Properties of High Performance Self Compacting Concrete In Fresh and Hardened State

Farhang Farrokhi[1], Arash Sultany[2]

1- PhD in Structure Engineering, Zanjan University, Zanjan, Iran
2- MSc in Structure Engineering, Zanjan University, Zanjan, Iran

Farhang.Farrokhi@Gmail.com
arash.Soltani@Yahoo.com

Abstract

Increasing concrete strength is always one of the main scopes of concrete technology. Because of high viscosity of cement paste, concrete compaction performed difficulty. To improve the compaction characteristics of the concrete the idea of adding coarse aggregate and silica fume was developed. The first tests showed a good workability of the fresh concrete and a good self compacting ability. Test results show better workability, shrinkage tendency and the modulus of elasticity.

Keywords: High Performance Self compacting concrete, Viscosity, Fresh Concrete.

Introduction

Increasing the concrete strength is always one of the main desires of concrete technology. Since more than 20 years high strength concretes with compressive strength ranging from 50 N/mm² up to 130 N/mm² have been used worldwide in tall buildings and bridges with long spans or buildings in aggressive environments. Building elements made of high strength concrete are usually densely reinforced. The small distance between reinforcing bars may lead to defects in concrete. If high strength concrete is self-compacting, the production of densely reinforced building element from high strength concrete with high homogeneity would be an easy work. Self-compacting concrete is a concrete that flows and compacts only under gravity. It fills the whole mold completely without any defects. The usual self-compacting concretes have a compressive strength in the range of 60-100N/mm². In this paper the proportioning and properties of a ultra high performance self-compacting concrete (UHPSCC) with a strength about 150 N/mm² is presented.

Consideration for the Self-Compacting High Strength Concrete

It is well known that the properties of concrete are affected by cementations matrix, aggregate, and the transition zone between these two phases. Reducing the water-cement ratio and the addition of pozzolanic admixtures like silica fume are often used to modify the microstructure of the matrix and to optimize the transition zone. The Reduction of the water-cement ratio results in a decrease in porosity and refinement of capillary pores in matrix. In high performance concrete water to cement ratio ranges usually is between 0.28 and 0.38. In ultra high performance concrete the water to cement ratio is even lower than 0.2 [1].

The effect of silica fume can be explained by its pozzolanic reaction with calcium hydroxide released from cement hydration and filling effect in the voids among cement or other powder material particles [2]. In the case of Portland cement, 18% silica fume (in cement weight) is theoretically enough for the total consumption of calcium hydroxide released from cement hydration [3]. Concerning the filling effect, more than 25% silica fume should be added to concrete to get the densest granular mixture [4], [5]. On the other hand, decreasing water-cement ratio may negatively influence the flowing ability of the fresh concrete. Special attention must be paid to ensure the extremely high flowing ability required in self-compacting concrete. According to the design method for conventional self-compacting concrete proposed by Okamura et al, the volume of coarse aggregate, fine aggregate and paste consisting of powder (<0.125 mm) and water are approximate 50% Vol. , 20 Vol.% and 30 Vol.% [6]. In the case of ultra high strength self-compacting

---

1- Assistant Professor in Civil Engineering Department of Zanjan University & Institute for Beton-technology-Technical University of Graz (TU-Graz)-Austria
2- MSc of Structure Engineering department, Zanjan university

concrete with very low water-powder ratio, paste volume should be increased. Another way to increase concrete flowing ability is minimizing the voids among particles of the powder mixture composed with cement, silica fume and other fine components. Voids among powder particles can be evaluated by the water demand (3p. Pp is the volumetric ratio of water to powder material, at which all voids among solid particles are just filled with water. It can be determined according to the method described in section 4.1. The lower (3p is, the lower is the voids volume in the powder mixture. An ideal powder mixture should be composed of components with different fineness, so the voids among coarse particles can be filled with finer particles.

