Self Compacting Concrete for high performance structures

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INTRODUCTION

Self Compacting Concrete has left his early stage of laboratory studies and has now become an industrial product.
Several building applications, many in high volumes, show it can be prescribed and used as a reliable product in mass applications with confidence in supply and casting.
Next step has now to be the extension to a "standard" solution for many structures, combining all the steps of the building process to achieve the maximum results in performance and cost.
An overview from premixed concrete industry point of view will be given, focusing on product performances actually available and developments in the near future.

SELF COMPACTING CONCRETE PERFORMANCES

Self Compacting Concrete, born in Japan in late 80's to solve problems of pouring and setting concrete in high rebar densities structures, has slowly spread all over the world, showing many other characteristics and attracting attention first in laboratories and then in application.The most relevant performances of SCC are already well known and have been confirmed in large scale applications. High filling capacity, no vibration needed, reducing noise and unhealthy tasks for workers, high flow for longer distance pouring, homogeneity due to absence of poor workmanship in casting, high strength and durability, excellent surface are the main performances recognized to the product.
Ready-mix industry experiences in mass production con add some comments about them.

Compaction grade and specimens

The structure of concrete is highly influenced by the presence of voids due to incomplete compaction: compaction grade 1 is the perfect compaction obtained preparing test specimens, but when pouring concrete in a wall, a slab or a column compaction is more difficult. Depending on consistence class and accuracy of compaction, both by means of vibrating pokers in the concrete or external vibrators applied to the formwork, the resulting compacting grade can spread from 0,93 to 0,98 [8]. As a consequence of a compaction grade less than 1, strength will be reduced of about 5% every 0,01: for a grade 0,97 a reduction of 15% in strength has to be expected in the structure, moreover the compacting grade will not be uniform.
For SCC the possibility of reaching compaction grades close to 1 is confirmed: weight of SCC specimens is same or higher than accurately vibrated standard concrete ones, i.e. density of concrete and consequently compaction ranges from 0,98 to 1. Compressive strength confirms the results.
Two other important consequences come from self-compaction:

- Compaction grade will be the same in all the structure, regardless of shape, dimensions, variations in geometry and reinforcement bars density.
- All the test specimens will have exactly the same compaction grade of the structure: finally specimens are really representative. So a good sampling of SCC will leave no doubts about the final result.

Self compaction allows also "impossible" solutions with standard concrete, as in cases where vibration will be impossible, as shown below. In the picture a small box for services (lightning, electrical supplies) is inserted in the wall before pouring and a perfect compaction is obtained also below the box.

Fig. 1 . Perfect compaction where vibration should be impossible.

An additional performance of SCC reported by some authors is an increase in pull-out force, which can lead to best safety margins in some applications.

Compressive strength

Of course high compressive strength was to be expected due to the high compaction grade, but the results are surprisingly even better. In our experience C25/30 was the lowest result maintaining SCC properties, while C30/35 was most usual a C55/60 was easily obtained without changing components, i.e. without silica fumes, fly ashes or special admixtures.

Mix design robustness

As the production of SCC can involve several different components, depending on local availability, there is no fixed rule for amount of cement, filler and admixtures. What makes the deal is a clear understanding of the behaviour of the combined components and a procedure for mix definition. Trials and errors won't give any lasting result and can not face variations in raw materials. A well proportioned mix will show good robustness, i.e. can be tailored to specific requirements, e.g. different flows, without losing other performances. Variations in materials can be faced and even some tempering operations at the pouring site can be successful. Transportation time and air temperature do not affect SCC more than any other type of concrete, as well as pumping.
What makes the enormous difference to standard concrete is that SCC does not change from truck mixer to formorks: no one on the site can think about water additions and the absence of vibration does not affect the homogeneity of the mix. This is an extra robustness that standard concrete con never reach.

Permeability

A strong reduction in permeability is expected due to the high content of fines in the mix. Some test carried out with comparison to standard concrete mixes having the same water/cement ratios gave impressive results, as shown below.
Water penetration is reduced to about one third, with two additional remarks:

- penetration depth increases more slowly as w/c rises in SCC than in standard concrete: this seems to be related to the presence of fines particles to maintain a compact structure even with less cement. So SCC with relatively high w/c ratio can guarantee a reduced permeability (compressive strength goes in the same way).
- Spread between average and maximum penetration depth is reduced in SCC: this may be a consequence of the higher homogeneity of SCC.

