HYDRATION, MICROSTRUCTURE, TRANSPORT PROPERTIES AND DURABILITY OF SELF-COMPACTING CONCRETE

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INTRODUCTION

Because of the different mix design in comparison with traditional concrete and the absence of vibration, different durability characteristics can be expected for self-compacting concrete (SCC). The degradation mechanisms of a cementitious material are greatly influenced by the permeability of the material for potentially aggressive substances. As the pore structure is different for SCC in comparison with traditional vibrated concrete, some changes in durability behaviour can be noticed.
This paper is first giving an overview of hydration, microstructure, and transport mechanisms of self-compacting concrete. Afterwards, available durability results are summarized in general. In this way some more general view on durability of Self-Compacting Concrete is obtained.

HYDRATION AND MICROSTRUCTURE DEVELOPMENT

To obtain a concrete that is self-compacting, it is needed to combine a high flowability and a high segregation resistance into one concrete. This is possible by the use of new generation superplasticizers in combination with viscosity enhancing agents and/or high concentrations of fine particles (1-3). In case of powder type SCC, cement and filler materials (like limestone filler, fly ash, and blast furnace slag) are often blended, in order to control the heat of hydration.

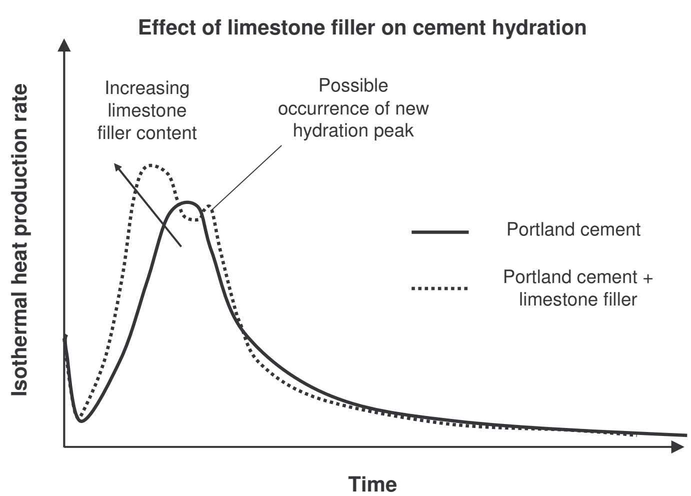

Figure 1. Effect of limestone filler on cement hydration

The cement hydration can be influenced by the presence of fillers, even for the case of inert fillers like limestone powder (4). This is schematically illustrated in figure 1, giving the evolution of the heat production rate during hydration in isothermal conditions. Due to the increased nucleation possibilities by the presence of limestone filler, the induction period is shortened, and the hydration is accelerated in comparison with the case of pure Portland cement. The maximum value of the isothermal heat production rate (second peak) is increasing when the cement/powder ratio is decreasing, i.e. when more limestone filler is present and less Portland cement. This is illustrated in figure 2.

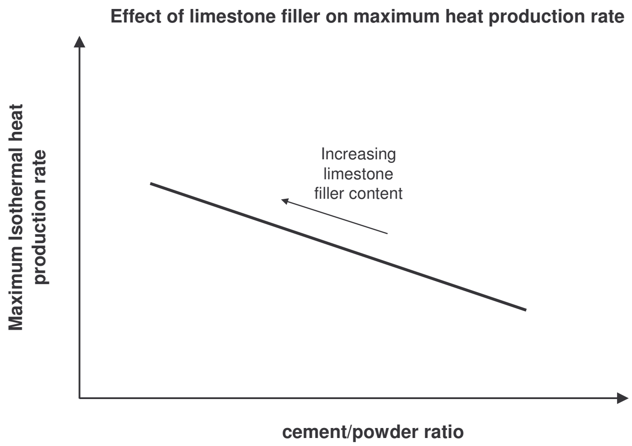

Figure 2. Effect of limestone filler on maximum heat production rate

Furthermore, a new (third) hydration peak can occur in some combinations of (C_3A-rich) Portland cement and limestone filler, as illustrated in figure 1. Two different theories can be formulated to explain this phenomenon (3,4,5).

The first theory starts from the hypothesis that limestone filler is inert and therefore not taking part in the reactions chemically. According to this theory, limestone filler is acting as a catalyst for the transformation of ettringite into monosulfate.

The second theory considers the limestone filler being not inert and thus taking actively part in the reactions, with the formation of monocarboaluminate. In this respect, it is to be mentioned that relative to the cement mass, only a minor part of the limestone filler can react with the Portland clinker, depending on the Al_20_3 content (6). The very limited chemical reactivity of limestone filler is also supported by means of thermogravimetric analysis (after 28 days), as schematically shown in figure 3. Around 750°C, a mass loss is noticed, almost entirely equivalent to the decomposition of the $CaCO_3$ amount present by the addition of limestone filler. This means that the limestone filler is still present (as inert particles) after the hydration process of the cement.