MATERIALS

An ordinary Portland cement CEM I 42.5 R and Portland cement with high sulphate resistance CEM I 42.5R-HS were used in this experiment. As pozzolanic material a uncompressed white silica fume was added in concrete. Its particles are in the range of 0.1 to 1 µm. A quartz powder with a particle diameter smaller than 10 µm was used as micro filler to optimize the grading curve of the granular mixture composed of 100 g cement, 30 g silica fume and 42,8 g quartz powder. The grading curves of row materials and the mixture are shown in Fig. 1.
The use of a super plasticizer on polyethercarboxylate basis ensured the flowing ability of the concrete. At high dosage it exhibits a strong retarding effect on the cement hydration. Quartz sand with a size of 0.3-0.8 mm and crushed basalt in the range of 2-5 mm were used as aggregates. The aggregate mixture is composed of 30 % sand and 70% basalt in mass.

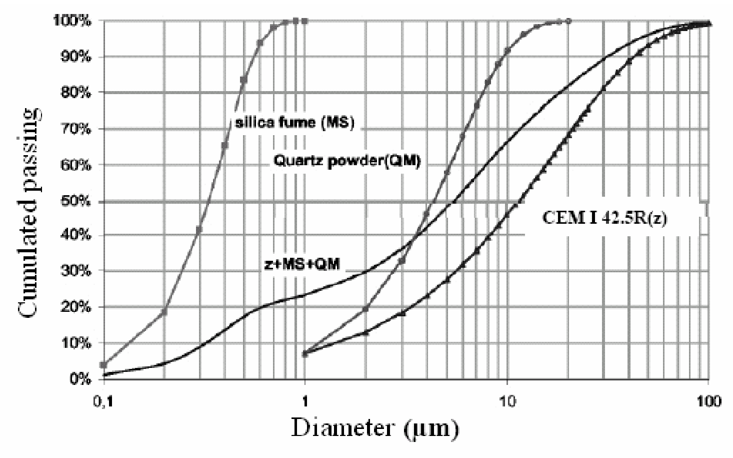

Fig. 1 grading curves of raw materials and mixture

EXPERIMENTS AND RESULTS

Experiment on cementations paste

Flow tests were carried out on pastes containing different water to powder ratios or different super plasticizer dosages with a flow cone as in conventional self compacting concrete. The results showed that a super plasticizer dosage of more than 2% of the powder mass could not improve the flowing ability of the paste anymore. For all latter experiments the super plasticizer dosage was determined about 2.0% in powder mass.
The relative slump flow was calculated from measured slump flow as flowing:

Where *d* is the measured flow diameter and d_0 is the flow cone diameter. The relationship between relative slump flow and volumetric water to powder ratio V_w/V_p is shown in **Fig.2** (super plasticizer dosage was 2% in powder mass). The intercept point with the ordinate is (3p . The *Pp* with a low value of 0.319 indicates a high packing density of the granular mixture composed from cement, micro silica and quartz powder.

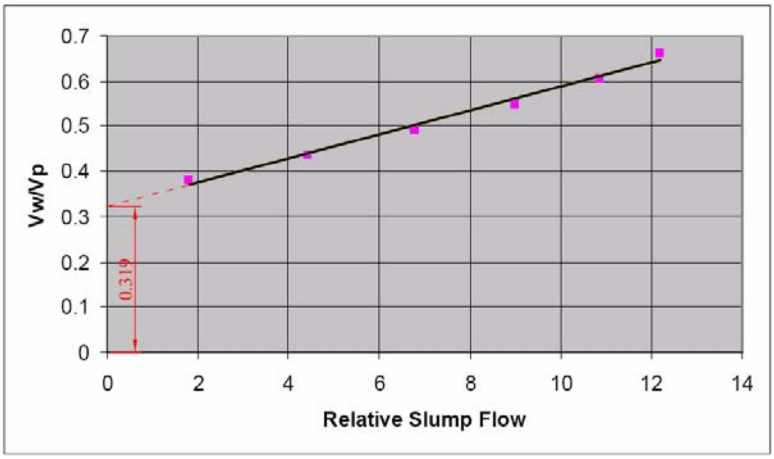

Fig. 2 relationship between relative slump flow and Vw/Vp

Experiment on concrete

All concretes have been mixed in an intensive mixer with the following procedure: All dry materials were mixed till a homogenous mixture was built up. 2 min after mixing, water and super plasticizer have been added and the mixture was mixed about 6 min till a flowing and homogenous concrete was formed.

