LIGHTWEIGHT SCC : SYSTEMATIC APPROACH AND CASE STUDY

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Abstract

Lightweight Self-Compacting Concrete (L-SCC) combines the properties of a self-compacting concrete (SCC) with the advantages of a lightweight aggregate concrete (LWAC). This type of SCC is usually intended for precast wall panels, housing elements and other large precast elements where dead load and transport weight are important issues.

This paper presents a systematic approach to the mix design of a lightweight SCC. The main objective was to obtain a flexible design method, rather than one optimised mixture composition. The presented design method integrates the most important characteristics of the different components, such as water demand of filler and cement, and particle distributions for filler, sand and lightweight aggregates.

The proposed approach is based on the modified Chinese mix design and incorporates the possibilities to realise a L-SCC in function of two major parameters: density class and compressive strength class. The theoretical basis, the modelling and testing and a case study are presented, together with a critical analysis of benefits and drawbacks of this approach for the average precast producer.

1 INTRODUCTION

The wish or need to reduce the dead load of a construction results in the use of lightweight concrete. This is especially the situation that occurs for e.g. floor renovations (or for new constructions when the bearing capacity of foundations is limited), precast wall or other panels. The main objective, the reduced weight, brings along other advantages compared to normal-weight concrete: good fire resistance following from the refractory properties of this kind of aggregate and improved heat insulation due to the cellular texture of the lightweight aggregates (resulting however in a reduced thermal mass as well).

Furthermore, compressive strength which was one of the weaknesses of the materiel in the past, can be designed as for common concrete. Production of an LC30/33 is no problem, while statistical evaluation of the traditional concrete production in Europe reveals that 90% of the production in 2005 was associated with the classes C30/37 or lower [8]. Combining these characteristics with the advantages of a self-compacting concrete (SCC) offers great opportunities for the precast industry where a large number of elements are produced already with SCC. A further reduction in weight gives the above mentioned dead load reduction for the construction itself, but also reduces drastically the transportation costs.

With an increasing market share for lightweight aggregate concrete (LWAC) solutions, precast producers try to integrate Lightweight Self-Compacting Concrete (L-SCC) in their production. However, they have to deal with some practical problems, inherent in the

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application of lightweight aggregates, as for instance water absorption of the grains, segregation of the mixture and problematic surface finish.

The BBRI developed a mix design method that can be widely applied in all types of precast plants, with varying boundary conditions: large flexibility towards used basic materials and resulting mixes. After all, the mix design should be applicable for all possible precast producers, each of them working with different basic materials and producing other elements, demanding different combinations of compressive strength and density. The basic principle of the approach: not one optimal mix design, but rather a flexible method for all possible concrete element producers.

2 MODELLING THE MIX DESIGN

SCC mix design models have been widely investigated worldwide since the development of SCC, and some models have been published already. The Japanese method was the starting point for most of these methods [1]. Few years ago the Chinese method has been published [5], and later on studied and modified by Brouwers et al. [6]. The advantage of this last method is the integration of the particle size distribution (PSD) of the different basic materials, in order to obtain an optimal particle packing.

