

## SCC-Concrete in Europe – a higher-grade product for the 3<sup>rd</sup> millennium

*Prof. Ir. Wim Bennenk*

*Emeritus professor at Eindhoven University of Technology, (EUT), Niederlande, Manager BFBN – BELTON research projects on SCC*

### Abstract

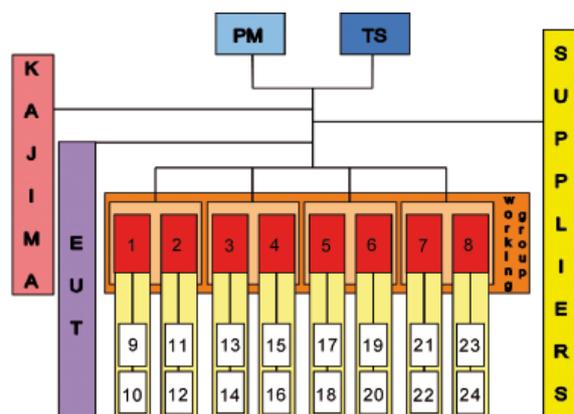
In 1998, 24 Dutch precast concrete element manufacturers united in the association BELTON initiated the project to investigate the possibilities to apply Self Compacting Concrete in the industry. The required knowledge on SCC showed to be not available in the Netherlands, so it was decided to ask Kajima Corporation in Tokyo to transmit their knowledge on SCC to a small group of BELTON representatives. That was effectuated in the fall of 1998 at Kajima Technical Research Institute, KATRI, in Tokyo. The gained knowledge was then spread to all manufacturers and a huge collective development project of 24 companies started. Within 1 year the first commercial production was a fact and in 2000 most of the companies were producing SCC on a daily base. After having followed training courses organized by BELTON nowadays over 60 Dutch precast companies apply daily SCC for precast products of all kind under third body control; in 2006 almost 800.000 m<sup>3</sup>.

SCC differs in many aspects from vibrated concrete. Attention has to be paid to: the mix design procedure, the characteristics of fresh SCC in relation with the product, the modifications in installation and equipment, the mould technique, the way of casting and finishing, the appearance, the mechanical properties, the durability and the economical aspects. The listed aspects are discussed in this paper.

### 1 SCC, a challenge

Innovation is an essential condition to maintain and develop the position of the precast concrete industry, which is the most important supplier in the Dutch building industry. Almost 50% of all 16 million m<sup>3</sup> concrete produced in our small and densely populated country is used for precast concrete units, varying from pavement to bridge girders. In the construction sector the

supplying industry is responsible for 80 % of all innovations, SCC is one of these. The BFBN is the national association affiliating 150 Dutch precast concrete manufacturers, while the association BELTON unites within the BFBN the 24 concrete element manufacturers. The idea to apply SCC for the production of precast concrete was discussed in 1998 within the BELTON many times, because it looked challenging and likable. A literature survey did not bring the essential knowledge. In principle it was decided all 24 BELTON members should join the development project on SCC, managed by the author. That is a peculiar and unusual situation, because the companies are competitors in the market. The first common decision in the project was to request Kajima to transfer their expertise concerning the design and application of SCC in general. After signing an agreement with Ka-



*Figure 1: Schematic representation of the project organisation*

jima, a very stimulating learning process started for all companies involved. A group of four went to Kajima Technical Research Institute in Tokyo to be trained in a 2 weeks lasting learning process. After the return to the Netherlands the acquired know how was globally transferred to all partners in the project. A project organisation as shown in Fig.1 was established. A working

group with representatives of 8 companies took the lead, each of them taking care for 2 other partners. The working group was working 2 by 2 together. The support of EUT and the co-operation with suppliers during the whole process was important for everyone. The project was partly financed by the Dutch Ministry of Economic Affairs.

## 2 The design of SCC

The design of SCC according the method developed by professor Okamura may be important for on site applications in Japan, but showed to be too costly for the industry. Nevertheless, we adopted the development method, according [1] resulting in the following:

- The fluidity and viscosity of the paste is adjusted and balanced by careful selection and proportioning of the cement and additions, by limiting the water/powder ratio and then by adding a super plasticizer and (optionally) a viscosity modifying agent (VMA). Correctly controlling these components of SCC and their interaction is the key to achieving good filling ability without vibration and stability against segregation.
- Controlling temperature rise, thermal and drying shrinkage cracking as well as strength, the fine powder content may contain a significant proportion of type I (inert) or type II (hydraulic or pozzolanic) additions to keep the cement content at an acceptable level.
- The volume of the paste must be greater than the void volume in the aggregate so that the individual aggregate particles are fully lubricated by a layer of paste. This increases fluidity and reduces aggregate friction, especially in the fine aggregate.
- The proportion of fine and or coarse aggregate in the mix is thus reduced so that individual stones are fully surrounded by a layer of mortar. This reduces aggregate bridging when the concrete passes through narrow gaps in reinforcement and is characterised as increasing the passing ability of the SCC.

