Casting of Self Compacting Concrete

Final report of
RILEM Technical Committee 188-CSC:
Casting of Self Compacting Concrete

Edited by Å. Skarendahl and Peter Billberg
Casting of Self Compacting Concrete
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- prepare technical recommendations for testing methods,
- prepare state-of-the-art reports to identify further research needs,
- collaborate with national or international associations in realising these objectives.

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FINAL REPORT OF RILEM TC 188-CSC – CASTING OF SELF COMPACTING CONCRETE

Contents

1. INTRODUCTION ..............................................................................................................1

2. SCC – A BREAKTHROUGH CHANGE IN THE CONCRETE PRODUCTION PROCESS ..................................................................................................................2

3. REQUIREMENTS ON FRESH SCC .................................................................................3

4. MECHANISM OF CHANGE .................................................................................................5

5. KEY CONSTITUENTS AND THEIR HANDLING .................................................................7

   5.1 Key constituents .........................................................................................................7

   5.2 Handling of constituent materials ...........................................................................7

   5.3 Sensitivity to variations .........................................................................................8

   5.4 Recycled water .......................................................................................................10

   5.5 Overall recommendation ..................................................................................10

6. MIX DESIGN ..................................................................................................................10

7. MIXING AND TRANSPORT ..........................................................................................11

   7.1 Mixing Technique ...................................................................................................11

   7.2 Mixer types ...........................................................................................................11

   7.3 Ready Mix Plants .................................................................................................12

   7.4 Transportation ......................................................................................................12

8. QUALITY ASSURANCE .................................................................................................13
9. FORMWORK DESIGN AND PERFORMANCE ............................................... 14
  9.1 Formwork design to loads ........................................................................ 14
  9.2 Concrete surface quality ........................................................................... 15

10. CASTING ................................................................................................. 18
  10.1 Planning ................................................................................................... 18
  10.2 Filling of formwork .................................................................................. 18
  10.3 Finishing .................................................................................................. 20
  10.4 Curing ....................................................................................................... 20
  10.5 Working environment .............................................................................. 21

11. INDUSTRIAL PRODUCTION .................................................................... 22

12. CONCLUSIONS ....................................................................................... 23

13. REFERENCE LITERATURE CONNECTED TO RILEM WORK .............. 25
FINAL REPORT OF RILEM TC 188-CSC – CASTING OF SELF COMPACTING CONCRETE

Abstract

Increased productivity and improved working environment have had high priority in the development of concrete construction over the last decade. Development of a material not needing vibration for compaction - i.e. self-compacting concrete, SCC – has successfully met the challenge and is now increasingly being used in routine practice.

The key to the improvement of fresh concrete performance has been nanoscale tailoring of molecules for surface active admixtures, as well as improved understanding of particle packing and of the role of mineral surfaces in cementitious matrixes. Fundamental studies of rheological behaviour of cementitious particle suspensions were soon expanded to extensive innovation programs incorporating applied research, site experiments, instrumented full scale applications, supporting technology, standards and guides, information efforts as well as training programs.

The major impact of the introduction of self-compacting concrete is connected to the production process. The choice and handling of constituents are modified as well as mix design, batching, mixing and transporting. The productivity is drastically improved through elimination of vibration compaction and process reorganisation. The working environment is significantly enhanced through avoidance of vibration induced damages, reduced noise and improved safety. Additionally, the technology is improving performance in terms of hardened material properties like surface quality, strength and durability.

1. INTRODUCTION

The emerging development of self-compacting concrete (SCC) in the middle of the 1990’s was observed in RILEM Technical Committee discussions on workability of fresh concrete. This discussion within that broad international forum rapidly led to the establishment in 1996 of a RILEM Technical Committee especially devoted to SCC. Members from ten countries covering four continents joined the work. Japanese ideas, research and early applications became an important starting point. The committee (TC 174-SCC) organized the first International RILEM symposium held in Stockholm in 1999 with approximately 70 papers from 13 countries [1]. 20 of the papers described applications which show the rapid uptake of the research findings in the building industry. The technical committee (TC 174 SCC) concluded its work through producing a state-of-the-art report [2].