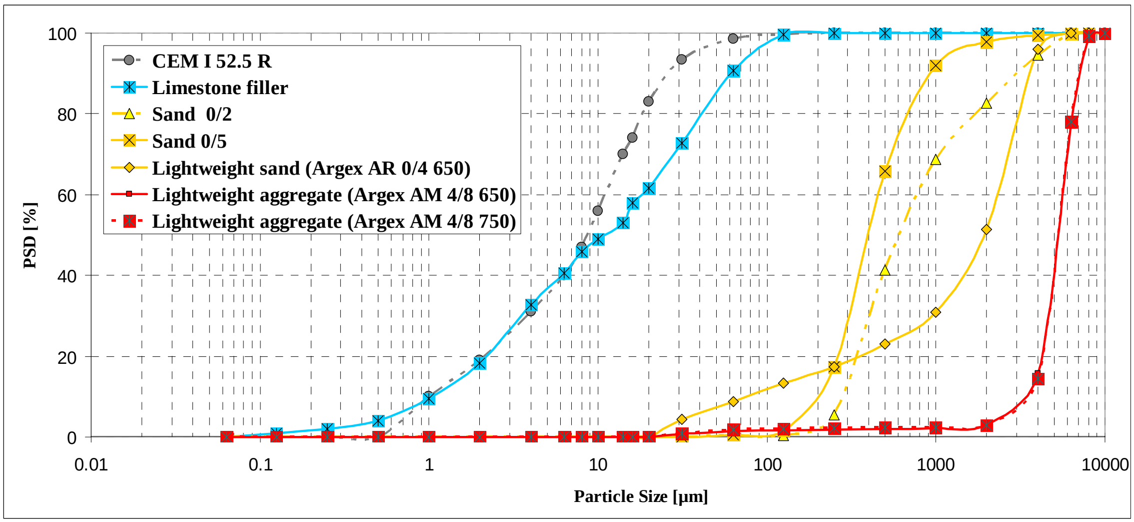

Figure 1: Particle size distributions (PSD) of the basic materials used in the testing program

The objective of the Chinese method was to obtain a medium strength SCC, with less paste (and thus less cement and/or filler) and more sand. Experiments showed the importance of the packing density. Brouwers illustrated that this approach actually resulted in an optimisation of the packing density with the so-called modified Andreasen and Andersen curves, rather than with the well known Fuller grading. In Brouwers' approach not only aggregates, but also cement and fillers are integrated for the packing optimisation. The cement content is fixed in function of the minimum compressive strength. The minimum water quantity is based on the water demand of the powder, the same as it is determined in the Japanese method.

In a first feasibility study, this approach seemed to be suitable for L-SCC [7]. A more detailed study, based on the above mentioned principles showed indeed good results for most of the combinations density – compressive strength, as will be presented in this paper. The objectives of the project, in terms of performance of hardened L-SCC are summarized in Table 1 (in accordance to NBN EN 206-1 and NBN B15-001 [2, 3]).

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Table 1: Target combinations of density and compressive strength

Density classes (D-class)	Requested compressive strength class (LC-class)
D 1.6 (1400 < oven-dry density < 1600 kg/m³)	**LC 25/28**
	LC 30/33
	LC 35/38
D 1.8 (1600 < oven dry density < 1800 kg/m³)	**LC 30/33**
	LC 35/38
	LC 40/44
D 2.0 (1800 < oven dry density < 2000 kg/m³)	**LC 45/50**
	LC 50/55

Figure 2 shows the result of a nearly perfect PSD-optimisation for a mixture type D1.6, based on materials as showed in Figure 1, and based on the approach of Brouwers. This means, an optimisation of the packing density with the modified Andreasen and Andersen curves. During the project, different parameters, influencing the shape of the curves, were evaluated.

