixtures. A small amount of incorporation can fine-tune the behavior of the conventional polycarboxylates for application in high performance concretes. Referring to *Stecher* et al., effectiveness and limitations of these materials in terms of deformability and adsorption is studied extensively [7].

An interesting study performed by *Dhonde* et al. in which they introduced a non-toxic calcite depositing bacteria. The bacteria is implemented in the fresh concrete in order that the self-heal cracks in hardened concrete micro level could start. Results showed an increase in the mechanical properties such as compressive and tensile strength [8]. *Fig. 3* shows the cell walls of the Gram-positive bacterium B. subtilis. Cytoplasm which contains the majority of cell content is enclosed by a cell membrane, which is enclosed by a cell wall containing peptidoglycan as the major component.

Another exciting study is the one which uses a low-pH concrete to stabilize radioactive wastes. These are often stored for a very long time in deep and stable geological clayed formations. Low-pH cementitious materials, including cement suspensions, mortars, and concretes, containing up to 60% of supplementary cementitious materials as replacement of cement, were developed. The suspensions were prepared to develop a combination of supplementary cementitious materials (SCM) leading to low final pH over time. The macro-encapsulation consists of using concrete to make large containers (caissons) with highly-dense steel reinforcement and used as radiation shielding to encapsulate the as-received cemented radioactive waste (CRW) in pails. Results were adequate in terms of strength, shrinkage and cesium leaching [9].

4. Test methods

Evaluation of fresh properties of SCC is critical for obtaining a product which satisfies the required specifications. Several measurements are available as recommendations or standards for testing SCC in fresh state [10]. In order to obtain homogenous concrete elements, several properties for fresh state must be controlled especially when it comes to the resistance against segregation of SCC. Thereby a new approach is applied to evaluate SCC and its segregation stability [11]. The proposed method is divided into two rating systems. The first can be applied partially in the fresh state and verified later in the hardened state. It evaluates the appearance of coarse aggregate particles at the freshly cast top surface of a cylindrical specimen. On the other hand, the second is employed in the hardened state. The second rating system is based on the formation of specific gravity in the hardened state. Cylindrical specimens (150 × 300 mm) are used for the procedure, allowed to harden and saw-cut into 8 sections, resulting in 8 (quarter / half) discs. The discs' thickness should be adopted according to maximum aggregate size. The mass of discs are measured in dry and water saturated condition to determine the specific gravity. The result is a plot of the data alongside the specimen height hence for classification. For more details, cited article "A New Homogeneity assessment concept applied to evaluate self-consolidation and segregation stability of self-consolidating concrete" details the complete procedure and evaluation relevant to the proposed approach [12, 13]. *Fig. 4* shows how the rating can be carried out in hardened state.

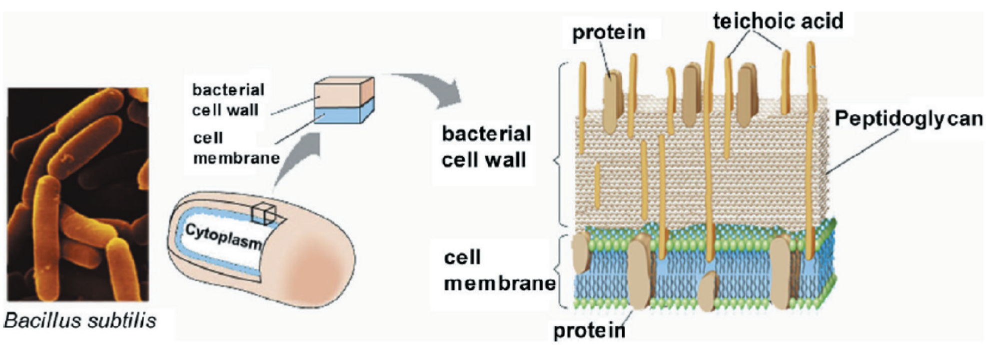

Fig. 3. Microscopic details of B. subtilis bacterium cell [8].
3. ábra B. subtilis baktérium sejt mikroszkopikus részletei [8].