### 2.1 The selection of the constituent materials

A wide range of cement types and brands is used by the 24 companies, while several filler types and plasticizers were available in the mar-

ket. An investigation started to learn the interactions between the different constituent materials in the paste as well as the performance of the paste itself. For this research at the EUT the flow-cyl method [2] is used to achieve that in a relative short period of time for quite a number of combinations of powder materials the relationship between the water cement ratio, the cement-filler plasticizer ratio, the early strength development and the paste flow could be determined. It provided the companies a deeper insight in the interactions between the constituent materials of the paste + plasticizer. There are some important considerations to make when selecting the materials:

- In general the type and brand of cement is the same as used for many years by a company. There must be strong reasons to change that. More cement types demand for silo capacity.
- In combination with the type of cement one may select a type I or II filler. Important is the water-retaining ratio  $\beta_p$ , showing the amount of water necessary to moisten the particle surface. A lower  $\beta_p$  means a lower water demand.
- The fillers of type I do hardly contribute to the short term strength development, but do slightly contribute to the 28 days compressive strength. The colour of the concrete will be rather constant and will show a perfect even surface with a slight grey–yellow tint.
- In case the concrete is not visible after construction a type II filler, like fly ash, is preferable, because fly ash contributes in the strength development although at a later stage, so can partly replace cement, although the early strength generally is dominant for the final cement content. The colour of SCC with fly ash will be grey and more uneven
- The selection of the plasticizer is based on a relative short workability and a strong water reduction. The dosage of the PCE plasticizer to create the required workability has firstly to be determined in mortar tests. Adjusted finally in full scale trial mixes.
- VMA is not widely used in the precast industry, because it is covering several changes in dosing or material properties. In one way attractive, but one should notice these changes in the mix and anticipate

immediately, to avoid lower product qualities than required.

- Attention should continuously be paid to possible changes in material properties, to be sure that the fresh concrete is reproducible.

## 2.2 Reproducibility

It is necessary for a successful production that the fresh concrete can be produced within small tolerances on fluidity and viscosity. That depends on one hand on the composition of the SCC and on the other hand on the selected materials.

Cement chemistry may affect the performance of SCC and may, for instance, determine the type of plasticizing admixture that can be used. Cement of a given type and from the same plant will normally be consistent within a small range from batch to batch but some manufacturers do make periodically changes to the chemistry and or fineness.

Moving to another source of cement, even of the same type or from the same manufacturer may have a larger effect and should be checked before a supply change is made.

Cements with a high water requirement tend to increase the viscosity of the paste and should be controlled by plasticizer addition rather than water, however in some cases, there may then be problems resulting from sensitivity to the dosage of admixture.[1]

The same situation is valid for the filler. The source, the chemical composition and grading may vary from delivery to delivery.

Therefore it is required to design a fresh self consolidating concrete with enough **robustness**. It means that small changes in the materials properties and dosing do change the characteristics of the fresh SCC only slightly. The robustness can be checked in mortar tests, see chapter 2.3.

Supplied cement, filler and plasticizer can be tested by checking the flow of paste containing the new material. A deviation in strength can be tested on 40 x 40 x 100 mm paste prisms.

## 2.3 The mix composition

### 2.3.1 The development of a specific SCC

In the BELTON project each manufacturer performed his own paste tests following the procedures learned in Japan. Starting with tests on paste, then on mortar and finally on fresh

concrete in the laboratory. The next step is to perform full scale trial mixes in practise.

It was quite a change for the concrete technologist to work on a laboratory scale, with parts of grams, etc, see Fig.2. Results and experiences were discussed in the Working Group and then periodically shared with all partners in progress sessions.

The mortar may contain a relative high volume of sand, compared with the Japanese mortar in SCC. It was learned that a ratio  $V_{\text{sand}} / V_{\text{mortar}} = 0,45$ , a slump flow of 300 to 350 mm and a funnel time between 5 and 12 seconds is a good base for SCC in the industry.



Figure 2a:  
Weighing powder  
and water  
accurately.



Figure 2b: Mixing  
the paste  
according to the  
fixed procedure.



Figure 2c: The  
flow of the paste  
measured.

