

Maintaining required workability of SCC in time

Workability consistency is the most important QC parameter as far as concrete construction is concerned. Workability retention plays critical role in maintaining required consistency. Concrete loses workability due to two main mechanisms: (a) plastic stiffness caused by water loss in the mix because of evaporation and early cement hydration – gradual workability loss that can be partially reinstated, and (b) structural build up, or thixotropy – temporary workability loss that can be reversed. The degree of workability loss depends on many factors. Particle size distribution and their packing, cement chemistry, ambient conditions, time – to list some. Maintaining required workability of self-compacting concrete (SCC) is far more important than of conventional vibrated concrete (CVC), as the quality of finished concrete structures made of SCC nearly entirely depends on the plastic properties of SCC. If neglected, it can cause surface defects, and durability and structural failures of concrete structures.

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Introduction

Concrete is a complex composite material largely consisting of aggregate and cement paste. The cement paste coats the aggregate particles and fills the space between them. Cement paste also provides the “lubricant” which reduces the friction between the aggregate particles and imparts workability to the fresh mix [1]. Aggregates are dispersed in cement paste. The paste is a suspension of cement particles in water and it maintains the particles of the aggregate in dispersion generated during mixing and enables the particles to move and re-arrange their original spacing. Hence fresh concrete is a suspension. Fresh concrete has also been defined as a material that intermediates between a fluid and a humid packing of particles [2].

Developments in concrete technology, especially the introduction of wide varieties of chemical admixtures, mineral additives and cementitious supplementary materials, have increased the importance of fresh concrete properties. These developments have also permitted production of very workable and self-compacting concretes. Such concrete mixes are more expensive, but the extra cost of the additional ingredients is often far exceeds by savings in the cost of the concrete construction process.

Workability of concrete is a complex, general term which cannot be neither simply defined nor can it be measured in its entirety by any one single method [1]. Workability characteristics of self-compacting concrete (SCC) are vital in achieving good quality concrete structures. Maintaining required fresh SCC properties for the specific time is the task that requires knowledge and experience. Because SCC at fresh state is very different to conventional vibrated concrete (CVC) and also due to the fact that fresh properties of SCC depend on a great number of influencing factors, the practices to control workability of SCC in time would differ accordingly. Due to the complexity, mainly because concrete has a very wide spread in particle sizes and has time dependent characteristics, the basic properties influencing the performance in casting and compaction of fresh concrete in general and SCC in particular are the best described by the science of rheology. Behaviour of fresh concrete from rheological point of view deals with new characteristics such as yield stress, plastic viscosity and thixotropy. And these characteristics are the ones that change with time and are the ones that have to be maintained.

Workability and rheology of Self-Compacting Concrete (SCC)

In workability terms, self-compactability means the ability of concrete to flow after being discharged from a delivery truck, from a pump hose, a skip or similar only by means of gravity and to fill intended space in the formwork to achieve a zero-defect and uniform quality concrete [3]. Fresh SCC properties have been well defined and studied. There are three key properties of SCC:

- Filling ability
- Passing ability
- Resistance to segregation (static and dynamic stability)

SCC must be able to easily deform to change its shape very quickly under its own weight only. The meaning of filling ability includes the distance SCC can flow and the speed it flows. In cases where there are narrow openings in the formwork or where the reinforcement is congested, a blockage of coarse aggregate through bridging should be avoided. This is related to passing ability of self-

compacting concrete. In order to achieve sound filling ability a good balance between the deformability capacity and the deformation velocity of SCC should be found. Deformation capacity of SCC is usually evaluated as the final flow diameter on a slump flow test board and closely related to the yield stress. Deformation velocity can be evaluated by the timing of SCC spreading to 500 mm diameter on slump flow boards (T_{500}), or by the timing SCC drains from V-Funnel and closely related to the plastic viscosity.