Based on the potential of the technology to give a breakthrough change in the production process of concrete, a second RILEM SCC committee was established in 2001, named TC 188-CSC (Casting of SCC). In 2001 the second international
symposium on SCC was held in Tokyo, hosted by Tokyo University, with 74 papers presented from 20 countries [3]. It was generally agreed that the rapid development of SCC worldwide required a schedule for international symposia every second year and the third International RILEM symposium was arranged in Reykjavik, Iceland in 2003 with the involvement of TC 188-CSC. At the Reykjavik symposium 108 papers from 26 countries were presented [4].

In addition to the series of International RILEM Symposia, many regional and national meetings have been organised. In 2002 the first North-American Conference was held in Chicago (in North America SCC stands for Self Consolidating Concrete) In May 2005, the first Chinese International Symposium on SCC was arranged in Changsha, China [5] co-sponsored by RILEM.

The fourth International RILEM Symposium on SCC, combined with the second North-American Conference on SCC, was held in Chicago in late October 2005 [6] with 140 papers presented by participants from 38 countries. The fifth International RILEM Symposium on SCC will be held in Ghent, Belgium, in September 2007.

The present report is discussing the various aspects on the concrete production process from the handling of raw materials up to finishing after casting. The report is based on the experience of the committee members and reflects the vast literature now present in proceedings and journal papers. Due to the substantial amount of papers published on the subject over the last years, the committee decided not to give specific references in the report but rather encourage the readers to search on the web for literature following the specific aspects of their interest.

RILEM Technical Committee work on the SCC technology is continued covering rheology aspects (TC RFC) as well as durability aspects (TC 205-DSC)

2. SCC – A BREAKTHROUGH CHANGE IN THE CONCRETE PRODUCTION PROCESS

The technique of casting fresh concrete has remained basically unchanged over decades. Transport equipment and compaction tools have gradually facilitated the process and admixtures have made it possible to use concrete requiring less compaction effort. However, the basic procedure of casting by using vibration energy to compact (consolidate) fresh concrete has remained the same. The need for a breakthrough improvement has been obvious from the point of view of productivity increase as well as for the improvement of the working environment.

The introduction of SCC has radically changed the way a formwork is filled. SCC is a particle suspension with an extreme great span in particle sizes (like vibrated concrete) from micrometer sized fines to aggregate in the centimetre range. The development has been made possible through application of nanotechnology in the tailoring of surface active molecules used in chemical admixtures. The introduction of new developments of superplasticizers and viscosity modifying admixtures (VMA) leads to systems with controllable higher fluidity and moderate viscosity in the fresh state and with high density in the hardened state. The understanding of the behaviour of mineral surfaces of
constituent inorganic particles has also been important and has applied knowledge on particle packing leading to an elaborated use of fillers.

The concrete construction process is changed resulting in an improved productivity and a possible automation. This leads to new modes of organising workplaces and business. At the same time the development gives distinct working environment advantages. However the full potential of using the technology will be achieved only through evaluating and optimizing the whole production process.

SCC is an innovation in the sense that it is now successful on its own merits on competitive markets. In precasting there are numerous examples of factories having fully converted to the use of SCC. The lead time for the development has been very short by construction sector standards. The development is however still in its infancy and many interesting challenges are lying ahead for both research and business. Important for a rapid and wide spread of the technology is that much of the knowledge generated is in the open domain and that necessary constituents and machinery can be accessed on competitive conditions from several suppliers. SCC is now used in large quantities in many countries around the world and a strong future growth can be forecast.

3. REQUIREMENTS ON FRESH SCC

The functional requirements on a fresh SCC are different from those on a vibrated fresh concrete. Filling of formwork with a liquid suspension requires workability performance which is recommended to be described as follows:

- Filling ability Complete filling of formwork and encapsulation of reinforcement and inserts. Substantial horizontal and
vertical flow of the concrete within the formwork with maintained homogeneity.