As a result of the (nearly) inert character of the limestone filler, a somewhat porous interface can occur in between neighbouring limestone filler particles, as illustrated in figure 4, showing a simulated microstructure. These more porous zones have been confirmed by scanning electron microscopy (SEM) on real paste samples. In spite of these porous zones, the overall porosity of the limestone filler type cement paste is lower than pure Portland cement paste, as shown by means of SEM and by mercury intrusion porosimetry (MIP) (figure 5).

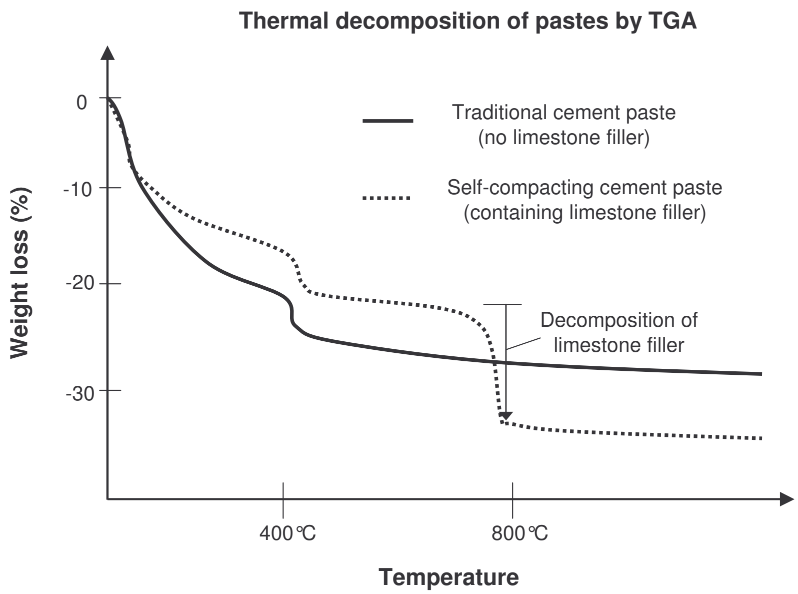

Figure 3. Thermal decomposition of pastes by TGA

The cumulative pore volume in case of traditional cement paste is significantly higher in comparison with self-compacting cement paste containing limestone filler, and this for comparable water/cement ratios. From the derivative of these curves, the threshold or critical pore diameter can also be determined. In general, for self-compacting cement paste containing limestone filler, the critical pore diameter is slightly lower in comparison with traditional cement paste without limestone filler (3,5,7,8).

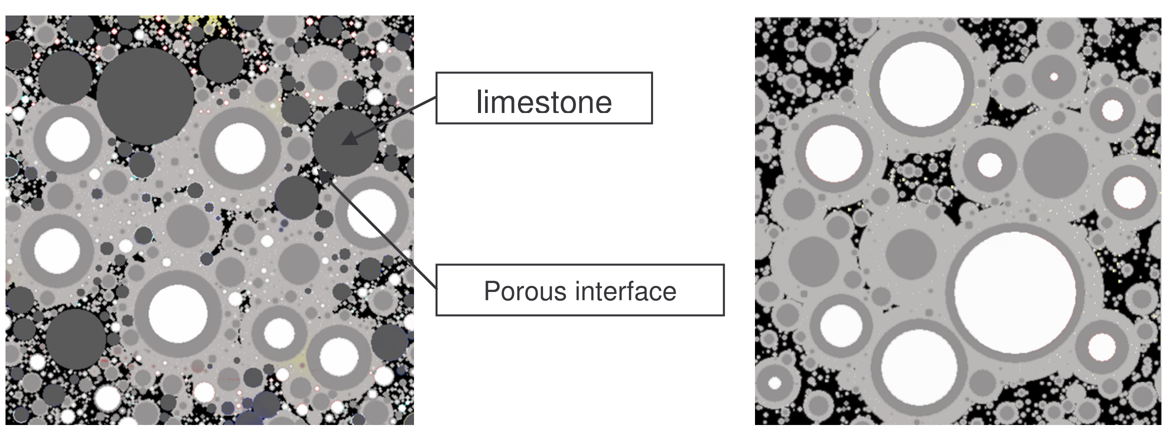

Figure 4. (left) 2D structure of self-compacting paste containing limestone filler, at a degree of hydration of 0.62, porosity 10% (right) 2D structure of a traditional paste at a degree of hydration of 0.62, porosity 17.4% (7,8)