Properties of fresh concrete

The flowing ability of fresh concrete is described with slump flow investigated with Abrams cone. The low water-powder ratio and the high fineness of silica fume and quartz powder formed a paste with high viscosity. During flowing neither segregation nor bleeding occurred, even though the density of crushed basalt is high. Compared with conventional self-compacting concrete the slump flow of UHPSCC should be more than 700 mm instead of 650 mm, to reduce the air content to a minimum level. This purpose can’t be reached by the variation of the super plasticizer dosage, as in conventional self-compacting concrete, but through increase of the paste volume in concrete. As shown in Tab.1 the paste volume in concretes lies between 46% and 55%. A slight decrease in water to powder ratio leads to a significant increase in paste volume.

Except high flowing ability a homogenous spreading of the concrete through narrow spaces between reinforcing bars is also of great importance. During flowing coarse aggregate should not be blocked by reinforcing bars. Blocking tendency of coarse aggregate was investigated with M6. It was observed that coarse aggregate was flowing together with viscous mortar through the obstacles of the block-ring without any difficulty.

SCC must keep its high flowing ability for about 90 min to ensure casting at building place. The consistency loss of concrete can be influenced by some factors, such as type and dosage of super plasticizer, cement type and fineness, water-powder ratio, fresh concrete temperature, and mineral admixtures. Experiences in HPC show that ordinary Portland cement, with low water-binder ratio and the addition of silica fume often shows a rapid concrete setting [7].

The evolution of fresh concrete properties was investigated on M6 with the obstacle-ring. The distance between the steel bars of this block-ring was 16 mm. Slump flow and blocking tendency of coarse aggregate were measured every 30 min after mixing. Before each measurement the concrete was mixed again for about 90 sec. Results in Tab.2 show that the properties of the concrete have not changed significant during 2 hours after mixing. This can be explained by the strong retarding effect of the super plasticizer on the cement hydration.

Measurements of the hydration of a 150*150*700 mm beam showed, that temperature in concrete did not increase during the first 24 hours after mixing. Cement hydration was completely stopped during this time.

Properties of hardened concrete

The compressive strength, splitting tensile strength and modulus of elasticity are shown in Tab.1. The specimens were remolded 2 days after casting. Then they were cured in water at 20°C till 3 days before testing.

In Tab.1 can be seen that the difference between compressive strength determined on cubes and cylinders is not significant. This indicates that the compressive strength of UHPSCC is not so strongly depending on the slenderness of the test specimen as conventional high strength concrete. This is the same case as in conventional self-compacting concrete. This phenomenon can be explained by the high powder content and the small size of the coarse aggregate [8].

The modulus of elasticity of the concrete depends on the properties of coarse aggregate, the matrix and their ratio. CEB suggested an equation predicting the modulus of elasticity of HPC with the following equation:

$E_{cm} = E_{c0}\, k$

with E_{cm}: Modulus of elasticity of concrete

f_{cm}: compressive strength of concrete

E_{c0}: 20500 N/mm²

k=1.2 for concrete containing basalt coarse aggregate

Results calculated from this equation using cylinder compressive strength in Tab.1 are about 20% higher than experimental values. This can be explained with the lower coarse aggregate volume in UHPSCC than in conventional concrete. The value of k should be reduced to 1.0 for this UHPSCC.