- **Passing ability**
  Passing of obstacles such as narrow sections of the formwork, closely spaced reinforcement etc. without blocking caused by interlocking of aggregate particles.

- **Resistance to segregation**
  Maintaining of homogeneity throughout mixing and during transportation and casting. The dynamic stability refers to the resistance to segregation during placement. The static stability refers to resistance to bleeding, segregation and surface settlement after casting.

Additional criteria on fresh concrete, both SCC and vibrated concrete, can be described as follows. Characteristics for SCC are commented:

- **Open time**
  Has to be closely following specified time. New generations of admixtures offer increased possibilities of setting a specified target open time, e.g. very short for precast applications and very long for in-situ castings with long transports.

- **Precision and accuracy**
  More essential to keep target workability for SCC as the casting is fully relying on the material properties as no tools normally will be available for manual material transport and compaction.

- **Pumping ability**
  SCC is generally easier to pump. Depending on the specific rheological properties of the fresh concrete the pumping pressure versus the feeding rate has to be optimized.

- **Finishing ability**
  SCC normally has less bleeding tendency. In many cases the finishing will be made on a coarser and stickier
surface. Appropriate materials on the finishing tools are thus to be recommended.

- **Working environment**
  - Drastic improvement when using SCC. Reduction of noise level and avoidance of blood circulation disturbance (white fingers) induced by handheld vibrators. Improved safety through more mechanisation and remote control. Substantial reduction of hazardous objects, e.g. elevated platforms, electrical cables, vibrators.

- **Hardened concrete**
  - The fresh concrete has to be composed to meet the target performance during hardening and in the hardened state. SCC has shown to give improved microstructural features leading to potential improvements of strength, durability and surface quality.

- **Cost**
  - Increased cost for additional constituents, improved knowledge of workforce and improved quality assurance. The higher material cost is overrun by reduced cost for casting as well as improved performance – as has been shown on competitive markets!

### 4. MECHANISM OF CHANGE

To simply increase the water content in a mix to achieve a SCC is obviously not a viable option. Instead, the challenge is to increase the flowability of the particle suspension (the fresh concrete) and at the same time avoid segregation of the phases. The main mechanisms controlling the balance between higher flowability and stability are related to surface chemistry. The development of SCC has thus been strongly dependent on surface active admixtures as well as on the increased specific surface area obtained through the used fillers. Evaluation of these mechanisms requires studies of the rheological behaviour.

The performance parameters of the fresh concrete being most vital in material design are the following:

- yield stress
- viscosity
- thixotropy
- dispersion
- water retention

In addition to these surface chemistry-related properties the physical property of particle packing is also central.
To be able to understand, modify and characterise the material behaviour it is necessary to work on a molecular scale which implies studies on material nanostructures as well as microstructures. Fillers as well as chemical admixtures are decisive for the behaviour of the fresh concrete and consequently the research on SCC has been focused on these materials.

The interest for SCC has thus strongly increased the interest for rheology evaluation of fresh concrete. Rheology is increasingly used in mapping of mechanisms, in optimisation of constituent materials, in understanding the relation between thixotropy and formwork pressure, in fluid mechanics approaches used in modelling of flow etc. Rheological evaluation is not only used by research laboratories but also by laboratories of frontline suppliers of admixtures, fillers, cement and concrete. This technique is still primarily used for research and development and not yet in any significant way as a tool in quality assurance procedures. An extension into this area is requiring further test method development.

In material design in practice, as well as in quality assurance and acceptance control, fresh concrete behaviour is most often evaluated through method specific workability test methods, e.g. slump flow, L-box, J-ring, U-box, V-funnel.

