Belgian Building Research Institute

Lightweight self-compacting concrete with Argex aggregates

1. Introduction and project objective:

This document is a short overview of the research project entitled "Lightweight self-compacting concrete with Argex aggregates". As part of this project, a design method was studied and developed for several types of lightweight self-compacting concrete. The following principles provided a starting point for the project:

- Use of ***Argex aggregates*** and particularly grains intended for "structural applications";
- A ***systematic approach***, based on a theoretical mix design model, in order to develop a versatile procedure, which can be adjusted to the various primary materials used.

Designing a lightweight SCC presents a challenge at various levels:

- Integrating porous, lightweight aggregates may have an impact on the water demand of any mixture, as well as consequences for the rheology and effective E/C factor.
- Lightweight aggregates carry a risk of (inverted) segregation: due to their lower density, they may rise to the surface of the matrix/mixture.
- Using accurately measured quantities of lightweight aggregates, in order to obtain a specific density for the concrete, makes it necessary to limit the total grain size in the skeleton.

Figure 1: 4/8 fraction Argex aggregates

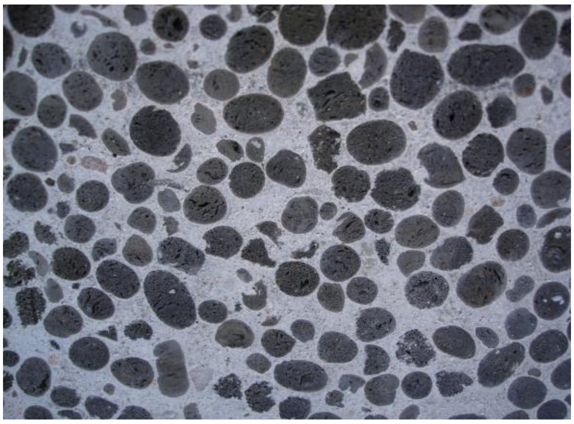

Figure 2: Section of lightweight SCC with Argex aggregates

The project focused on a wide range of possible types of lightweight SCC, in terms of the ***compressive strength class*** and ***dry density*** of the concrete. Roughly speaking, the dry density (oven dried) is between 1400 - 2000 kg/m³, while the compressive strength class ranges from LC 25/28 to LC 50/55 (Table 1: Combinations of compressive strength and).

Table 1: Combinations of compressive strength and dry density

	Compressive strength class
D 1.6 **(1400 < dry density ≤ 1600 kg/m³)**	**LC 25/28 - LC 35/38**
D 1.8 **(1600 < dry density ≤ 1800 kg/m³)**	**LC 25/28 - LC 40/44**
D 2.0 **(1800 < dry density ≤ 2,000 kg/m³)**	**LC 30/33 - LC 50/55**

In addition to the resulting characteristics for hardened concrete, the properties of fresh liquid concrete are obviously crucial. The programme of practical tests made it possible to fine-tune or broaden the known criteria for typical SCC tests, such as flowability (“slump flow”), V-funnel flow time, L-box and other tests.

2. Approach and basic principles

The model adapted by Brouwers, based on the Chinese design model, served as a starting point for this project. The basic principles of this method are as follows:

- The matrix is made compact by optimising the granular skeleton. In order to achieve this, Fuller’s principle is applied, but the theoretical curve is adjusted, so that finer sand can be used. The curve adapted by Andersen & Andreassen is more suitable for concrete types with a relatively high quantity of sand and fillers, such as high resistance and self-compacting concrete.
- In principle, a compact matrix produces a more compactable mixture and greatly improves its liquid behaviour.
- Using fine sand may reduce the filler content, which is useful in economic terms.

Using this method to design an extensive test programme made it possible to make specific adjustments for lightweight SCC, in which the integration of large quantities of lightweight aggregates sometimes adds an extra problem. The development of a new set of reference curves, adapted to each density class, facilitates the new mix design (see also Figure 3).