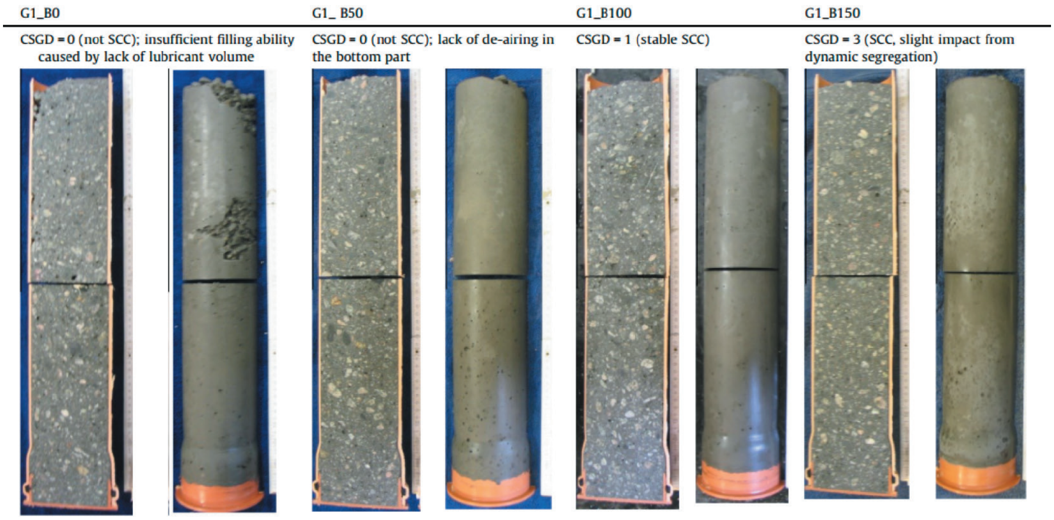

Fig. 4. Appearance of specimen of powder-series for sedimentation resistance according the new concept Classes of Specific Gravity Distributions (CSGD) [13].
4. ábra Próbatestek a szétosztályozódás szemléltetésére az új testsűrűség-megoszláson alapuló osztályozáshoz [13].

5. Durability of SCC

In order to have an acceptable pore structure in SCC which can resist to environmental influences covered by exposure classes, durability factors should be investigated to obtain an adequate SCC design. Thereby, a comparative study has been performed at Budapest University of Technology and Economics (BME), Department of Construction Materials and Technologies to compare non air-entrained and air-entrained SCC mixtures, incorporating supplementary cementitious materials such as metakaolin (MK) and silica fume (SF) with respect to reference mixtures [14]. The aim of the study was to compare the effect of cement replacement by MK or SF at similar dosages on durability properties. Constant parameters were: type of cement and grading curve of aggregates. Variable parameters were: water to cement ratio, limestone powder content, air entraining agent and supplementary cementitious materials type and content. The following laboratory tests were evaluated: air void characteristics, resistance to water penetration, accelerated durability tests such as carbonation, chloride migration and de-icing salt scaling resistance test. Results indicate that durability of SCC could be highly enhanced incorporating MK or SF but in selective percentages of cement mass replacement.

To visualize some interesting results, *Fig. 5* illustrates a comparison between air entrained mixtures of reference mix (R1), metakaolin mix (M1), and silica fume mix (S1), in which silica fume mix showed the highest resistance against CO_2 diffusion.

Another interesting issue regarding durability properties is the effect of Gamma radiation on the hardening properties of SCC. Since the disposal of radioactive waste is proceeded through cementitious barriers, the cementitious layer will be exposed to the radioactive rays during hardening. Therefore, a study done by *Craeye* et al. evaluated the effect of cement-waste interaction on the compressive strength, scanning electron microscopy (SEM), and nitrogen adsorption tests. Results indicated that Gamma radiation affect negatively the strength development. The higher the absorbed dose, the higher the strength loss. *Fig. 6* reveals SEM-analysis showing that Gamma radiation played a significant role in the formation of needle type crystals. These needles are mostly Ettringite and they are directly responsible for internal microcracking within the paste microstructure [15].