Tab. 1 Composition and properties of UHPSCC

Mareials	Density (Kg/m^3)		M1	M2	M3	M6	M4	M5
CEM I 42.5R	3.05	Z	665	609	540	480		
CEM I 42.5R-HS							540	540
Micro silca, Elkem Grade 983	2.3	MS	200	183	162	144	162	97.2
Quartz powder (0-10 µm)	2.63	QM	285	261	231	205	231	296
Quartz powder (0.3-0.8 µm)	2.65	QS	1019	398	440	475	440	443
Crashed basalt (2-5 mm)	3.1			936	1027	1108	1027	1034
Total water		W	178	163	163	162	163	163
super plasticizer		SP	23	21.1	16.8	14.9	16,8	16.8
w/b=w/(z+MS)			0.21	0.21	0.23	0.26	0.23	0.26
w/(z+MS+QM)			0.155	0.155	0.175	0.195	0.175	0.175
Volumetric water to powder ratio		V_W/V_P	0.431	0.431	0.487	0.543	0.487	0.487
Paste volume in concrete			61.5%	54.9%	50.4%	46.0%	50.4%	50.4%
Slump flow (mm)			690	700	710	710	700	730
t500 (sec.)			---	11	9	8	---	--
Density of hardened concrete (kg/m³)			2320	2525	2568	2590	2547	2564
Compressive	fc.cube100*100	28d	149.8	160.7	166.2	160.6	---	--
	fc.cyl.100*300	28d	155.7	155.9	151.4	148.7	151.2	150.0
Splitting tensile strength (N/mm²)	fsp.cyl.100*200	28d		8.7	8.6	8.5	---	
	fc_x. l100*300	28d	48110	50118	52837	53944	---	---

Tab. 2 Evolution of flowing ability of M6 (T=18,7 °C, RH=78% in environment)

Time after mixing	5 min	35 min	65 min	95 min	125 min
Flowing value (mm)	710	700	695	690	675
Flowing time t500 (sec)	8	8	9	8	9
Height difference	0	0	0	0	0

Autogenously shrinkage

Autogenously shrinkage was measured in M1, M2, M3, M4, and M5. Concrete was cast into a metallic mould with the dimension of 50*100*1000 mm. In order to prevent the friction between concrete and the mould, a plastic foil had been inserted in the form before casting. After casting the concrete was covered immediately to avoid any surface water loss. The change in length of the concrete specimens was recorded every 15 min. The total deformation of all mixtures is shown in **Fig. 3**. Variations in the room temperature during the experiment make M1, M2, M3 and M4, M5 incommensurable. But deformation curves show a similar characteristic. After the dormant period during the first 24 hours, which is caused by the retarding effect of super plasticizer on cement hydration, concretes began to shrink. This contraction was the summation of two contrary deformations: chemical shrinkage caused by cement hydration and thermal expansion caused by temperature increasing in concrete. A few hours later thermal expansion was dominant, which resulted in a slight expansion. Afterwards the temperature in the concrete decreased. At the same time the chemical shrinkage continued. Contraction caused by cooling and chemical shrinkage outbalanced. The concrete shortened again.

In **Fig. 4** the autogenously shrinkage was calculated form the time when concrete began to shrink again. The autogenously shrinkages in all tested concretes are much higher than in conventional high strength concrete. Influences of water to binder ratio and silica fume content on autogenously shrinkage have the same tendency as in conventional high strength concrete. As expected, M3 with higher water to powder ratio shows lower autogenously shrinkage values than M2. M4 with higher silica fume content has a higher autogenously shrinkage than M5. Except of these both factors paste volume in concrete is also a main factor influencing autogenously shrinkage. M1 and M2 had the same water-cement ratio and silica fume content, but the higher paste volume in M1 leads to a much higher autogenously shrinkage than in M2.

It is noticeable that the great part of difference in autogenously shrinkage among these concretes occurred during the first 14 days after casting. Afterwards, all concretes show a similar development in autogenously shrinkage.