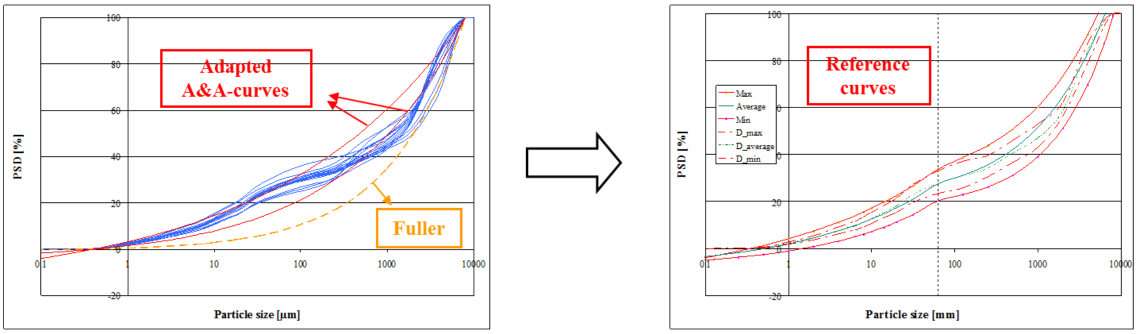

Figure 3: Development of empirical reference curves based on results obtained using theoretical curves relative to grain sizes

3. Integration of lightweight aggregates

The main problem, when using lightweight aggregates, is caused by the influence of slightly less porous aggregates on the water demand of the mixture. Certainly in their dry state, the aggregates can absorb water relatively quickly, as shown for 3 types of Argex grain in Figure 4. It becomes clear that the absorption speed is very high at the start of this curve (for the first 5 minutes), but gradually falls. The solution is therefore to pre-moisten the aggregates, which greatly reduces absorption (Figure 5).

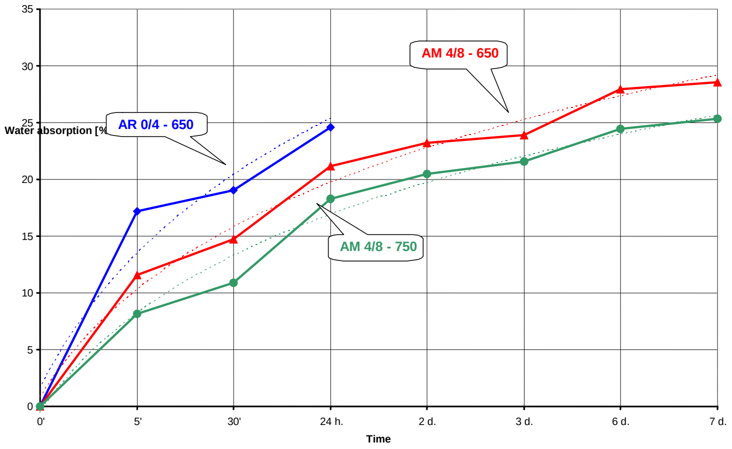

Figure 4: Absorption curves for Argex grains from dry state

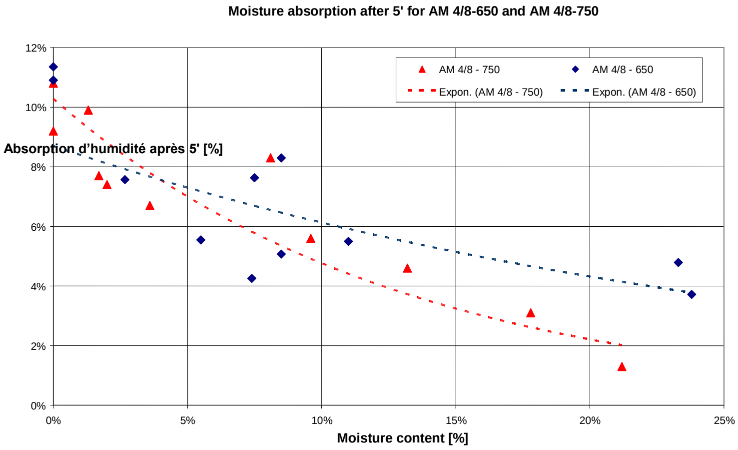

Figure 5: Measurements of water absorption by aggregates after 5 minutes starting from a specific initial moisture content

When the moisture content of the aggregates exceeds a certain threshold, such as 15%, it can be seen that any further absorption is limited and should not disturb the mixture anymore. For this study, the researchers therefore used pre-moistened aggregates with a moisture content of approx. 20%. For everyday use, we would probably agree that a moisture content of 15 - 25% is perfectly acceptable. Excessively moist aggregates and a high level of absorption around the grains can lead to the release of water.

Another new method of controlling this absorption involves applying a coating around the Argex grains, which greatly limits the absorption of water (see Figures 6 and 7).