Water penetration according to ISO 7031

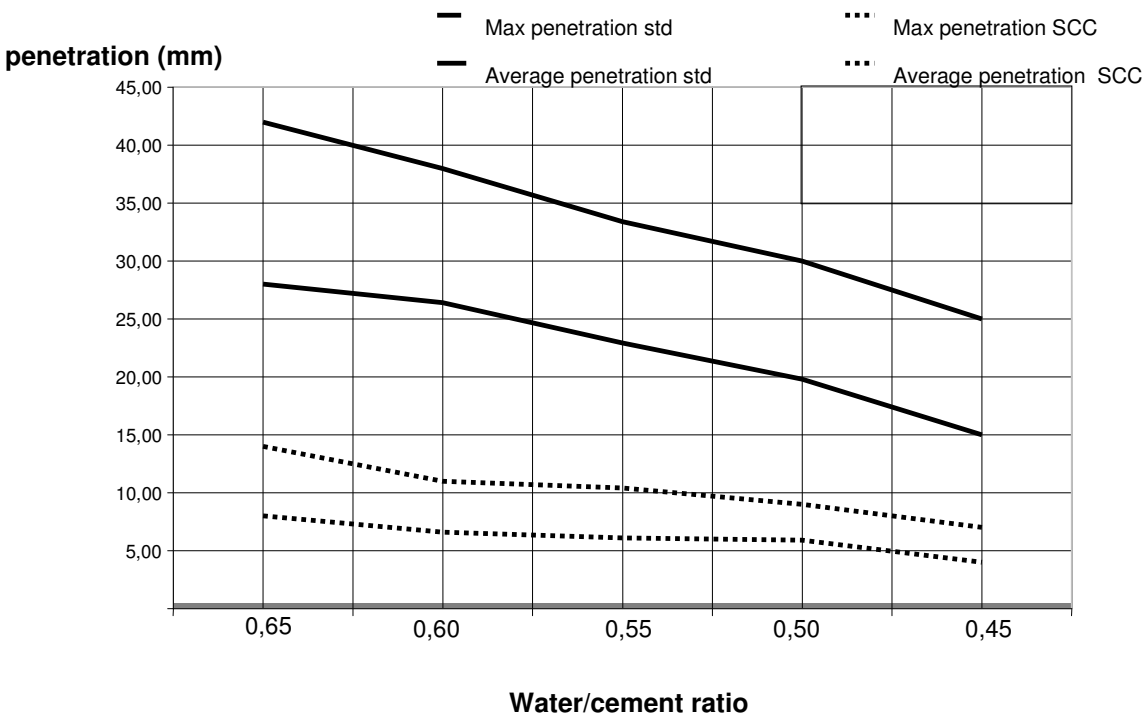

Fig. 2. Test results for water penetration.

POURING AND FORMWORK

Self Compacting Concrete may need some changes in pouring techniques, but it is related to local situations. In general it can be said that well organized building companies having clear pouring planning and using good quality formworks (and with good skill in formwork setting) can easily switch to SCC without any major change in their operations.
Some suggestions in pouring SCC rise from experience:

- Pouring rate should not be too slow to avoid setting before adding a new layer of concrete
- The best solution is pouring SCC from below the formwork to avoid air to be entrained: external hoses are very effective
- If SCC is pumped, the pump hose should be maintained slightly below the surface of poured concrete
- SCC can flow up to10 or 15 meters without problems
- Thin section of 5-7 centimetres can be filled without any problem
- Special applications as drilled foundation piles fit perfectly with SCC: after drilling the hole and filling with SCC the cage enters easily
- No specific skilled workmanship is needed during pouring

Fig. 3. Pouring in formwork

Fig. 4. Pouring in thin sections

Fig. 5. Easy cage fitting for drilled foundation piles

Formwork pressure

Simple wood panels can be used as formwork for SCC, but external reinforcements need to be very close and wall height and length is limited. Best results are obviously obtained using framed formworks that usually combine also surface quality and reduced set-up time.
Practical experience and formwork manufacturers recommendations show that up to about 3 metres wall height no problems arise using standard materials. Taking special cautions in formwork selection and reinforcement, values of 10 metres can be reached. Howewever full concrete weight is taken into account for pressure calculations: this is a cautioned issue as field tests [9] show that effective pressures are some 20% lower than expected.
Pouring rate can also influence formwork pressures: particularly for large dimensions or slow rates, bottom layers of concrete reduce their pressure on formwork before upper layers are added.

Formwork sealing

Sealing is essential: from this point of view SCC is not forgiving. But it is again a matter of good building technique: bad sealing will affect also normal concrete pouring with leakage of cement paste while SCC will find his way out of the formwork. Sealing for SCC needs no difference than good sealing for normal concrete.

Surface

Good surface finish is one of the most attractive features of SCC, mostly from an architectural point of view. But it needs many cares and involves several factors. In standard situations SCC offers a surface finish that is as good as a normal concrete with good vibration. Sometimes local concentration of tiny voids on the surface may appear as, without vibration, air doesn't have enough energy to leave the concrete from the free surface and migrates to the formwork. Solutions may be found in mix modification, pouring rate, formwork surface material and mould release agent.
In case of wide surfaces special care has to be taken when pouring SCC in several stages: without vibration mixing different layers some marks may result.
Excellent results have been achieved with non treated wood panels: the shape of the wood will be copied in a perfect way as shown below.
Sharp edges have also been obtained.