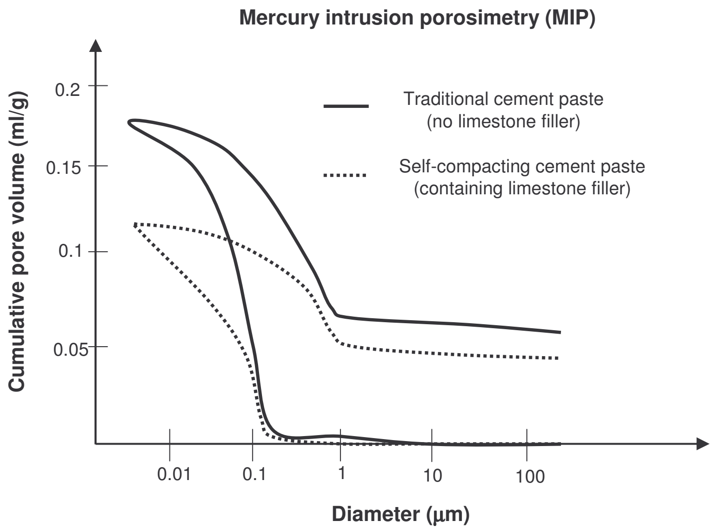

Figure 5. Mercury intrusion porosimetry (MIP)

For more details on hydration and microstructure development in case of other types of fillers, reference is made to literature (3,5). The overall conclusions however are that the combination of lower water/powder ratios, fillers and superplasticizers necessary to give satisfactory fresh properties of SCC lead to a denser structure and decreased porosity of the hardened concrete in comparison to traditional concrete. The total porosity of both the bulk paste and the paste/aggregate interface are significantly reduced, and there are fewer defects and less crack formation.

TRANSPORT PROPERTIES

Movements of gases, liquids and ions through concrete occur due to various combinations of differentials in air pressure, water pressure, humidity, concentration or temperature. Depending on the driving force of the process and the nature of the transported matter, the transport processes for deleterious substances through concrete may be diffusion, absorption and permeation (9). The transport properties surely depend on the microstructure of the material, as resulting from the hydration process (10,11). As the microstructure of SCC is somewhat different (depending on the type of SCC) in comparison with traditional concrete, it is expected that also the transport properties can differ. This is most strikingly illustrated with the study of gas permeability, as reported in (11,12). The gas permeability of limestone filler based SCC is significantly lower in comparison with traditional concrete.

In order to enable a more fundamental modelling, and not just a mere comparison between two specific mixes, one being traditional and another being self-compacting, the capillary porosity can be considered as a very important parameter. While water/cement ratio and water/powder ratio cannot explain the different behaviour in transport between SCC and traditional concrete, it can be noticed quite often that capillary porosity can explain the difference (3,10,11). This is illustrated in figures 6 (for water vapour diffusion) and 7 (for water permeability).

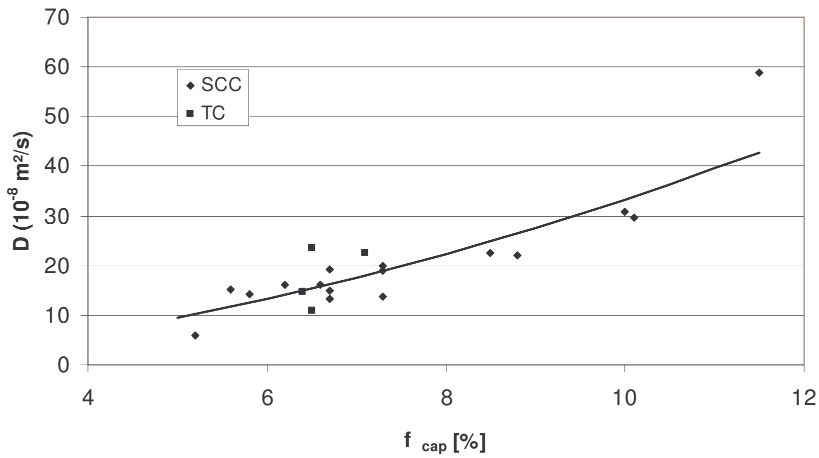

Figure 6. Relation between capillary porosity and water vapour diffusion coefficient in case of SCC and traditional concrete (TC) (10)