Fig 3 - Viscometer used for determining rheological material data and workability testing in practice (Courtesy of M. Sonebi).
5. KEY CONSTITUENTS AND THEIR HANDLING

5.1 Key constituents

The key to enable a concrete to be self-compacting, i.e., extremely flowable and at the same time homogeneous, lays within the properties of the constituents in general and in the micro- and nanoscale behaviour in particular. In the micro-nano metre size range, colloidal forces and surface chemistry are dominating. Most colloidal particles in concrete, i.e., cement, fillers and the smallest aggregate particles, flocculate to different degrees spontaneously when immersed into the mixing water. Thus, they have to be dispersed to free entrapped water and to break the solid structure to enable the suspension to flow, i.e., reducing the yield stress as described by the Bingham model. Normally this pronounced dispersion obtained through addition of superplasticizers results in so much released mixing water that the suspension becomes unstable and segregates. Therefore, instead of decreasing W/C, either additional filler material or a viscosity modifying admixture (VMA) is added to bind the surplus water and prevent segregation. Thus, the most important mechanisms related to SCC fresh properties are dispersion of flocculated particles and wetting/binding of water.

The most common superplasticizers used for SCC belong to the third generation of dispersing surfactants. These are specially designed to meet different demands from different fields of concrete production, e.g., precast elements and ready mixed concrete. Both the first and the second generations of superplasticizers are to different degrees made from by-products (e.g., lignin, melamine and naphthalene) while the present, third generation is often based on polycarboxylate ether (PCE). The latter type is developed by the chemical industry using the recent tools in nanotechnology.

Fillers are primarily used to bind excess water and to gain sufficient stability and viscosity but also to increase the volume of the continuous phase which in some cases is the key to gain passing ability.

Today, many types of VMA’s are produced in liquid form and mostly consist of different types of polymers.

5.2 Handling of constituent materials

One of the most important advantages of SCC is that it can be successfully made using cement and aggregates used to produce other types of concrete. Materials for SCC can be stored in the same manner as they would be for production of vibrated concrete; in ground bins, plant overhead bins, silos, bags, and tanks for liquid admixtures, although consistency of raw materials needs to be controlled more frequently. It is recommended to apply the best practices on the maintenance of stockpiles of materials, i.e. moisture contents, free drainage, cleanliness, and prevention of segregation. In this instance overhead bins may suit better, but the limited number of overhead bins at the most ready-mix plants may affect the flexibility of the plant operation.
In addition, concrete plants need to be able to store various filler materials and therefore needs additional silo capacity. Concrete ready-mix plants have a set of high-volume tanks for liquid admixtures to produce vibrated concrete. Since SCC always is produced by using superplasticizers and sometimes also VMA, it might be required to install extra storage tanks and dispersing systems. At this point of time no combined admixture, i.e. SP and VMA, is recommended mainly because of the different dosage rate requirements of each admixture to achieve different properties of SCC.

5.3 Sensitivity to variations

During production SCC is more sensitive to fluctuations in the total water content than vibrated concrete. Fluctuations in raw material gradations and moisture contents can have dramatic influence on the stability and fluidity of the concrete mix. The total water content consists of mixing water and water from the surface moisture of aggregates. Thus, the surface moisture of aggregates is of a greatest concern in production of SCC. Moisture contents of fine aggregates normally are greater than those of coarse aggregates. There are at least two methods of measuring moisture parameters of aggregates, which can be successfully applied for production of SCC.
- moisture probes (sensors)
- manual drying tests.

Both methods have some advantages as well as disadvantages. Moisture probes can offer real-time result, although accuracy of the results may depend on the position of the probe in the production chain. However, the maintenance cost can be high and there is still a lack of comprehensive investigations of the performance of on-line moisture probes. Manual drying tests are very accurate, simple and reliable but these tests take time and consume labour and cannot offer real time results. Information obtained from these methods should be used to adjust the amount of mix water required by the mix design.

![Image: Fig 5 - Moisture sensor for continuous measurement of sand moisture in the batching process (Courtesy of Franz Ludwig GmbH, Germany).]