Since fresh SCC properties bear much higher importance than those of conventional concrete and, as discussed above, workability term is very wide and greatly undefined, the conventional approach to workability assessment is no longer applicable to SCC. This is not only the test methods that are no longer provide necessary vital information of the fresh concrete properties, but also lack of such information. Test data obtained from conventional test methods, like slump (or slump flow) and bleeding tests, do not explain the very specific behavior of SCC, namely degree of deformation and stability (resistance to segregation). Rheological approach to assessment of fresh concrete behaviour is a much greater tool for understanding of fresh SCC properties and to control its behaviour. The main differences between conventional (vibrated) concrete and SCC in rheological terms are that SCC has much lower yield stress (approaching Newtonian fluid with yield stress = 0) and usually higher plastic viscosity (Fig. 1).

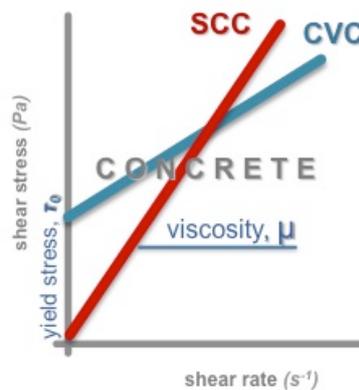


Fig.1 CVC and SCC in rheological terms

The combination of the two main rheological parameters, that is yield stress and plastic viscosity covers a huge spectrum of different types of SCC. Viscosity on its own plays significant role in fresh SCC. Plastic viscosity of SCC linked to:

- Speed of flow (speed of construction);
- Pumpability and pump pressure
- Static and dynamic stability of SCC
- Thixotropy
- Form pressure

True rheological properties are measured by rheometers or viscometers, but there is rather strong correlation between true rheological properties and workability parameters assessed by relatively simple test methods. For example slump flow (or slump) is closely related to yield stress, as speed of flow evaluated by either time SCC spreads to 500 mm diameter or goes through the V-Funnel is related to plastic viscosity.

All the above is valid for fresh SCC properties evaluated at any given time. But these properties change as time passes by between SCC mixing and placement. Fresh SCC properties evaluated at the concrete batch plant, as initial QC check, may substantially vary from those assessed at the job site. This means that SCC has an open window, within which SCC can be safely poured into the mould. The open window is different for different concretes and can vary due to changes in the ambient conditions. Usually any concrete, including SCC, loses workability with time, although it's not an exception when concrete gains workability with time.

Why Concrete Loses Workability?

Freshly made concrete stiffens with time (this not to be confused with setting). This is because some water from concrete mix is lost by evaporation, especially if concrete is exposed to sun or wind, some water is absorbed by the aggregate if they are not fully saturated, and some water is removed by the initial chemical reactions. The exact value of workability loss depends on several factors, such as:

- The higher the initial workability, the greater the loss,
- The rate of workability loss is higher in rich mixes,
- The rate of loss depends on the properties of the cement used: the rate is higher when the alkali content is high and when the sulphate content is too low [4].

Concrete workability loss is also affected by concrete temperature and batching sequence. Superplasticisers in concrete can too affect the workability retention. Superplasticisers are usually used to increase workability of concrete. But the effectiveness of superplasticisers lasts only as long as sufficient superplasticiser molecules are available to cover the exposed surface of cement particles. As some of the superplasticiser molecules become entrapped in the product of hydration of cement, the supply of superplasticiser becomes inadequate and the workability of the mix is rapidly lost.

All these factors are applicable to self-compacting concretes. However there is an interesting phenomenon that places highly deformable concretes like SCC into a very special category.

Many non-Newtonian fluids show a change in viscosity when a constant rate of share is reached and maintained. The rate of decrease of viscosity can reduce with the duration of the shearing and level off. The fluid shows a 'recovery' when the shear rate reduces and stops; the same or a different yield value can be restored, and the whole process can be repeatable. Such fluids are called thixotropic (Fig. 2) [5]

