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SELF COMPACTING CONCRETE: A REVIEW

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ABSTRACT

Self-compacting, or "self-consolidating" concrete (SCC) was first developed in Japan in the early nineties. Substantial research was carried out with regard to the properties of SCC. Because of the well-controlled conditions, the introduction of SCC in the precast concrete industry was successful. With regard to the application in situ, the development is slower, because of the sensitivity of the product. In this paper the mechanical properties of SCC in comparison to conventional concrete are discussed.

INTRODUCTION

Concrete is one of our most common building materials, it consists of aggregates bonded by cement paste. The compressive strength of concrete is to a large extent dependent on the water to cement ratio (w/c). Cement is a hydraulic binder, meaning it hardens by a reaction with water to something that is not water soluble. The smallest particles of the concrete paste are in the range of micro-meters (or even nanometers), the largest particles, the aggregates, are ranging several centimeters. The types and proportions of the concrete constituents not only influence concrete's hard properties, but also its fresh properties. Concrete is the most widely consumed material in the world, after water. Placing the fresh concrete requires skilled operatives using slow, heavy, noisy, expensive, energy-consuming and often dangerous mechanical vibration to ensure adequate compaction to obtain the full strength and durability of the hardened concrete. It was against this background that self-compacting concrete (SCC), which eliminates the need for compaction, has been developed and its advantages exploited. Pioneering studies in Japan in late 1980s was followed by several spectacular uses; the technology then spread rapidly many other in countries in Asia and Europe and more recently to North America (where the alternative name self-consolidating concrete is used). In Europe, a major project carried out by a consortium of eight partners between 1997 and 2000 demonstrated that environmentally-friendly SCC could be produced and used, with benefits to the construction process, to workers, and to people living near construction sites. With the advent of Self-Compacting Concrete (SCC) that flows freely, under the sole influence of gravity, the wish for hassle-free and predictable castings even in complex cases, spurged the simulation of concrete flow as a means to model and predict concrete workability.

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To achieve complete and reliable form filling with smooth surfaces of the concrete, the reinforced formwork geometry must be compatible with the rheology of the fresh SCC. Predicting flow behaviour in the formwork and linking the required rheological parameters to flow tests performed on the site will ensure an optimization of the casting process. The variable conditions at the construction site, the more complicated control of the mixture composition and disagreement with regard to the question how the properties should be measured at the site were retarding factors. In spite of a number of successful examples, some problems due to unsuitable use of SCC generated further scepticism. Hence, the major task now is to develop SCC mixtures, which are less sensitive to deviations in properties of the components and external conditions.

The Japanese way of composing the optimum mixture composition of SCC consists of a number of steps. At first, in a small test, the optimum ratio water to powder is determined. Then a number of general criteria have to be met, the most important of which are that the coarse aggregate volume should be 50% of the solid volume of the concrete without air, and that the fine aggregate volume should be 40% of the mortar volume, where particles finer than 0.09mm are not considered as aggregate, but as powder. If the composition of the mixture, obtained in this way, is mathematically analyzed, it is found that this procedure leads to a concrete composition with a little bit of "excess paste". That means that slightly more paste is in the mixture than necessary to fill all the holes between the particles: this implies that around any particle a very thin "lubricating" layer exists, by virtue of which the friction between the particles in the fluid mixture is greatly reduced in comparison to conventional mixtures.

Review Works

The use of concrete or cementations materials as building material is very old. In ancient Egypt, mostly calcined impure gypsum was applied, whereas the Greeks and the Romans preferred calcined limestone. The oldest evidence of concrete is a concrete floor found in actually dating back to the Galilee in Israel 7000 B.C. The strength of the material has been tested to exceed 30 MPa, its microstructure is rather dense and it was apparently manufactured from hydrated lime. Later, sand and crushed stone, bricks or tiles were added. Since lime mortar does not harden under water, the Romans mixed powdered lime and volcanic ash and finely ground burnt clay tiles. Silica and alumina in the tiles and the ash combined with the lime resulted in a binder that became known as pozzolanic cement. Its name comes from the village Pozzuoli near Vesuvius, where the volcanic ash was first found. The optimum thickness of those layers lies between narrow limits. If the thickness is too small, there is too much friction to achieve self compactability.