SCC is much more sensitive to significant deviations of material quantities. A concrete mixing plant with the sound history of producing concretes of consistent quality is able to successfully produce high quality SCC. Normal weighing tolerances regulated by national and international standards are in general acceptable for production of SCC. It should be noted, though, that larger load sizes of concrete lead to better consistency, so it would be recommended to avoid whenever possible batching of small loads of SCC. Accuracy of weighing equipment may affect the consistency of SCC and eventually on the cost to produce SCC, so the more accurate equipment will eventually produce more economical SCC.

Batching equipment should be regularly checked for the accuracy. A special attention should be paid to the accuracy of liquid admixture dispensing/dosing equipment. Depending on the type of dosing equipment and its set-up (e.g. pulse meters, weighing, length of the pipe lines, free fall distance, etc), accuracy may vary substantially. Hence
equipment accuracy check and verification should be carried out more frequently. In countries with high seasonal temperature variations, viscosity of liquid admixtures may vary, which could influence on the accuracy of dosing of those admixtures.

5.4 Recycled water

Some measures to control quality and quantity of recycled water used in production of SCC should be taken into account. Solids from the slurry, as an extra source of ultra fine particles, can be beneficial for SCC, but the amount of solids in the slurry must be known and maintained constant. In such a case, the SCC mix design should be adjusted accordingly. Chemistry and age of recycled water and slurry may effect on the SCC workability life. Considering importance of potential influence of recycled water on fresh and hardened properties of SCC it would be wise to use a sample of such water when SCC laboratory development and full scale trials are conducted.

5.5 Overall recommendation

It should be emphasised that SCC can be successfully produced in a consistent and continuous way only at a properly equipped concrete mixing plant under an established and reliable quality assurance system. Experience shows that SCC does not forgive any short cuts.

6. MIX DESIGN

It is important to stress the fact that SCC is not a special category of concrete but instead a big family of different mixes having the least common property of self-compactability in the fresh state. Thus, any vibrated concrete used today aiming for certain properties such as; strength, durability, self desiccation etc. can be transformed to be self compacting. It has also been proven that SCC can be produced with local materials even though different actions regarding mix design must be taken.

Many different approaches have been made around the world to create a mix design model for SCC. Even though they differ in some respects many of them are based on the concept of SCC being a particle suspension. The coarse aggregate is regarded as the solid phase suspended in the continuous phase micro- or fine mortar. As already discussed in section 4, the basic mechanisms behind SCC can be found in this continuous phase where all water, fine particles and admixtures are included.

If the basis for the SCC is a vibrated concrete mix design, optimisation often means to minimise the difference from the original. That is, finding the most cost-efficient type of filler material and the minimum amount necessary. This minimum amount will depend on the packing density of the coarse aggregate, on the characteristics of the cement and the fine aggregate. It must however always be investigated how the mix behaves during hydration and in the hardened state. In addition it is equally important to find the optimal combination of chemical admixtures, filler and cement.
Fibre reinforced concretes have proven to be possible to become self compacting. To achieve required filling ability when fibres are used shifting in amount of coarse to finer aggregate is necessary. There is also a threshold value of fibre amount depending on fibre characteristics and mix design respectively. Another important property is the passing ability which must be secured in appropriate applications.

Regardless of what mix design approach is utilised, the SCC properties shall be verified.

7. MIXING AND TRANSPORT

7.1 Mixing Technique

For production of SCC, as is the case for vibrated concrete, the loading- and mixing sequences are very important. It is even more important for SCC as it contains a very high amount of fine particles needed to be efficiently dispersed in an optimal way. Suitable loading- and mixing sequences is to be determined for each plant individually by conducting some batching experiments. SCC normally requires a more efficient mixing, e.g. longer mixing time, to make sure that all constituents have been mixed thoroughly. However, shorter mixing times are possible for the production of quality assured SCC by changing the mixing speeds in concrete mixers. Thus, economically favourable mixing times are also possible for the production of SCC with appropriate changes to the concrete mixer.

Admixture manufacturers recommend that superplasticizer should be diluted in water before added to the concrete. This permits a better distribution of relatively small quantity of admixtures within the mass of SCC. Practice in general confirms this.