The robustness of the mortar can be tested by choosing a fixed  $V_{\text{sand}} / V_{\text{mortar}}$  ratio and dosage of plasticizer and by varying systematically the W/P ratio. Measure the flow and the funnel time at each step. Repeat the test by changing the plasticizer dosage slightly at a fixed W/P ratio. Perform then the previously described procedure for a slightly different  $V_{\text{sand}} / V_{\text{mortar}}$  ratio. In a flow–funnel diagram the dots can be plotted for each  $V_{\text{sand}} / V_{\text{mortar}}$  ratio. The magnitude of the changes in the flow–funnel values

for small differences in the materials or dosage shows the robustness of the mortar.

The last step in the development was to determine the right content of gravel or crushed coarse material, 16 mm and a small percentage of 32 mm. The upper limit is 60 %. The Dutch SCC shows high flow values, 750-850 mm and low funnel times without any segregation and enough stability. The possible high sand and gravel percentages, applying Dutch materials, were also found by Takada in his research at the Delft University.[3]

The total amount of water is approximately 160-170 litre, the cement content generally  $350 \pm 30$  kg, the powder  $525 \pm 25$  kg per  $m^3$ . For durability reasons an effective water cement ratio of 0.45 is often required, which is feasible.

### 2.3.2 The performances of the SCC in fresh and hardened state

The fresh SCC should meet requirements on: stability, viscosity, filling and passing ability. The performance of the fresh self consolidating concrete in the precast concrete industry is directly depending on the type of element to produce. For elements produced in a horizontal positioned mould the fluidity and filling ability is dominant. For elements produced in a vertical mould and high reinforcement rates the viscosity and passing ability is dominant. In the precast concrete industry each type of element has in principle its own mix composition.

Another aspect that has to be reviewed is the compressive strength after  $12 \pm 2$  hours, for double shift productions even after  $7 \pm 1$  hours ( $> 35$  MPa for prestressed elements and  $> 25$  MPa for reinforced elements). The 28 days compressive strength is mostly beyond 75 MPa. The mechanical properties and time depending behaviour is generally spoken comparable with the normal concrete, although a lower E modulus may cause more camber of prestressed beams prestressed at an equal compressive strength. Tests show that cold joints may cause less shear capacity in the joint. In chapter 4 this subject is discussed.

### 2.3.3 Material costs

Depending on the type of filler, the material costs for SCC are € 5 to € 7 higher than for normal concrete (NC), while the SCC designed

with 40% sand and 50% gravel is € 11 to € 14 higher. It is clear that the cost increase has to be reviewed carefully in a very competitive market. It is the company's philosophy to design SCC at the lowest possible costs and to balance on the brink of segregation or to design SCC with a higher powder content to some higher costs, at the safe side and with a low rate of failure costs.

## 3 The modifications

### 3.1 The storage of materials.

It took some time for some companies to introduce SCC in the daily practise, due to the lack of storage capacity for an additional powder, such as the filler. The costs to position 1 or 2 additional silos are rather high, due to the required piling, foundation works and the screw transport of the powder to the weighing bunker.

### 3.2 The mixing station

A second modification concerns the containments for the new and additional plasticizer assuming that normal concrete will be used as well. Another modification concerns the programming for the adjustment of the water volume to add to the dry mix, respecting the measured moisture content of sand and gravel. These measuring methods are in general not accurate enough, even when newly installed.

It may be necessary to increase the weighing capacity of the balance for powders.

The mixing cycle will be slightly longer than for normal concrete. The installation of a wirbler in the mixing pan supplies more mixing energy and will increase the mixing quality and dura-



Figure 3: Wirbler and scraper installed



Figure 4: Hot and cool water installation

tion, see Fig.3. The latter is important because the casting speed tends to increase and waiting for the next delivery during casting operations is unacceptable. The possibility to cool and heat the mixing water is introduced in several installations, see Fig.4.

### 3.3 The concrete transport and temporarily storage system

The next step is to pay attention to the concrete transport system. Sometimes easily done with a 'kubel', a casting bucket directly filled under the mixer and transported with a forklift truck. During that transport the fresh SCC is continuously in movement and will not start to consolidate,

Figure 5



which is a comparable situation as for fresh SCC transport using tilting buckets.

In case the fresh concrete is stored temporarily, the SCC starts to consolidate. New energy has to be supplied to get the fresh SCC workable again. In the silos, used for temporarily storage of the fresh SCC, screws are installed to keep the SCC 'alive', see Fig.5.

### 3.4 Casting buckets, skips, casting machines

The casting buckets, skips, are for the same reason as mentioned previously also modified, while also the shape of the casting opening in many cases is adjusted. Casting SCC is quite different from casting normal concrete. By making a narrow casting opening, the available energy of the SCC comes free when cast. When an element is cast properly, the top surface of the concrete is may show the gravel particles floating in the SCC.

