MECHANICAL PROPERTIES OF SELF-COMPACTING CONCRETE

Aurelia Bradu, drd. ing., Nicolae Cazacu, drd. ing.
Tehnical University „Gheorghe Asachi" from Iassy

1. INTRODUCTION

Concrete is the most commonly used structural material in the construction (buildings, bridges, roads, dams, etc.). Self compacting concrete also referred as "Self-consolidating concrete" was discover in 1986 by Japanese prof. Okamura as a solution to improve the concrete durability, decreased due to the lack of skilled workers. This new material is able to flow and consolidates itself without additional mechanical compaction. The elimination of vibration reduces labor, shortened construction time, diminished equipment costs and improve working environment. The workability of SCC makes it convenient for placing in difficult conditions (complicated shapes, narrow sections, congested reinforcement). The self compactibility properties require high deformability of mortar and resistance to segregation when the concrete flows through confined zones. The procedures to determinate its fresh properties and allowable values are described in "European Guidelines for self-compacting concrete" [1].

The properties of hardened SCC were less studied despite of its importance in design concrete structures, they were conventionally adopted the same as for the vibrated concrete.

2. GENERAL FEATURES OF SCC

SCC components are similar to vibrated concrete (cement, mineral admixtures, aggregates, mineral and chemical admixtures, water), but the final composition of the mixture and its fresh characteristics are different (fig.1).

SCC requires a larger proportion of powder materials and higher quantities of high range water-reducing admixtures. The correct choice of cement and its quantity is determined by each application and must conform to EN 197-1 and EN 206-1. In order to keep the necessary paste volume without cement excess, in the composition of SCC is added mineral admixture, usually they represent industrial by-products: limestone filler, fly ash, silica fume, blast furnace slag.

Limestone filler is chemically inert and is the most commonly mineral addition, due to its particles size improves the mobility of fresh concrete and fills the gaps between cement grains.

Figure 1. Slump flow test of SCC.

Fly ash is a by-product of burning pulverized coal in an electrical generating station, it use increases the flowability, reduces the cement hydration heat and enhances the viscosity of fresh concrete. Fly ash have a pozzolanic activity, in the presence of moisture chemically reacts with calcium hydroxide, and form silicate hydrate and cementititous compounds.

Silica fume is also very effective in reducing or eliminating bleeding and this can solve the problem of rapid surface crusting. The high level of fineness and almost spherical shape its particles lead to a good cohesion and an improved resistance to segregation.

The passing ability of SCC is evaluated by its capability to flow through tight openings including spaces between reinforcing bars. The maximum aggregate size should generally be limited to 12 – 20 mm. In order to obtain a more consistent product is recommended to use washed aggregates.

Viscosity modifying admixtures (VMA) improve the cohesion of the SCC without significantly altering its fluidity. These admixtures are used in SCC to minimize the effect of variation in moisture content, making the SCC more robust.

The superplasticisers are the most important admixtures improving concrete performance; for SCC is recommended to use polycarboxylate ether based (PCE).

Typical range of mix design SCC according to the study ICECON S.A [2]:

- volume of paste varies between 32-42% of concrete volume;
- volume of coarse aggregate varies between 28-38% of concrete volume;
- the content of powder varies between 445-605kg/m³;
- the water powder ratio varies between 0,26-0,28;
- the content of fine aggregate varies between 38-54% of binder volume;
- the maximum aggregate size should be limited to 16 – 20mm;
- the most used cement type is Portland cement and the addition is mineral fillers.

SCC is produced with a low water/cement ratio and higher paste volume. To maintain the homogeneity and resistance to segregation, the aggregate is chosen more rigorous by shape, origin, nominal maximum size.

3. ESSENTIAL MECHANICAL CHARACTERISTICS

The modifications made in the mix design of SCC affect its mechanical behavior as compared to NVC in hardened state.

The main requirements which SCC (according to EN 206-1) must correspond are mechanical strength and durability.

Durability represents the capability of a concrete structure to withstand environmental aggressive situations during its design working life without impairing the required performance [EN 206-1]

The study of the mechanical characteristics of SCC became one of the research objective for the last years. The most important mechanical properties of the concrete are: compressive strength, tensile strength, the modulus of elasticity.

3.1. Compressive strength

Compressive strength is one of the most important mechanical characteristics of the concrete. Many of the other mechanical properties (e.g. tensile strength, modulus of elasticity, compressive strain) and physical properties (e.g. related to durability) of concrete are moreover expressed as a function of this parameter [1].

The compressive strength of concrete is affected by: W/C, cement compressive strength, properties of the aggregates (shape, grading, surface texture mineralogy, strength, stiffness, and maximum grain size), air-entrainment, curing conditions, testing parameters, specimen parameters, loading conditions, and test age.

In Eurocode 2, concrete is classified solely on the basis of its compressive strength, in accordance with EN 206-1 where cylinders 150/300 mm and cubes 150 mm are used as a reference.