Most stationary mixers have a steady mixing speed, while truck mixers have a variable speed. When mixing SCC in a truck mixer, it should be at ‘mixing’ speed, which is normally between 15 and 25 rpm.

For better consistency, the volume of the SCC mix should be as near to the maximum mixer capacity as possible. Mixer shall be clean but not dry. Mixing vibrated concrete before mixing SCC may create some inconsistency in properties of SCC, especially if some incompatible admixtures such as superplasticizers were used before mixing SCC. In such situation one should ensure that the mixer is clean before loading. From the practicality point of view, in order to prevent any potential hold-ups associated with production of SCC, daily production program should be carefully scheduled to make sure that only compatible admixtures are used in between SCC loads.

7.2 Mixer types

Force type of mixers can normally be regarded as more efficient in mixing SCC than gravity mixers. Some studies indicate that larger mixers are more efficient than smaller, which in general means that longer mixing time may be required for “smaller” mixers.
7.3 Ready Mix Plants

SCC can be successfully manufactured by a concrete mixing plant of any configuration and batched either automatically or manually as long as it is able to produce different types of concretes with consistent properties and has a proven reliable history of doing so. It should be noted though, that if SCC is mixed in a truck mixer, quality and consistency of SCC might vary from truck to truck depending on the mixer configuration, mixing speed and the condition of the mixer of different trucks. In no way SCC should be mixed in a truck agitator.

![Fig 6 - Both factory mixing and truck mixing is viable for SCC (Courtesy of M. Khrapko)](image)

7.4 Transportation

SCC can be delivered either by truck mixer or truck agitator. The mixing/agitating bowl should be free from remains of the previously delivered concrete and remains of wash-out water, and it should not be dry. Truck mixers should be distinguished from truck agitators. In simple words, truck mixers are able to adequately produce, deliver, and discharge concrete while truck agitators can not adequately produce concrete. Often
properties of SCC need to be adjusted on the job site and for some SCC producers this is a part of production/delivery process. At such circumstances truck agitators shall not be used. Great care should be taken if SCC is to be delivered by tip trucks due to the risk of static segregation.

The limitations to the delivery load size would be only dictated by the road conditions, i.e. driving uphill. SCC can be safely transported over the reasonably hilly roads if the load size of SCC is not exceeding 80% of the full capacity.

8. QUALITY ASSURANCE

As SCC is designed to fill formwork and encapsulate reinforcement without any manual intervention it is important to keep these properties over the time needed for the process. As some of the requirements have to be judged qualitatively an experienced person has to be responsible for the quality assurance following the requirements (see section 3).

Several methods are proposed as quality assurance tools for SCC. Most such methods are workability related, e.g. slump flow including T500, V-funnel, L-box, sieve stability test and J-ring which all have been selected for European standardisation. Also more complex methods to evaluate “self-compactability” have been proposed. Measurement of rheological parameters as a quality assurance tool is seldom used as the rheometers generally are not suited for in situ routine testing. Observations on separation, bubbles on the surface, stickiness etc should be made by an experienced person.

The sampling of fresh concrete for testing is sensitive as well as time and labour consuming. To counteract this, an “all acceptance test” has been proposed. A devise placed in the discharge flow ahead of casting and all concrete is passing this devise. Concrete not fulfilling the criteria given are automatically rejected. Also measurement tools for registration of workability parameters or rheological material data automatically in the transport trucks or pumps are likely to appear in the future.

Especially at the beginning of a casting, large fluctuations of workability might occur. This is often caused by the starting up of mixers, trucks, pumps etc and normally levels out over time. It is thus important to have tighter quality schemes in the start up phase of castings. The site quality control plan has to take account of unpredictable variations in workability, for example slump flow values. If there are any uncertainties with regard to the delivered concrete, sampling of every batch or truckload is recommended. This should be done until the stability and constant quality of the delivered concrete has been ensured.