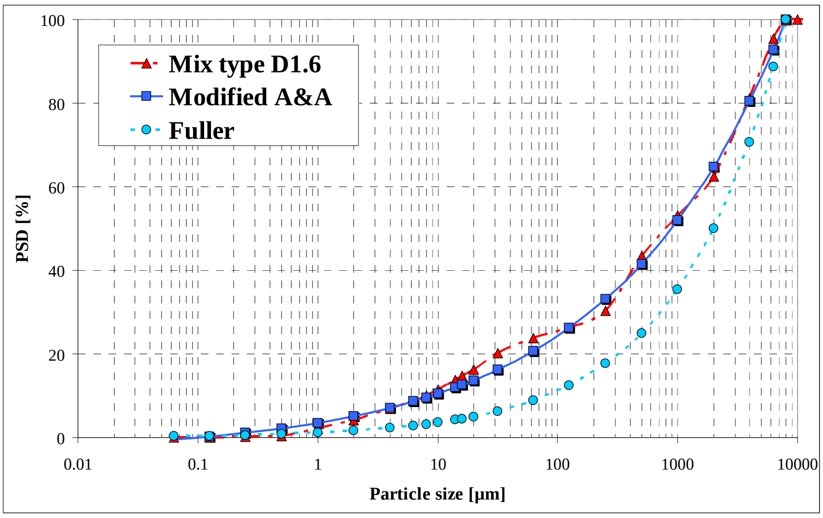

Figure 2: Result of an optimisation with the modified Andreasen and Andersen model for a mixture of type D 1.6. The figure illustrates the difference between the Fuller grading and the A&A grading. This last one appears to be very suitable for SCC.

In fact, compared to “normal” SCC, additional boundary conditions exist for L-SCC: the differentiation in density of course, and its impact on the compressive strength. A lower density can be translated into a higher amount of lightweight aggregates. The resulting lower strength (due to the lower compressive strength of the aggregates) has to be counterweighted sometimes with a higher amount of powder.

3 THE EXPERIMENTAL STUDY: MATERIALS, PROCEDURES AND RESULTS

The lightweight aggregate is an artificial aggregate produced by Argex n.v. from expanded "Boom" clay in Belgium. The aggregate grains (4-8 mm) are rough in appearance and rounded in shape, or crushed in order to obtain the lightweight sand (0–4 mm). The non-broken material has a surface made up of a brown microporous crust and an interior cellular texture. This last characteristic results in the main disadvantage of lightweight aggregates: the water absorption (see Figure 3). The dry grains absorb water very fast, and disturb possibly the workability of the mixture. Therefore, a pre-wetting has to be applied, if possible 15 to 20% in weight. In this case, the water absorption will be limited (see Figure 4). Basically, a

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humidity of 20% is aimed at, and corrections are applied in the mix design model if important deviations are detected. This implies a regular check of stocks.

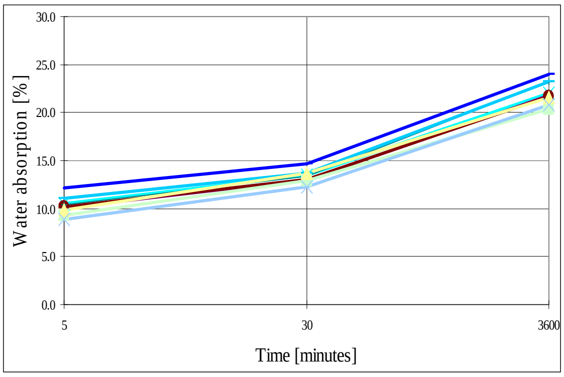

Figure 3: Water absorption of the lightweight aggregate (AM 4/8-650), starting from oven-dry condition.

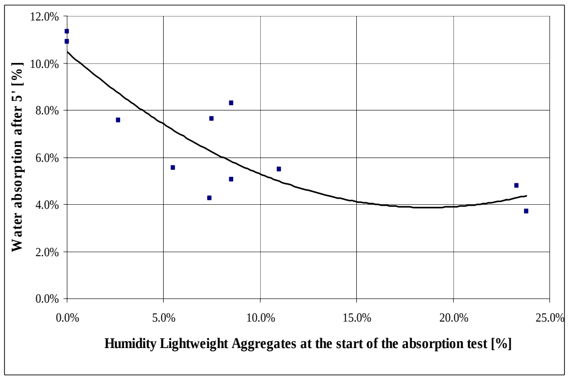

Figure 4: Water absorption of the aggregate (AM 4/8-650) after 5’, starting from a specific humidity.

Mixtures are always characterised in fresh and hardened state: the test methods for fresh SCC as described in the European Guidelines were used, and a viscometer analysis [4]. Most measured characteristics of the fresh concrete can be correlated with the viscometer measurements, facilitating the formulation of performance criteria in the fresh state. Some examples of mix designs and characteristics for the different density classes that were tested can be found in Table 2 and Table 3. In total, more than 70 mixtures were characterised.