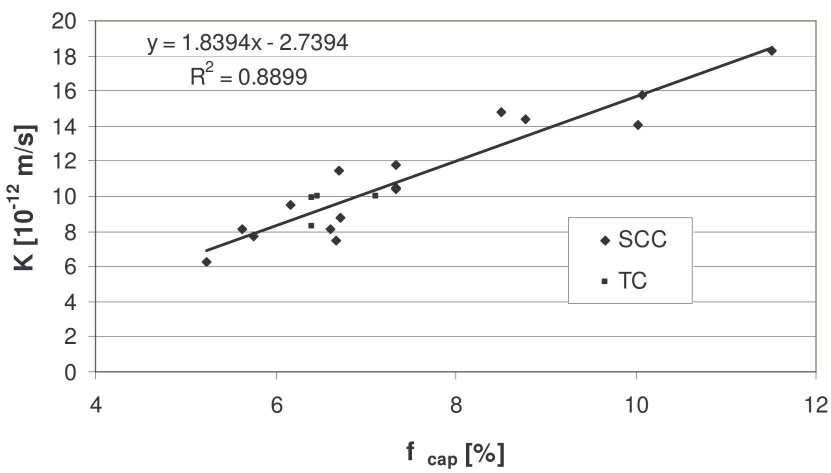

Figure 7. Relation between capillary porosity and water permeability coefficient in case of SCC and traditional concrete (TC) (10)

DURABILITY

As the microstructure and the transport properties of self-compacting concrete are somewhat different in comparison with traditional concrete, different durability behaviour can be expected to some extent. A detailed study of all relevant durability issues is not possible within the limited number of pages of this paper. For this, reference is made to literature (3,5,10,11).

As some general and practical conclusion, it can be mentioned that the durability of self-compacting concrete is at least as good as the durability of traditional concrete with similar water/cement ratio and cement content. However, when the comparison is made based on the concrete strength, self-compacting concrete sometimes might show a somewhat inferior durability. This can be attributed due to the fact that a similar strength can be obtained in self-compacting concrete with a higher water/cement ratio, leading to a microstructure of lower quality. A more fundamental comparison between self-compacting and traditional concrete can be obtained by means of the capillary porosity. It can be concluded that the capillary porosity is an important parameter concerning the durability of cementitious materials.

References

1. Noguchi T. and Mori H. (1998). "State-of-the-art report : Evaluation of fresh properties of self-compacting concrete in laboratory and on site." In: K. Ozawa and M. Ouchi, Eds. Proceedings of the international workshop on self-compacting concrete, Kochi 1998, 97-110.
2. Okamura H. and Ouchi M. (1999). "Self-compacting concrete. Development, present use and future." In: A. Skarendahl and O. Petersson, Eds. Proceedings of the first International RILEM Symposium on Self-compacting Concrete, Stockholm 1999, 3-14.
3. De Schutter G., Bartos P., Domone P. and Gibbs J. (2008) 'Self-Compacting Concrete', Whittles Publishing, Caithness, Scotland, pp.288.
4. Poppe, A.M. (2004) "Influence of fillers on hydration and properties of self-compacting concrete" (in Dutch), Doctoral Thesis, Magnel Laboratory for Concrete Research, Ghent University, Belgium, pp.240.
5. De Schutter G. and Audenaert K. (Eds.) (2007) 'Durability of Self-Compacting Concrete', State-of-the-art report of RILEM Technical Committee 205-DSC, RILEM Report 38, RILEM Publications S.A.R.L., ISBN 978-2-35158-048-6, pp.185.
6. Matschei T., Lothenbach B.and Glasser F.P. (2007) "The Afm-phase in Portland cement", Cement and Concrete Research, Vol. 37, pp. 118-130.
7. Liu X. (2006) "Microstructural investigation of self-compacting concrete and high-performance concrete during hydration and after exposure to high temperatures", Doctoral Thesis, Magnel Laboratory for Concrete Research, Ghent University, Belgium, pp.174.
8. Ye G., Liu X., De Schutter G., Poppe A.-M. and Taerwe L. (2007) 'Influence of limestone powder used as filler in SCC on hydration and microstructure of cement pastes', Cement & Concrete Composites, 29, 94-102.
9. Basheer L., Kropp L. and Cleland D. (2001) Assessment of the durability of concrete from its permeation properties: a review. Construction and Building Materials, 15, 93–103.
10. Audenaert K. (2006) "Transport mechanisms in self-compacting concrete in relation with carbonation and chloride penetration" (in Dutch), Doctoral Thesis, Magnel Laboratory for Concrete Research, Ghent University, Belgium, pp.370.
11. Boel V. (2006) "Microstructure of self-compacting concrete in relation with gas permeability and durability aspects" (in Dutch), Doctoral Thesis, Magnel Laboratory for Concrete Research, Ghent University, Belgium, pp.320.
12. Boel V., Audenaert K. and De Schutter G. (2008) 'Gas permeability and capillary porosity of self-compacting concrete', accepted for Materials and Structures