The values $f_{c,cub,x}$ and $f_{c,cyl,d}$, represent the compressive strength determined on cubes side x and cylinders with diameter d. According to Domone [3], the ratio $f_{c,cyl,d}/f_{c,cub,x}$ for SCC increases from 0.8 to near 1.0 with increasing strength. The mean value of the strength ratio $f_{c,cyl,d}/f_{c,cub,x} = 0{,}9$. The experimental conversion of this factors for VC are generally situated within the region of 0.70–0.90.

Self-compacting concrete with a similar water cement or cement binder ratio will usually has a higher strength compared to the traditional vibrated concrete, this is due to the use of powder material, with particle size smaller than 0.125 mm, that improves the microstructures of concrete, complements the aggregate distribution and thus, the pores become extremely small. Additionally, absence of external vibration improve the bond between paste and aggregate. It should be taken in account, that SCC have reduced porosity and interfacial transition zone of higher quality compared to NVC due to the use of smaller aggregate.

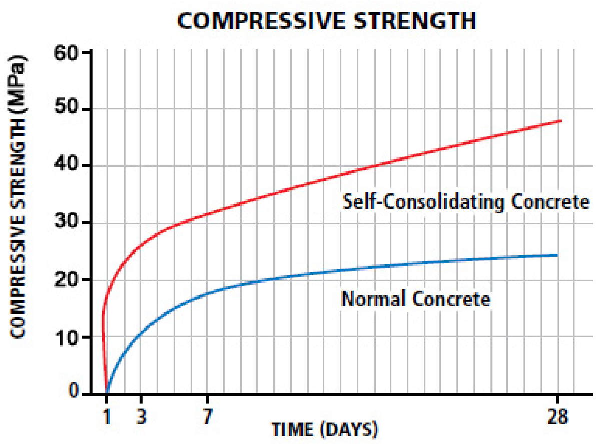

Figure 2. Compressive strength of SCC vs vibrated concrete [10].

At a constant W/C, a higher C/P leads to lower strengths. It is probably expected to the fact that increasing the cement content also requires the increase in water content to maintain the W/C, thus leading to a higher W/P. More water in the mixture leads to a higher capillary porosity and lower compressive strength.

The speed with which it gains strength also eliminates the need for steam or heat curing of concrete to facilitate early strength gain. SCC can attain significantly higher early and 28-day strengths

Coarse aggregates can have an influence on the compressive strength due to their shape, nominal maximum size, surface texture, and origin. Crushed aggregate mixtures have higher cube strengths. It is similar to the behaviour of VC, but the average difference between the two best-fit curves for SCC was found to be small (4 MPa) compared with VC(8 MPa).

3.2 Tensile strength

The tensile strength of the concrete is used to evaluate the cracking moment and to draw the curvature diagrams. Its value is less than the compressive strength (from 1/6 up to 1/20) as result of the concrete heterogeneous nature. Cement stone contains numerous gaps: pores, micro cracks that favor concentration of tensions in a small volume.

There are three methods to assess the tensile strength: direct tensile test, the splitting tensile test and the bending tensile test.

Direct tensile strength tests are rather scarce due to its difficult setup. Splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength.

Volume paste has no significant influences on the tensile strength. The tensile strength for self compacting concrete is similar to vibrated concrete for the same class.

The structure of SCC an vibrated concrete can be analyzed after splitting tensile test, (fig.3, fig.4). The effect of the Cement/ Powder is shown in the Fig.5 where SCC mixtures with a C/P less than 0.75 tend to lie beneath the mean values proposed by the Eurocode2 and the design code Model Code 2010.

Tensile strength of the concrete depends essentially on the tensile strength of cement stone, and its cohesion with the coarse aggregate, its value slightly increases with the cube compressive strength development.

Figure 3. Structure of SCC.

Figure 4. Structure of vibrated concrete.

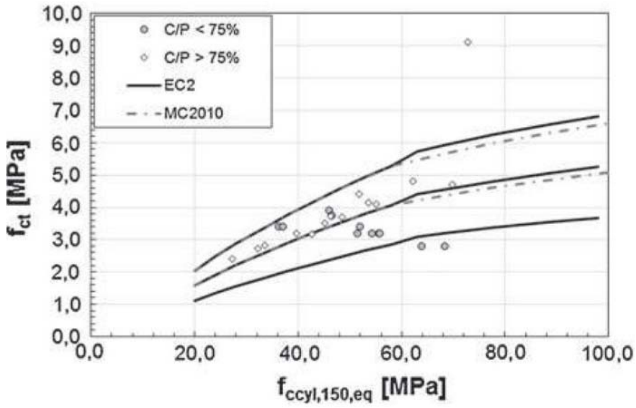

Figure 5. Direct tensile strength vs cylinder compressive strength and C/P [4].

3.3 Modulus of elasticity

The modulus of elasticity E-value, represents the ratio between stress and strain. This value is influenced by the elastic modulus of the aggregate and volumetric proportion of aggregate in the concrete.