Besides packing density, a well dosed combination of superplasticizer (SP) and viscosity agent (VMA) is necessary for a good result. The use of a VMA has two advantages: it enhances the robustness of the mixture which is important with inevitable fluctuations of water content. Furthermore, it keeps the lightweight grains from floating, which occurs often with such a fluid mixtures, actually an “inverse” segregation. Low W/C-factor is furthermore necessary when combining very low dry density (oven-dry density around 1450 kg/m^3) and normal compressive strength (LC 35/38).

Table 2: Typical mixture compositions for the different D-classes L-SCC

Mixture design [kg/m^3]	LD 1.6	D 1.8	D 2.0
Cement	400	350	350
Limestone filler	154	154	154
Sand 0/2	201	415	803
Sand 0/5	0	395	0
Argex AR 0/4 650	534	163	0
Argex AM 4/8 650	160	261	0
Argex AM 4/8 750	0	0	411
water	215	189	189
SP	6.9	4.1	6.3
VMA	6.9	2.3	5.6
Theoretical density [kg/m^3]	1669	1934	1912
W/C [-]	0.55	0.55	0.55
W/P [-]	0.39	0.39	0.39

Table 3: Properties of fresh and hardened concrete

Characteristics fresh concrete	LD 1.6	D 1.8	D 2.0
Slump flow [mm]	755	725	690
T50 mm [s]	4	4	7
Funnel time [s]	13	6	10
J-Ring (slump flow) [mm]	675	715	650
with blocking step (h1/h2)	6	4	13
L-Box (ratio)*	0.86	0.88	0.84
Air-ratio [%]	2.0	3.0	4.0
Fresh density [kg/m^3]	1709	2016	2016
Yield Value [Pa]	12	11	31
Viscosity [Pas]	28	35	59
Characteristics hardened concrete			
f_cm_cube 1d [N/mm^3]	24	29	31
f_cm_cube 7d [N/mm^3]	34	38	46
f_cm_cube 28d [N/mm^3]	43	46	54
f_ck_cube 28d [N/mm^2]	37	43	50
Resulting LC-class	LC 30/33	LC 35/38	LC 45/50
Oven-dry density 28d [kg/m^3]	1570	1690	1820

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For the hardened concrete, compressive strength and oven-dry density were determined.. Table 3 summarises the results for 3 typical mixtures. The mix design method allowed for the fabrication of all target combinations of density and compressive strength, which illustrates the flexibility for both LC and D classes, one of the main objectives of the project.

For each mix, a small plane element was cast as well, in order to evaluate the surface quality. The formwork surface quality of the concrete could be optimised with a good admixture dosage. The upper surface however, is difficult to post-treat and gives a rather rough result. Further solutions will be investigated.

Based on the extensive testing program from which some results were given above, some corrections are applied to the modified Andreasen and Andersen curves. In fact, a compromise was found between these theoretical curves, and the empirical curves that followed from the laboratory tests. These adaptations concerned mainly the increase in minimum powder content in case of large amounts of lightweight aggregates. This gives different curves for each D-class. An example for a D1.6 mix can be found in Figure 5.