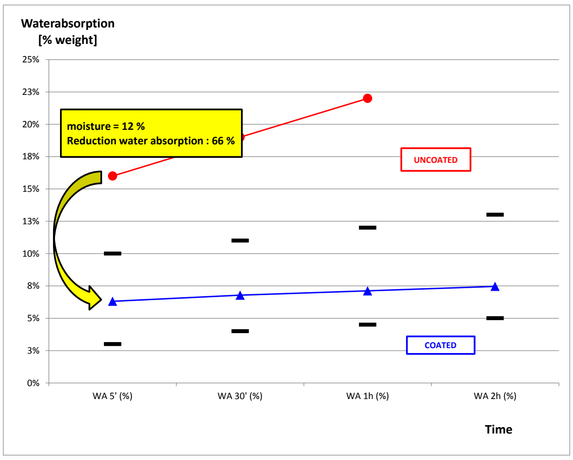

Figure 6: AM 4/8-650 C coating - Measurements of water absorption by aggregates over a period of time (in compliance with EN 1097-6)

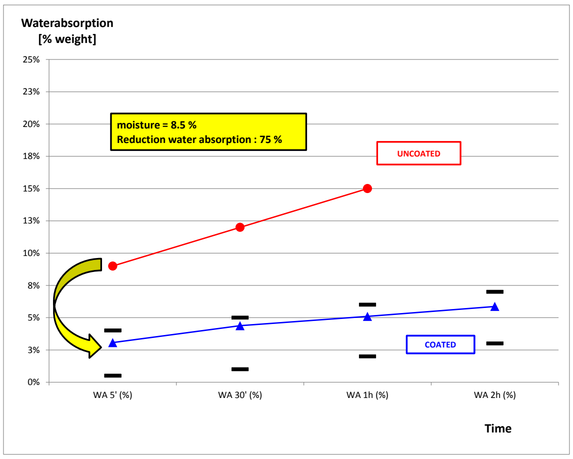

Figure 7: AR 0/4-700 C coating - Measurements of water absorption by aggregates over a period of time (in compliance with EN 1097-6)

A second problem associated with the use of lightweight aggregates is caused by the risk of (inverted) segregation: lightweight aggregates have a tendency to rise to the surface. Generally, using an admixture to increase viscosity can resolve this problem. In addition, this adixture can act as a buffer and counteract the effects of any variations in the moisture content of the aggregates.

Finally, it is also necessary to pay careful attention to the dosage of lightweight aggregates. Both the volume and weight of the lightweight aggregates can be dosed. Due to the potential risk of expansion (especially for light 0/4 fraction sand), weight dosage is always advisable. Weight dosage mainly involves regularly checking that the density and moisture content of the moist aggregates is correct. In fact, this value is used in the calculation. Checking that the moisture content is right makes it possible to adjust the aggregate dosages and to assess whether the moisture content is suitable for the production of high quality SCC.

4. Laboratory test programme

The basic characteristics of the designed mixtures were monitored, using tests conducted in the laboratory, both in fresh and hardened state. For typical SCC tests conducted on fresh SCC, the following target values can be proposed, which are not very different from the values for a SCC with a normal density:

- Flowability or slump flow: ideally 700 - 750 mm, a broader range of 650 - 800 mm also being possible, provided the risk of insufficient fluidity or blockage is also taken into account;
- V-funnel flow time: 5 - 25 seconds, with high variations, depending on the chosen admixture;
- L-box ratio: minimum 0.7 (assessed according to the field of application);
- J-ring: blocking step below 15 mm;
- Sieve stability test: difficult to use, a test on the hardened concrete is recommended.

Figure 8: Spreadability test (left) and L-box ratio (right)

The compressive strength and dry density of the hardened concrete represent basic characteristics and were therefore determined for all laboratory mixtures. Figure 7 shows the ratio between the average compressive strength and measured dry density (oven dried). It also compares the results for a lightweight SCC to the average values for normal lightweight concrete. Figure 10 shows the characteristic values for compressive strength, according to dry density (oven dried) (based on 3 - 6 samples).