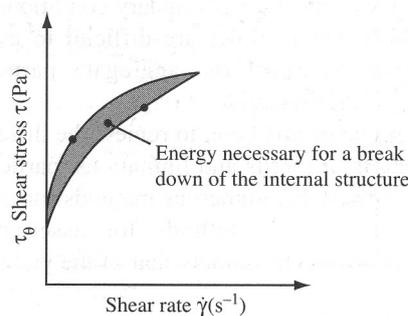


Fig.2 Non-Newtonian fluid showing thixotropic behaviour

British Standard (BS 5618:1976) defines thixotropy as a decrease of apparent viscosity under shear stress, followed by gradual recovery when the stress is removed. In simple words thixotropy is a behaviour of a suspension (concrete) when concrete loses its original flowability due to the structural build-up, but 'recovers' it when external forces, like mixing are applied, the ability of the suspension to go from one structural state to another and back again during a limited time. Mechanics of thixotropy described by the science of surface and colloid chemistry, but in principal it is an interaction between solid particles of the suspension and their tendency to pack in 'favourable' positions (structural build-up at rest). SCC is suspension and it exhibits thixotropic behaviour, but at different extends. It seems that aggregates play a significant role in developing thixotropic properties of self-compacting concretes. It has been shown [6] that different particle size distribution (PSD), particle shapes and surface textures produce different thixotropic properties. On Fig. 3 three identical SCC mix designs with three different aggregates were used. All three aggregates were originated from natural sources, so the porosity of all three aggregates did not vary significantly.

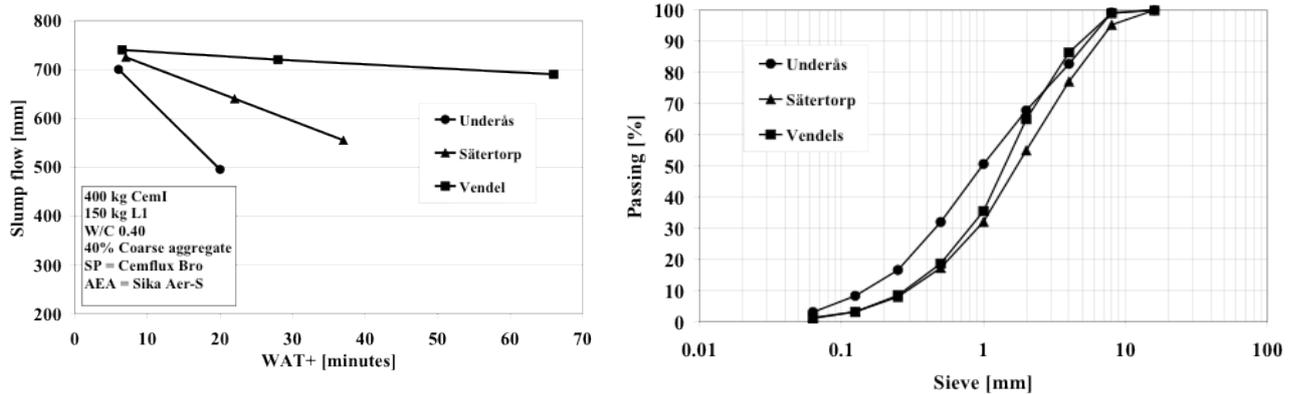


Fig.3 Slump flow loss during time of SCC with different aggregates

The temporary loss of workability of SCC due to thixotropy before it's poured to a form is not so much of a problem as the required workability can be recovered, however, premature stiffening of fresh SCC due to thixotropy before it properly fills the form can cause severe surface defects.

High deformability of SCC is achieved with the use of polycarboxylate ether (PCE) based superplasticisers. Different types of PCE deliver different open windows for SCC, as shown on Fig. 4