## 4 Placing, finishing and the appearance of the elements

### 4.1 Placing SCC

The implementation of SCC in the factories was a stepwise process; the implementation was executed per type of element. The workers were intensively coached by the concrete technologist and the quality manager. The casting technique of SCC had to be learned again.

Layers of cast concrete will start to consolidate. In case one waits too long, the second layer will not be combined with the first one. Using



Figure 6a:  
Casting on ease



Figure 6b:  
Casting rapidly

additional energy in the contact surface caused by lifting the kubel during casting, a joint is avoidable. Generally spoken, the casting speed will increase, see Fig. 6.

#### 4.2 Finishing concrete

For finishing SCC after casting, practical methods have been developed. After waiting a period of time and sprinkling drop of water on the concrete, the surface of the element can be treated and finished, as specified by the client, see Figure 7. That period of time is depending on the type of SCC, the ambient temperature



Figure 7: Finishing the surface.

and the relative humidity in the hall. The use of a rake to level the SCC is almost indispensable. All finishing techniques for hardened concrete are possible, even polishing, see Figure 7.

#### 4.3 The appearance

The visual quality of the element is generally beyond any expectation. The colour of SCC produced with limestone filler or quartz powder is equal and light grey, with a tendency to white, and is very appreciated by the clients and by architects. Even coloured SCC, based on white

cement and pigments, is widely produced. Due to the tightness of the joints and connections of the mould sides, the corners are sharp, as shown on the next images.

### 5 Results

In the next summary the positive aspects are listed:

- Working conditions are improved tremendously and will reduce the absence
- The coaching of the workers increases their involvement
- Moulds will wear less, complicated shapes are possible now
- Labour consumption is decreased
- No vibrators anymore necessary, savings > € 70.000 annually
- The visual quality is improved, the number of repairs reduced
- The better appearance is highly appreciated by the client
- Many applications and erections are finished successfully

The negative aspects are:

- The long term investments in equipment and installation
- The material costs increase
- More attention for material deliveries
- Increased efforts to maintain the quality of fresh SCC
- Training and coaching of the workers is required
- A high visual quality is demanded even when hardly necessary

Figure 8: Appearance SCC



## 6 Conclusion

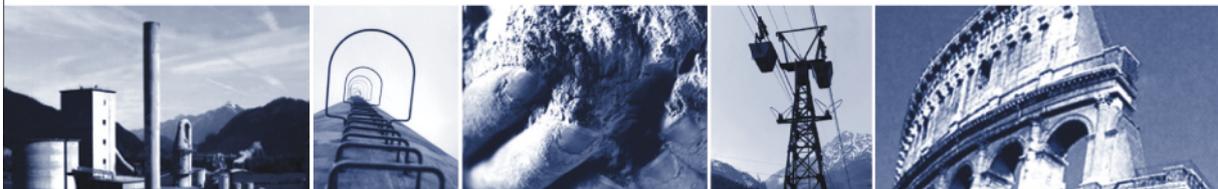
- SCC is the best innovation in the Dutch precast industry since many years.
- The collective development of BELTON members has improved the image of the precast concrete industry and also the contacts between the people involved in the process.
- The improved working conditions make it possible to interest young and skilled workers.
- Producing elements in SCC is cost effective and beneficial for both the precast concrete manufacturer and for the client.

## References

- [1] Guidelines and specification for Self-Compacting Concrete. 1st -Draft April 2006. Published by ERMCO, EFCA, BIBM and EFNARC
- [2] Ernst, R.: TUE / BELTON VAB-VBB report volume 1 and 2. Master thesis. Eindhoven University of Technology, November 1999.
- [3] Takada, K. Influence of admixtures and mixing efficiency on the properties of self compacting concrete. Sub title: The birth of self compacting concrete in the Netherlands. Doctor Thesis at Delft University of Technology. May 2004. ISBN 90-407-2501-2



Zement · Kalk · Gips · Spezialbindemittel · Spezialbaustoffe · Anwendungstechnik



**SCC-Spezialbindemittel ViscoCem**

**Hochleistungsbeton ViscoFill:**

- Höchste Endfestigkeiten
- Minimales Schwinden
- Hervorragendes Fließen

**mineralisch kreativ**

Schretter & Cie  
 A-6682 Vils · Tirol  
 Tel.: +43 (0)5677/8401 · 0  
 Fax: +43 (0)5677/8401 · 222  
 office@schretter-vils.co.at · www.schretter-vils.co.at