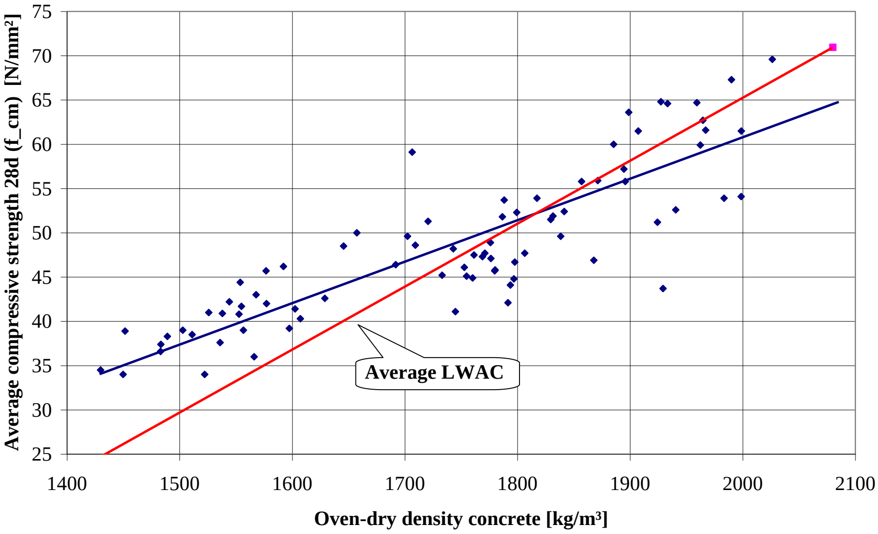

Figure 9: Ratio between the average compressive strength and dry density (oven dried)

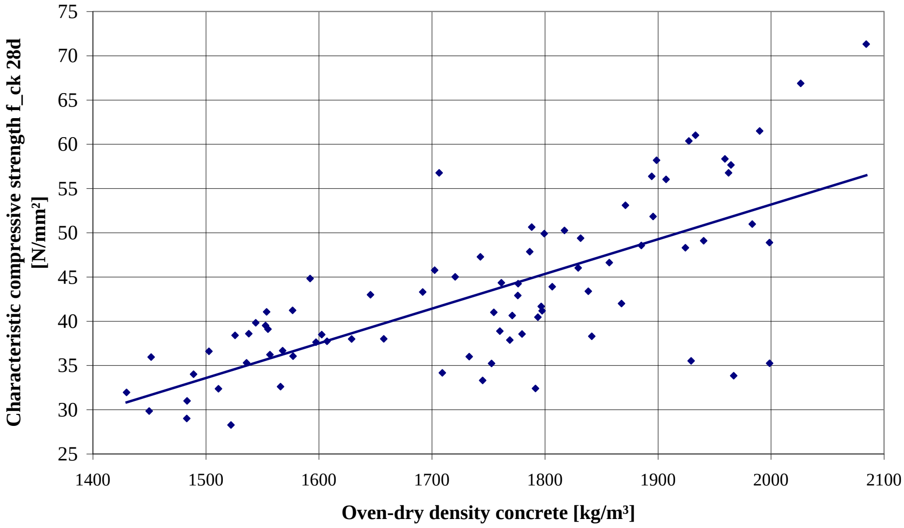

Figure 10: Ratio between characteristic compressive strength and dry density (oven dried)

For the sake of completeness, the shrinkage values and elasticity modulus were also monitored for a limited number of mixtures. The highest shrinkage values were observed on the lightest mixtures, which can be explained by two factors:

- Higher powder content (both cement and fillers);
- Lower total aggregate content.

The order of magnitude of the shrinkage values for lightweight SCC remains identical to that for normal lightweight concrete. Figure 11 compares the values measured to the shrinkage curves indicated for lightweight concrete in Eurocode 2 according to the relevant compressive strength classes.