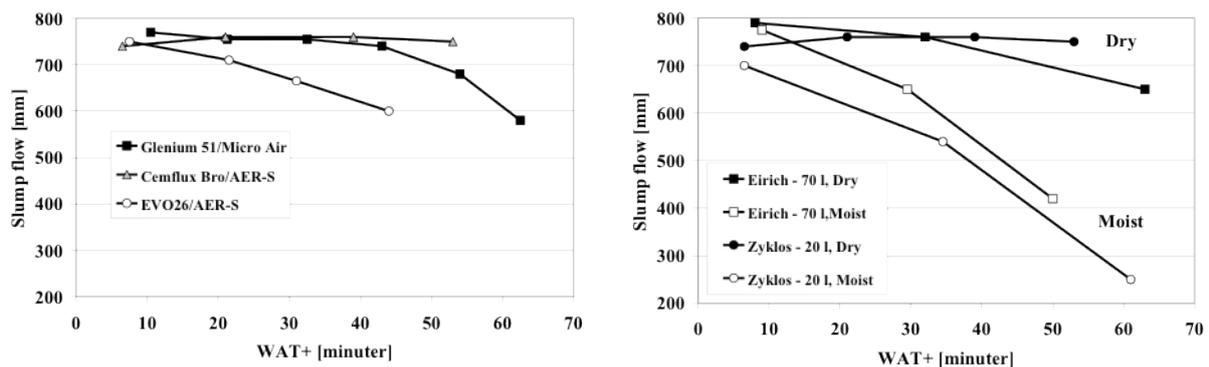


Fig. 4 Effect of different superplasticisers on SCC workability loss

In general, extend to what flowability of SCC is maintained determined by the amount of PCE superplasticiser molecules that are available for adsorption on the cement grain surfaces at any given time and those that are available for adsorption at later stage.

Maintaining required workability of SCC in time

As it was discussed above, adequate workability of SCC is essential to achieve required mechanical, properties, durability characteristics and aesthetical appearance. Adequate workability would mean the ability of SCC to maintain the fresh concrete characteristics within required and agreed boundaries for the time necessary for self-comactability of SCC. These fresh SCC characteristics' margins are usually established for each application individually between SCC supplier and SCC user (contractor).

As mentioned before, loss of water in concrete is one of the major causes of workability loss. This is due to water evaporation in time, especially in hot weather conditions and wind, absorption by dry aggregates and chemical reaction with cement. The latter is hard to control, unless cement with different chemical makeup is available. It is always recommended to compare different types of cements that are locally available, especially if cements have different alkalinity.

SCC usually requires high volume of fine material to prevent segregation. Where available and practicable, fly ash is usually used as a source of fines. In addition to extra fines, fly ash substantially increases workability retention of SCC. The dosages of fly ash are usually within 20-30% by weight of

total cementitious materials in the mix, but substitution of up to 40% and higher have been successfully used.

In order to minimize the impact of moisture loss due to aggregate absorption, moisture control of aggregates at concrete batching plant is vital. Aggregates must be at least fully saturated before batching.

Because the effectiveness of superplasticisers is limited in time, it is advantageous to add the superplasticisers to the SCC mix in two or more stages. It should be noted that workability restored by the second or subsequent dosage may decrease at a faster rate so that the re-dosage should preferably be applied immediately prior to placing of concrete. Some successful practices suggest to add about 80-90% of the previously established full dosage of superplasticiser at the concrete plant, and the balance is added on site. It should be noted here that the remainder of superplasticiser added on site could vary from the exact balance. It might be useful to establish correlation between current slump flow diameter of SCC and required superplasticiser dosage for required slump flow diameter before a full-scale application [7].

It was discussed above, that concrete loses water during the transit to the job site, which ultimately leads to the concrete workability loss. There would be two approaches of minimising the risk of a severe workability loss:

- (a) target higher slump flow at batching plant; for this the anticipated workability loss should be carefully calculated, and
- (b) compensate for the loss of water at the construction site; this is usually opposed by contractors and design engineers because of uncontrolled addition of water that historically often happens when CVC is used, which may lead to strength reduction, but SCC technology assumes that concrete supplier takes much more responsibility, including on-site quality control, hence, there should be no restriction for adding water on-site only to compensate for the loss of water and restore required workability and it should be done under tight control and supervision of SCC supplier.

If superplasticiser is to be re-dosed on site, it could be done together with water. This would save considerable time, which is very important to minimise its effect on SCC workability loss.

In conclusion it would be appropriate to say that origins of SCC workability loss are the same as they are for CVC: loss of water due to evaporation and hydration reactions, short efficiency life of superplasticisers and cement chemical makeup. However the rate of workability loss would be higher with SCC than CVC. The fresh properties of SCC are much more complex and, because of this, SCC is much more susceptible to the influence of the factors affecting its workability characteristics in time. Rheological approach to fresh SCC properties allows for much better understanding of fresh SCC behaviour and sets the basis for modelling to predict SCC flowing capabilities in time.

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