6. Sustainability

A new concept, the so called eco-efficient SCC (Eco-SCC) was recently introduced in Europe and Asia where the target is to produce SCC with low cement content. This concept is illustrated in *Fig. 7* where there is a comparision between SCC and Eco-

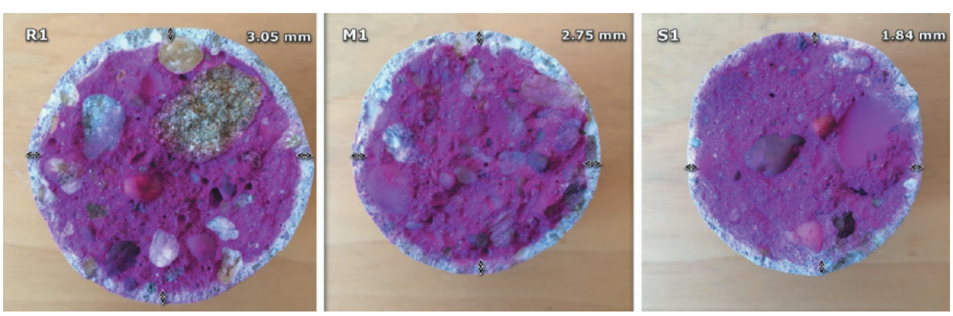

Fig. 5. Mean carbonation depth for air entrained mixtures R1, M1 and S1 [14].
5. ábra Karbonátosodási mélység az R1, M1 és S1 jelű keverékek esetén [14].

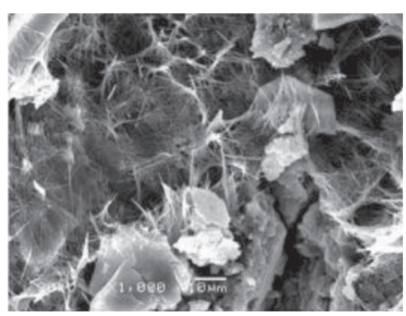

Fig. 6. Needle formation after Gamma irradiation of samples [14].
6. ábra Tűszerű kristályok képződése gamma besugárzást követően [14].

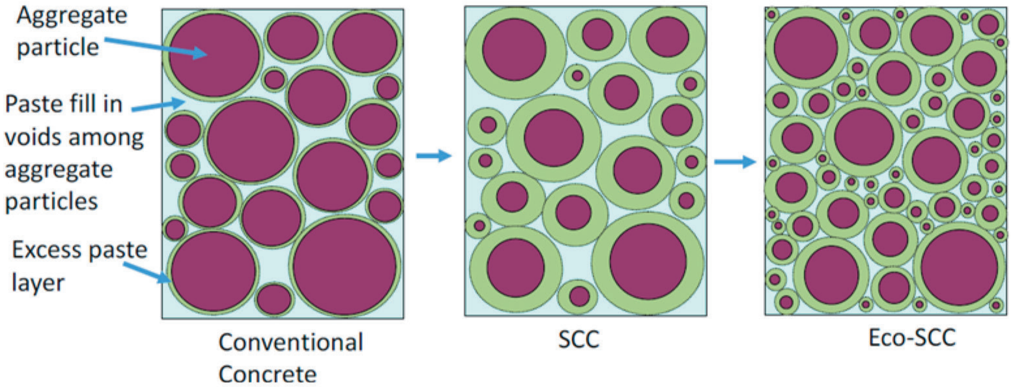

Fig. 7. Concept of SCC and Eco-SCC mixture design [16].
7. ábra SCC és Eco-SCC keverékek tervezésének koncepciója [16].

SCC design. In order to achieve adequate workability properties, excess paste content is needed for SCC. Thereby Eco-SCC is produced by optimizing aggregate gradation. Yet by insuring these conditions, also preventing aggregate segregation is critical in Eco-SCC design. According to *Hu* et al., the production of Eco-SCC incorporating recycled aggregate is possible. They demonstrated in comparison with conventional SCC that Eco-SCC is adequate in terms of both rheological (flowability, passing ability and stability) and hardened properties [16].

7. Conclusions

Recently, considerable growth and development is observed in the field of SCC. The Eighth International RILEM Symposium on Self-Compacting Concrete presented more than 120 papers collected from all over the world. The aim of the conference was to bring together all researchers and practitioners to present all the latest news and ideas about SCC. In the present paper, authors selected some of the most attractive and beneficial ideas which are available in the relevant articles and could possibly shift the production line of SCC.