If the thickness is too large, the coarse aggregate sink down and segregation occurs. The rheologic properties of the excess paste layers are determined by the choice of the super plasticizer. Furthermore, in the fresh state around the cement and powder particles thin layers of water are formed (Midorikawa *et al.*, 1997). In this way a three phase system (coarse particles, fine particles and powder) with intermediate layers of paste and water is obtained which minimize the internal friction in the fresh state. Midorikawa (Midorikawa *et al.*, 2001) carried out tests in order to find the optimum thickness of the excess paste layer. Fig. 2 shows the optimum thickness of the layer for a varying ratio V_w/V_p (volume of water to volume of powder) for different grading curves. It is seen, that the thickness of the paste layer, for which the concrete is still self- compacting, increases with decreasing volume of water. Fig. 1 shows excess paste layer around aggregate particles. An important question is, to which extent the lubricant layer influences the properties of the concrete in the hardened stage. It seems to be obvious, that for instance the modulus of elasticity of SCC is smaller than that of a conventional concrete of the same strength, as a results of the effect of the relatively soft lubricant layers. An evaluation by Holschemacher (Holschemacher, 2001) showed, that the E-modulus of an SCC is indeed somewhat smaller. It should, however, not be forgotten, that also the E-moduli of normal concretes are subjected to scatter, most of all in dependence of the stiffness of the aggregate used. For practical applications it can therefore be assumed, that the E-modulus of self-compacting concrete is not outside of the region of scatter of conventional concretes. Of course it makes sense to carry out suitability tests in the case of special applications, such as for structures in high speed railway lines. In that case, however, also the creep- and shrinkage properties should be carefully investigated. Another important aspect for the behavior in the hardened state is the concrete tensile strength. When the axial tensile strength of a SCC would substantially differ from that of the tensile strength of conventional concrete, this should have large implications for design, since the tensile strength is a governing aspect in the design for shear, punching, anchorage, crack width control and the minimum reinforcement. It is obvious to expect that the tensile strength of SCC is higher than for a conventional concrete, because of the more homogeneous interface between the aggregate particles and the cement past (no direct contact between the aggregate particles). An evaluation of test results (Holschemacher, 2001) confirms this. However, also here the results are in the range of scatter of conventional concretes, so that no complicating exception for SCC has to be made.

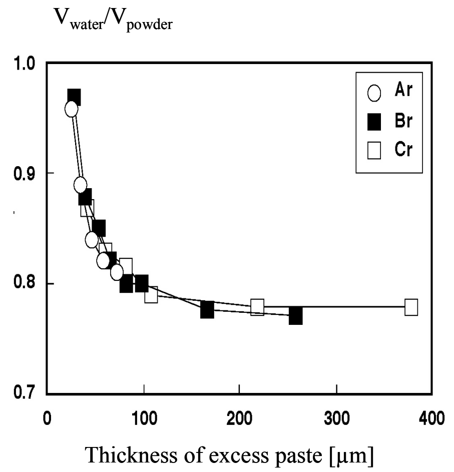

Fig. 1. Excess paste layers around aggregate particles

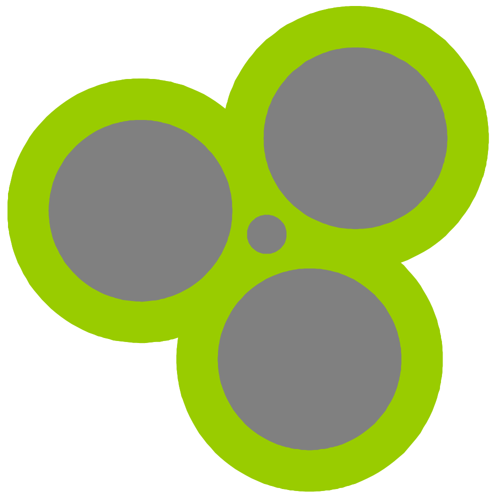

Fig. 2. Relation between thickness of excess paste layer and water to powder ratio for va- rious particle grading curves (Midorikawa *et al.*, 2001)