As the aggregate is the bulk of the concrete volume, the type and amount of aggregate as well as its E-value have the most influence. Aggregate usually has a modulus of elasticity higher than that of cement stone. Selecting an aggregate with a high E-value will increase the modulus of elasticity of concrete. This dependence is due to the biphasic nature of concrete.

The modulus of elasticity of the tested SCC mixtures was lower than that of VC mixtures, with a similar compressive strength. Pineaud [4] studied the effect of the paste volume and W/C. By varying the paste volume between 359 and 452 l/m3 a decrease in E-value was found for an increasing paste volume. A survey by Domone [3] indicates that the difference between SCC and VC in the modulus of elasticity is greater for lower compressive strengths.

The best fit line for the VC data is very close to that of the approximate relationship given in EC2, but the stiffness of the SCC mixes is on average about 40% lower than those of the VC mixes at low strength levels, with the difference reducing to less than 5% at high strengths. This behaviour is consistent with the lower coarse aggregate quantities in SCC (fig.4).

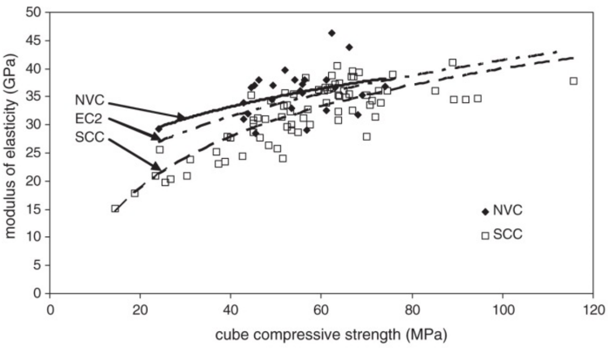

Figure 6. Elastic modulus vs cube compressive strength [12].

4. CONCLUSIONS

SCC is a relatively new material in the concrete industry. The mechanical properties of SCC were conventional adopted according to VC of a similar class. The results of research of the last years proved the existence of difference of properties in hardened state between VC and SCC:

- Compressive strength of SCC has higher strength comparated with VC, the main reason for the increase of is that packing density in SCC mix increases with increase of powder content.
- The tensile strength of SCC may be assumed to be the same as the one for a VC
- The elastic modulus of the SCC can be up to 40% lower than of VC at low compressive strength, but the difference reduces to less than 5% at high strengths
- The properties of the hardened SCC and its behavior over time represent a new direction for research.

References

1. The European Guidelines for Self-Compacting Concrete Specification*, Production and Use, May 2005.*

2. ICECON S.A. *Beton autocompactant – cercetare (prenormativă). februarie 2012.*

3. *Domone P.L. A review of the hardened mechanical properties of self compacting concret. Cement and Concrete Composites; 29(1), pag.1-12, 2007*

4. Khayat K.H., De Schutter G. *Mechanical properties of Self Compacting Concrete., State-of-the-Art Report of the RILEM Technical Committee 228-MPS on Mechanical Properties of Self-Compacting Concrete, 2014*

5. Sheinn A.M.M., Tam C.T., Rodrigo F.L. *Comparative study on hardened properties of self compacting concrete (scc) with normal slump concrete (nsc). 29th Conference on "Our world in concrete & structures" Singapore, pag. 485-494, 2004*

6. Almeida F., Barragánb B.E., Casasb J.R. *Hardened Properties of Self-Compacting Concrete — A Statistical Approach. Construction and Building Materials nr 24, pag.1608–1615, 2010*

7. Terec L, Szilágyi H. *Beton autocompactant (bac) pentru industria de prefabricate în construcţii. Revista „Urbanism. Arhitectură. Construcții", vol.1 nr.1, pag. 79-86, 2010.*

8. Vieira M., Bettencourt A*. Deformability of hardened SCC. In: Wallevik, O., Nielsson, I.(eds.) Proceedings of the 3rd International RILEM Symposium on SCC, Reykjavik, RILEM Publications S.A.R.L, Bagneux, pag. 637–644, 2003*

9. Okamura H., Outchi M. *Self compacting Concrete. Journal of Advanced Concrete Technology, vol 1, nr.1 pag. 5-15, april 2003*

10. Heirman G., Vandewalle L., Van Gemert D., Boel V., Audenaert K., De Schutter G., Desmet B., Vantomme J. *Time-dependent deformations of limestone powder type self compacting concrete. Eng. Struct. 30, pag.2945–2956, 2008*

11. Gesoglu M., Guneyisi E., Ozbay E. *Properties of self-compacting concretes made with binary, ternary,and quaternary cementitious blends of fly ash, blast furnace slag,and silica fume. Journal Construction and Building Materials 23, pag. 1847–1854, 2009*

Uysal M. *The influence of coarse aggregate type on mechanical properties of fly ash additive self-compacting concrete. Journal Construction and Building Materials 37, pag. 533–540, 2012.*

Recommended for publication: 18.03.2016.