References

[1] Okamura, H. – Ouchi, H. (2003): Self-Compacting Concrete, *Journal of Advanced Concrete Technology*, Vol. 1, No. 1, pp. 5-15.

[2] El Mir, A. – Nehme, S. (2015): Porosity of Self-compacting Concrete, *Procedia Engineering*, Vol. 123, pp. 145-152. http://dx.doi.org/10.1016/j.proeng.2015.10.071

[3] Desnerck, P. – Craeye, C. – Boel, V. – Van Itterbeeck, P. (2016): Mixture Compositions and Fresh Properties of Self-Compacting Concrete: Analysis of 25 Years of Research. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 65-75

[4] Cepuritis, R. – Jacobsen, S. – Smeplass, S. – Mortsell, E. – Wigum, B. (2016): Micro-Proportioning of SCC with crushed aggregates. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 3-13.

[5] Ouchi, M. – Attachaiyawuth, A. (2016): Development of air enhanced Self-compacting concrete. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 15-24.

[6] Plamondon, C. – Habert, G. (2016): Self-compacted clay concrete: A concrete with CSA and higher clay content. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 37-47.

[7] Stecher, J. – Plank, J. (2016): Phosphated Comb Polymers, A new generation of high effective superplasticizers. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 61-71.

[8] Dhonde, H. – Undre, A. – Choudekar, G. – Dashputre, T. (2016): Fresh and Hardened Properties of Self-Compacting Bacterial Concrete. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 287-297.

[9] Kassimi, F. – Bilodeau, A. – Bouzoubaa, N. (2016): Low-pH Cementitious Matrices to Stabilize Cemented Radioactive Wastes. *Proceedings of the 8th International RILEM Symposium on Self-Compacting concrete*, pp. 267-286.

[10] EFNARC (2002) Specification and Guidelines for Self-Compacting Concrete.

[11] Muller, F. – Wallevick, O. – Khayat, K. (2016): A New Homogeneity assessment concept applied to evaluate self-consolidation and segregation stability of self-consolidating concrete. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 123-132.

[12] Mueller, F. (2012): Design criteria for low-binder self-compacting concrete. *ECO-SCC*. PhD thesis. Reykjavik University, Iceland.

[13] Mueller, F. – Wallevik, O. H. – Khayat, K. H. (2014): Linking solid particle packing of Eco-SCC to material performance, *Cement & Concrete Composites*, Vol. 54, pp. 117-125. http://dx.doi.org/10.1016/j.cemconcomp.2014.04.001

[14] El Mir, A. – Nehme, S. (2016): Comparison of durability performance of conventional and air-entrained self-compacting concrete modified by metakaolin and silica fume. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp.61-71.

[15] Craeye, B. – De Schutte, G. – Gerardy, I. (2016): Hardening Self-Compacting Mortar Exposed to Gamma Radiation. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 867-878.

[16] Hu, J. – Ledsinger, B. – Kim, J., (2016): Development of Eco-Efficient Self Consolidating Concrete (Eco-SCC) with Recycled Concrete Aggregate. *Proceedings of the 8th International RILEM Symposium on Self-Compacting Concrete*, pp. 1033-1042.

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A legfrissebb hírek és fejlesztések az öntömörödő betonok területén – Beszámoló a 2016. évi RILEM szimpóziumról

A cikk összefoglalja az öntömörödő betonok tulajdonságait és vizsgálatát jellemző egyes legfontosabb kérdéseket. A cikk a szerzők által kiválasztott konferencia előadások és cikkek alapján készült, amelyek a 2016. évi RILEM szimpóziumon hangzottak el, Washington, D.C.-ben. A kiválasztott témák felölelnek többek között tartóssági, keverék tervezési, anyagválasztási és laboratóriumi vizsgálati kérdéseket, amelyek jelenleg iránymutatónak tekinthetők az öntömörödő betonok kutatása és alkalmazása során világszerte.
Kulcsszavak: tartósság, öntömörödő beton, fenntarthatóság, optimalizálás