Fig. 6. Sharp edges

Fig. 7. Natural wood surface

SCC SPECIFICATION

Specification of SCC can be approached in two different ways, depending on accuracy needed in defining product performances:

- simply prescribing strength class, durability (by definition of an exposure class), aggregate dimension and SCC as consistence.
- In addition other performances or details of the structure to be realized can bring to a "tailored" solution: surface finish, distance of pouring point, type of pouring (pumping from the top or from the bottom), rebar density, early age strength development, type of formwork used etc. In this case a close connection with Ready-mix Company would be hopeful.

Design

SCC's high performances can lead to relevant changes in design, affecting geometries, dimensions and workloads. As seen, high strength can be easily obtained and, most of all, will be maintained also after casting without any influence of bad or uneven vibration and with no water additions. Homogeneity in the structure is higher than using normal concrete; specimens are really representative.
All these conditions allow designers to choose higher workloads for the material with benefits in dimensions, weight and costs.
Complicated geometries that used to be difficult become now easy to fill, such as sharp corners, inserts as boxes or windows in the walls, thin sections, areas with no access or with congested reinforcement.
For calculations it has to be remembered that SCC is a state of fresh concrete; when hardened all characteristics are in general the same of a normal concrete of similar strength.

Other conditions

Best results are obtained when all conditions are set to suit SCC performances, so best design has to be matched with good practice in formwork selection, good casting practice and top product manufacturing. So a strict connection between engineers and architects, Building and Ready Mix Companies should lead to a process of continuous improvement of:

- mix modifications
- formwork refurbishment
- pouring scheme
- mould release agent type and quantity

Control

In Italy official standards have been set to control performances in the fresh state, using simple tools [1, 2, 3]. Anyway, as the mix is well established and people are getting experienced with it, a first impression about performances is easily obtained simply with the Abrams cone.
Workers become quickly skilled in judging every single truck mixer content so leaving other, more time consuming tests, to mix definition stage and periodical controls. The result is that pouring operations are not slowed down by the use of SCC.
If high quality surface finish is required, V-funnel test should be performed in addition.
Additional controls may be required in extreme weather condition (very hot, very cold) or during season changes (summer – winter) as changes in admixtures or in cement can be adapted to suit temperature changes.
For important applications, or if specific performances are needed, a pre-qualification of mixes can be useful to determine parameters to be controlled.

Fig. 8 . Abrams cone

Fig. 9 . V-funnel test

DEVELOPMENTS

Ready mix concrete companies are now producing Self Compacting Concrete not only as routine mixes but also with dedicated mixes specifically studied for single applications. So the Industry needs inputs from designers to find new directions of developments; as many studies are showing, the whole potential of SCC has not been discovered yet.
Calculations and design itself should change to benefit of SCC performances as reliability, testing, filling capacity and permeability.
As so far, interesting possibilities are related to Self Compacting Concretes with special components:

- Structural Lightweight SCC: using expanded clay as coarse aggregate will reduce weight of concrete of about 20% maintaining good performances. Not only this can lead to lighter structures, but also can reduce formwork pressures.
- Fibre Reinforced SCC: experiences show that the great homogeneity of SCC are strongly beneficial to the performances added by fibres, both made of steel or polypropylene.

Some developments are to be expected also in components: admixtures show continuous progress while a significant market grow may bring to massive production of fillers, mainly limestone, that could also reduce their cost while improving characteristics beneficial to the use in SCC.
Another development is expected from Construction Companies as more knowledge and acceptance in slightly higher material price to reduce construction costs and times and to improve quality.

Conclusions

Self Compacting Concrete has become an industrial product. It is mass produced in a reliable way using components that, although may vary from place to place, are usually available. Performances in real applications are as good as expected in terms of compressive strength, homogeneity and filling capacity. Pouring SCC needs minor changes in building sites, while gives engineers a largely higher confidence of material performance in the structure. Perfect representativity of specimens help evaluating the final result of the construction process.
Further developments are going on, showing good flexibility of SCC to be tailored to suit different needs and to enhance his performances.

REFERENCES

1. UNI 11040 2003. Calcestruzzo autocompattante. Specifiche, caratteristiche e controllo. 2003, Milan.
2. UNI 11041 2003.. Determinazione dello spandimento e del tempo di spandimento, 2003. Milan.
3. UNI 11042 2003. Prova sul calcestruzzo autocompattante fresco. Determinazione del tempo di efflusso dall'imbuto. 2003, Milan.
4. UNI 11042 2003. Prova sul calcestruzzo autocompattante fresco. Determinazione dello scorrimento confinato madiante anello a J. 2003, Milan.
5. ATECAP. Linee Guida per la produzione del calcestruzzo autocompattante. 2003, Roma
6. Okamura H, Ouchi M. Application of Self Compacting Concrete in Japan. *Proceedings of 3rd International RILEM Symposium*. August 2003, Reykjavik.
7. Walraven J, Structural aspects of Self Compacting Concrete. *Proceedings of 3rd International RILEM Symposium*. August 2003, Reykjavik.
8. Collepardi M, Il nuovo calcestruzzo. Edizioni Tintoretto. 2001, Treviso.
9. DOKA. Schema formati casseforme per getti SCC.