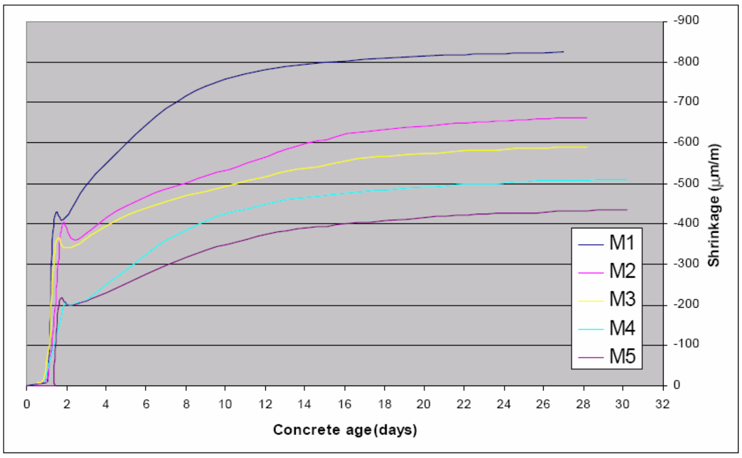

Fig. 3 free length changes in sealed concrete beams

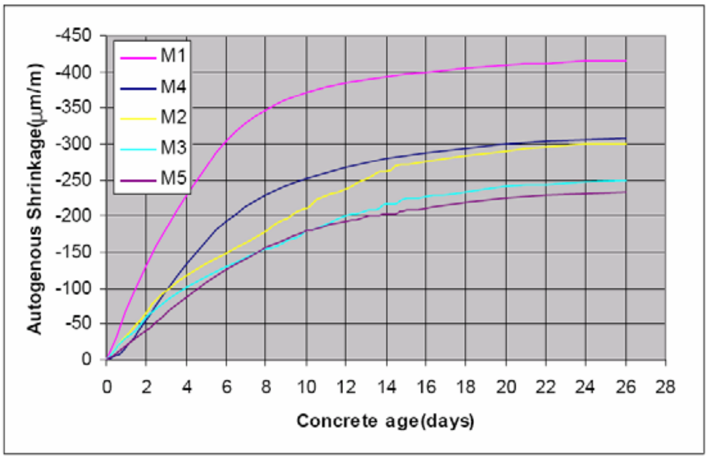

Fig. 4 Autogenously shrinkage of concretes

Conclusion

The application of new super plasticizers and powders in high performance concrete give the opportunity to produce self-compacting concretes that easily reach a compressive strength of more than 150MPa. These concretes show a very good workability in the fresh state, also the hardened concrete shows excellent quality. Future interests will try to reduce autogenously shrinkage to minimize the crack tendency of the young concrete. Further investigations to optimize the mix proportions will aim to the application of this concrete on site.

REFERENCE

[1] R. Bornermann, M. Schmidt, E. Fehling und B. Middendorf Ultra Hocheistungsbeton UHPC— Herstellung, Eigenschaften und Anwendungsmoglichkeiten, Beton- und Stahlbetonbau 96, 2001, Heft 7, Ernst & Sohn

[2] Ronald Konig, Jorg Peter Wagner Mikrosilika, Woermann,GmbH & Co. KG

[3] Vagelis G. Papadakis: Experimental investigation and theoretical modeling of silica fume activity in concrete Cement and Concrete Research 29 *(1999)*, pp.79-86

[4] Thorsten Reschke Der Einfluss der Granulometrie der Feinstoffe auf die Gefigeentwicklung und die Festigkeit von Beton Dissertation, Bauhaus-Universitat Weimar Schriftenreihe der Zementindustrie, Heft 62/2000

[5] Pierre Richard, Marcel Cheyrezy: Composition of Reactive Powder Concrete Cement and Concrete Research, Vol.25, No.7, pp.1501-1511, 1995

[6] H. Okamura; K. Ozawa; M. Ouchi Self-compacting concrete Structural Concrete, 2000,1, No.1

[7] Gert Konig, Nguyen Viet Tue, Martin Zink Hochleistungsbeton-Bemessung, Herstellung und Anwendung Ernst & Sohn, 2001

[8] Dirk Weil3e Einfluss des Betonsalters auf die Festigkeits-, Formanderungs- und Verbundkennwerte Selbstverdichtender Beton, herausgegeben von Gert Konig, Klaus Holschemacher und Frank Dehn, Bauwerk Verlag GmbH, 2001