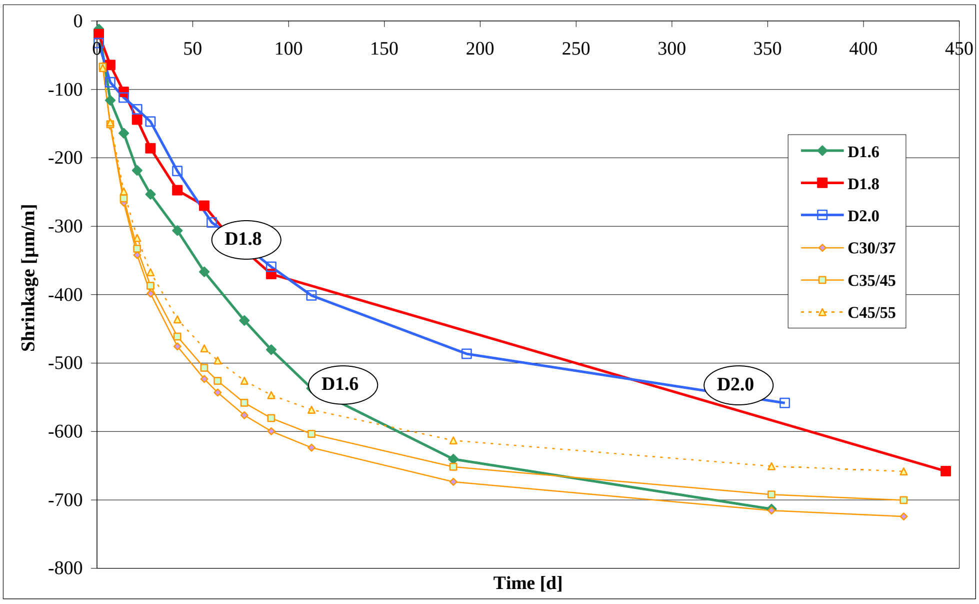

Figure 11: Comparison of shrinkage curves with the shrinkage curves in the Eurocodes for lightweight concrete

Finally, the elasticity modulus was also determined for six mixtures and the results of each measurement are shown in Table 2. The results are in line with expectations, if they are compared to the Eurocode 2 values (calculation based on compressive strength and density).

Table 2: Module E measurements and comparison with Eurocode 2 curves

	M	Mod E [N/mm²]	Values EC2 [N/mm²]	Difference compared to EC2 [%]
D1.6	M89	19806	19656	1
	M90	18929	16638	12
D1.8	M63	21970	23066	-5
	M64	24074	24521	-2
D2.0	M79	27669	27635	0
	M80	26580	29724	-12

5. Industrial tests

As part of the final phase, the proposed mix design method was assessed, based on a number of industrial tests conducted by prefabricated element manufacturers, which produce larger volumes of concrete and cast larger concrete elements. For each test, the following diagram was respected:

- Mix design
- Preparation of one or more laboratory mixtures, using the primary materials provided by the relevant manufacturer
- Optimised test on an industrial scale, with or without adjustments, such as admixture dosage
- Assessment of obtained elements and samples

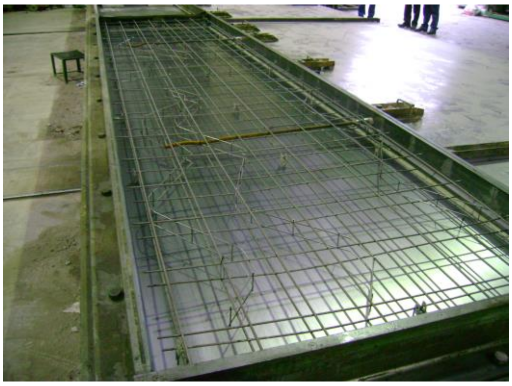

Figure 12: Lightweight SCC is often used for large wall panels.

Figure 13: The proposed mixes are used in the manufacturing process and cast using bins.

Figure 13: It is important to monitor the properties of fresh SCC (in this case, flowability or "slump flow").

Figure 14: Preparation of cubes, in order to monitor compressive strength and dry density

These industrial tests made it possible to fine-tune practical aspects of the design method. They also showed the extent, to which the theoretical mix design can be used to rapidly obtain a consistent mix that meets specific requirements (weight, compressive strength, fluidity, etc.).

6. Summary and conclusions

The project entitled "Lightweight self-compacting concrete with Argex aggregates" focused on a design method for several types of lightweight self-compacting concrete (LSCC). This study is based on the adapted Chinese method, while an extensive test programme made it possible to further optimise the design method and working procedures. The design method itself was integrated into software, which should make it possible, at a later stage, to rapidly design new mixtures, using new primary materials.

The resulting mixtures also show the wide range of possibilities created by lightweight self-compacting concrete, based on mix types and characteristics of the hardened concrete. The characteristics shown in Table 3 can be produced using the adjusted mixtures.

Table 3: Combinations of compressive strength and dry density

	Compressive strength class
D 1.6 **(1400 < dry density ≤ 1600 kg/m³)**	**LC 25/28 - LC 35/38**
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The project was not limited to laboratory tests and included industrial tests, in order to test the design process, which made it possible to work with other materials and under real working conditions. In most of the industrial tests, the above criteria for fresh concrete could be used, which required the same properties as for hardened concrete and met the necessary criteria. The following summary shows, once again, the conclusions based on tests conducted on fresh concrete:

- Slump flow: 700 - 750 mm
- V-Funnel time: 5 - 25 seconds
- J-ring: blocking step below 15 mm
- L-box ratio: minimum 0.7 (combined assessment!)
- Sieve stability test: less useable