Previously, it was pointed out that self compacting concrete mixtures are sensitive to variations in composition and environmental influences. For the precast concrete industry this is not a considerable difficulty, since the processes at the plant can be very well controlled. The advantages for using SCC in precast concrete plants are very considerable like,

- the substantial reduction of the noise level
- the absence of vibration
- the reduction of dust (quartzite!) in the air due to vibration
- the energy saving
- the omission of the expensive mechanical vibrators
- the reduction of wear to the formwork
- the use of less robust formwork with simpler connections
- the reduction of absence for illness
- the possibility to produce elements with high architectural quality

For the production of SCC successful production of SCC it is essential that the basic constituents, like sand, gravel, fillers and the third generation of super plasticizers, have a constant quality. This is not always the case. Moreover, not all cement producers supply a constant quality. So, there should be good agreements between the concrete producers and the suppliers of the constituents on the quality control. The step from a traditional concrete production to the production of SCC is not a big one. Installations with an age of say 5-10 years are generally suitable. Further to the traditional equipment a high intensity mixing machine and an installation to dose the fillers are needed. The introduction of SCC for in-situ applications was slower than in the precast concrete industry. There are a number of reasons for this:

- In case of failure the consequences for an in-situ application are much more severe than in the precast concrete industry. In the latter case the unsuitable elements can be simply rejected, whereas in the first case demolition might be the ultimate consequence.
- There was often no agreement on the way in which the properties at the building site have to be controlled.
- Self compacting properties can be more easily reached with higher strength than with lower concrete strength. In a number of practical applications the concrete strength was therefore higher than actually necessary, which has cost consequences. For many applications a concrete strength class C25 is sufficient. However, especially for the lower strengths classes it is more difficult to obtain robust and reliable self compacting concrete's.

Meanwhile, however, a lot of barriers have, or are being, removed. There is now a better insight into the required properties of SCC for particular applications. Furthermore qualifying test methods have been evaluated. Finally a new generation of super plasticizers has been introduced. A very important aspect to be regarded is the durability of SCC. There is a tendency that in the near future structures should not only be designed for safety (ULS) and serviceability (SLS), but as well – and with the same importance - for service life. This means that increased demands will be raised on the resistance of SCC with regard to chloride ingress, carbonation and frost-thaw cycles. It was shown by many research projects that SCC is approximately equivalent to conventional concretes with regard to the majority of its mechanical properties in the hardened state. However, with regard to the microstructure of hardened SCC and its significance to durability there are still quite a number of open questions. In this respect the interface between matrix and aggregates plays an important role. Furthermore the role of (combinations of) additives (super plasticizers, air entraining agents, viscosity agents) on the microstructure, including porosity and permeability should get due attention. In this respect special attention has to be devoted to the average and low strength concrete's used in in-situ structures, if exposed to more severe environmental conditions.

Conclusions

1. In spite of its short history, self compacting (or – consolidating) concrete has confirmed itself as a revolutionary step forward in concrete technology.
2. For the application of SCC in situ, it is necessary that SCC's are designed (tailor-made) for any particular case. General rules are available on the basis of experience.
3. It can be shown by cost analysis, that SCC in precast concrete plants can be more economically produced than conventional concretes, in spite of the slightly higher material price. Cost comparisons should always be made on the basis of integral costs.
4. There is a considerable future for self compacting fiber reinforced concretes
5. The most important task for research is to develop SCC's with decreased sensitivity to variations in constituents and environmental influences. This holds particularly true for in-situ concrete's, with medium and low strengths.
6. Further research into the potential role of viscosity agents and their interaction with super plasticizers is worthwhile
7. Since in the near future service life design (SLD) of concrete structures will be as important as design for safety and serviceability, increased attention should be given to the role of the microstructure of the various types of available SCC's and its role for durability.

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