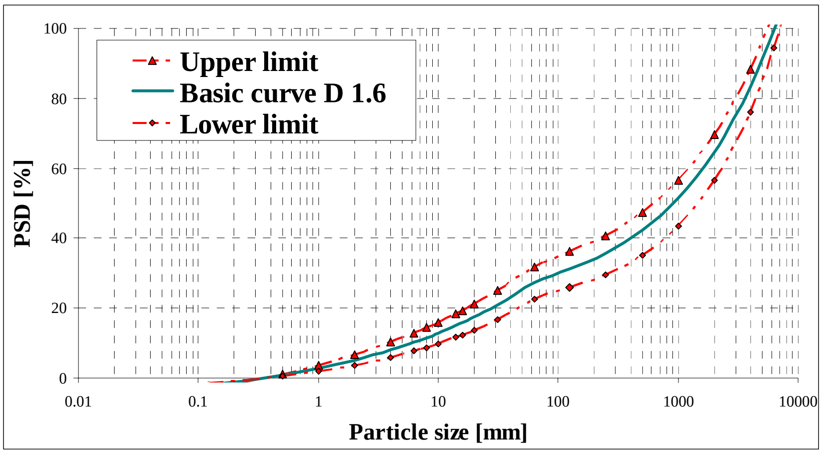

Figure 5: Basic curve for the optimisation of D-class 1.6 mixtures. The curve was established based on an empirical correction of the modified A&A-model.

4 BRIEF DESCRIPTION OF A CASE STUDY

The approach was tested on a larger scale in a French precast plant, for the production of housing elements. Based on the characteristics of the basic materials of the precast producer, the mix design model was used to calculate optimal aggregate curve and mix design. Several panels (120 x 700 x 15 mm³) have been produced from a 3m³ batch L-SCC. The main characteristics of fresh and hardened concrete are given in Table 4.

Table 4: Main characteristics for the L-SCC used in a case study

Mixture design [kg/m³]	
Cement	**354**
Limestone filler	**225**
W/C [-]	**0.59**
Characteristics fresh concrete	
Slump flow [mm]	**675**
Funnel time [s]	**13**
Fresh density [kg/m³]	**2059**
Characteristics hardened concrete	
f_cm_cube 28d [N/mm³]	**51**
Oven-dry density 28d [kg/m³]	**1800**

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The L-SCC showed excellent properties for both placing and hardened state. A small drawback is the rough, but homogeneous surface (see Figure 6 and Figure 7).

Figure 6: Casting of the L-SCC.

Figure 7: Homogeneous but rough surface.

5 CONCLUSIONS AND FURTHER STUDY

A flexible mix design method for self-compacting lightweight concrete (L-SCC) has been proposed, mainly based on the Chinese method and the adaptations of Brouwers. The basic objective was to provide the producers of precast elements with an easy-to-use and flexible model for the concrete mix design. The flexibility relies on the possibility to differentiate easily within the density and compressive strength classes. The testing program involved oven-dry densities ranging from 1400 kg/m³ to 2000 kg/m³, and results for the compressive strength ranging from 20 N/mm² to 64 N/mm². The optimal packing density gives a robust basis for the concrete composition, which can be optimised further with a well dosed admixture combination. The long-term properties of the hardened L-SCC were not investigated in the framework of this project.

6 REFERENCES

1. Okamura H. and Ouchi M., ‘Self-Compacting Concrete – Development, present use and future’, *Proceedings of the 1st International RILEM Symposium on SCC*, Sweden, 1999.
2. NBN EN 206-1:2001 – Concrete – Part 1: Specification, performance, production and conformity.
3. NBN B15-001:2004 – Supplement to NBN EN 206-1.
4. EPG working group (BIBM, CEMBUREAU, ERMCO, EFCA, EFNARC), The European Guidelines for Self-Compacting Concrete, may 2005.
5. Su N. and Miao B., ‘A new method for the mix design of medium strength flowing concrete with low cement content’, *Cement & Concrete Composites*, 2003, vol. 25, pp. 215-222.
6. H.J.H. Brouwers, H.J. Radix, ‘Self-compacting concrete: theoretical and experimental study’, *Cement and Concrete Research 35*, 2116-2136 (2005).
7. Huyge S., ‘Self-compacting concrete according to the modified Andreasen and Andersen model’, Master Thesis, KHBO, 2005.
8. ERMCO, European Ready Mixed Concrete Industry Statistics based on the Y2005 production data.

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