Ninth CANMET/ACI International Conference
on
Recent Advances in Concrete Technology

Warsaw, Poland
May 23-25, 2007

Low-Heat, High-Strength, Durable Self-Consolidating Concretes

by A. Borsoi, M. Collepardi, S. Collepardi, R. Troli and L. Zanardi

Synopsis: Low-heat, high-strength, and durable self-consolidating concrete (SCC) was needed for a reinforced slab foundation exposed to sea water. Three SCCs were studied as potential candidates for such a structure: all these concrete mixtures were based on blended cements with portland cement replaced by 50% of slag and/or fly ash. A polycarboxylate-based superplasticizer was used to manufacture SCC with a water-cementitious materials (w/cm) ratio as low as about 0.30.

Different techniques to characterize the rheology of the fresh mixtures were adopted and indicated that the SCC with slag or slag and fly ash are much more mobile than the corresponding SCC where fly ash alone was used.

The following properties were measured on the concretes in the hardened state: thermal change in quasi-adiabatic conditions, cube compressive strength, drying shrinkage, chloride ions and carbon dioxide penetration in specimens placed without vibration. The maximum temperature increase was about 30°C at 3 days for all the three concretes. The early compressive strength was higher for the slag-concrete than in the other two concretes; however, at longer ages (60-90 days), the maximum strength (over 85 MPa) was recorded with the fly ash-slag concrete.

The penetration of chloride ions and carbon dioxide was very low (3 mm at 1 year) in all the three concretes.

The drying shrinkage of concretes exposed at the open air with RH of 50% at 20°C) was about 15% lower in the fly ash concrete with respect to the other two concretes (about 450 microstrains at 6 months).

Keywords: Chloride diffusion, drying shrinkage, durability, high strength, mass concrete, sea water, self-consolidating concrete.

Antonio Borsoi is a laboratory technician of Enco. He is active in the area of concrete mixture design. He is author of several papers in the field of superplasticized concrete mixtures.

Mario Collepardi, is President of Enco, Ponzano Veneto (TV) – Italy, is author or co-author of numerous papers on concrete technology and cement chemistry. He is also the recipient of several awards for his contributions to the fundamental knowledge of superplasticizers and their use in concrete.

Silvia Collepardi is a research civil engineer and director of the Enco Laboratory, Ponzano Veneto, Italy. She is working in the field of concrete durability and superplasticized concrete mixtures and has published numerous papers in this area.

Roberto Troli is a research civil engineer and technical director of the Enco. He is author of numerous papers in the field of concrete technology and in particular in that of chemical and mineral admixtures.

L. Zanardi is a researcher working in the area of cement chemistry (Cementirossi) particularly in the area of quality control of portland and blended cements.

INTRODUCTION

Special concretes were studied for a reinforced massive structure exposed to sea water. Because of the very congested metallic reinforcements, self-consolidating concretes (SCC) were manufactured on a laboratory scale with the following additional properties:

- low heat of hydration to avoid thermal stresses;
- high compressive strength for structural purposes (at least 55 MPa at 28 days);
- long-term durability for the severe exposure to sea water.

With respect to a previous research in this area [1] a higher performing SCC was studied in the present work in terms of higher compressive strength and long-term durability. Three concretes were studied as potential candidates for such a structure all based on blended cements with slag and/or fly ash. The following properties were studied: rheology, thermal heating, compressive strength, durability and drying shrinkage.

EXPERIMENTAL: MATERIALS AND METHODS

Table 1 shows the chemical composition of the raw materials to produce blended cements: portland cement, granulated ground blast furnace slag (ggbfs) and fly ash.

Table 2 indicates the three blended cements adopted in this study all manufactured by grinding in a laboratory mill portland cement, slag and fly ash, if any, at approximately the same Blaine fineness of 400 m^2/kg The reason why these blended cements (called CEM III, CEM IV and CEM V according to the European standard: EN 197-1) were used instead of pure portland cement is due to the fact that a low heat development was absolutely needed for such a work.

Three SCCs were manufactured all with a blended cement content of about 500 kg/m^3, containing 250 kg/m^3 of portland cement. Natural sand and gravel were used with a maximum size of 16 mm. A polycarboxylate-based superplasticizer (30% in aqueous solution) was used at an adequate dosage (by weight of cement) to produce a self-leveling concrete mixture. Table 3 shows the composition of the three concretes. The main characteristics of these mixtures is the different superplasticizer (SP) dosage needed when the cementitious material (slag or fly ash) is used : the dosage (0.73%) was lower when the cement with only slag (CEM III) is used, and higher (1.30%) when only fly ash (CEM IV) was used; an intermediate superplasticizer dosage (1.00%) was adopted for the composite cement (CEM V).

RESULTS

In the following sections the results are shown on rheological tests, thermal heating, compressive strength, penetration of chloride ions and carbon dioxide, and drying shrinkage.

Rheological Behavior. The three concrete mixtures were characterized from a rheological point of view by carrying out the following tests: slump-flow, V-funnel, U-box, L-box with vertical bars, and L-box with horizontal bars [2]. Figure 1 shows the equipments needed for these tests. All the results of these tests (Table 4) indicate that, at a given slump-flow (the most used workability test for SCC), concretes with slag-cement (CEM III) or the composite one (CEM V) perform with the highest mobility in terms of lower time taken to reach a position of rest (Table 4); SCC with the pozzolanic cement appears to be the most cohesive concrete and then the slowest one.

This behavior is confirmed by the results of the L-box test with the vertical bars (Table 5), as well as by those of the L-box with the horizontal bars (Table 6) the latter being perhaps the most severe test to assess the mobility of SCC through a very congested metallic reinforcement without causing segregation. All these concrete mixtures did not show any segregation at all, although no viscosity agent was used.

Thermal Heating. About 250 L of fresh concrete was placed into a wood cubic container (630 mm) thermally insulated by a polystyrene coating 40 mm thick in order to measure, in quasi-adiabatic conditions, the temperature through a thermocouple in the center of the container. The maximum temperature increase was recorded at 3 days and was about the same (30 °C) for all the SCCs with a slight lower value for the concrete with pozzolanic cement (28 °C).

Compressive Strength. Figure 2 shows the compressive strength as a function of time at 20 °C . The strength at early ages (3-21 days) is higher for the SCC with slag cement than for that with pozzolanic cement, whereas the concrete with slag and fly ash shows an intermediate behavior. All the concretes meet the project requirement of a 28-day cube compressive strength of at least 55 MPa. At longer ages (60-90 days) the SCC with the composite cement performs a little better (≈ 85 MPa) than that with slag cement (≈ 82 MPa) and better than the pozzolanic cement (≈ 75 MPa)

Durability. Figures 3 and 4 show the penetration depth of chloride and carbon dioxide, respectively, in concrete specimens cured 7 days and then immersed in a 3.5% NaCl aqueous solution or exposed to air with relative humidity (RH) of 70 % . All the results in terms of Cl^- diffusion (Fig. 3) or CO_2 penetration (Fig.4) indicate that the very low permeability behavior found in ordinary concretes [3,4] is confirmed in SCCs manufactured at a w/cm as low as 0.31 and with replacement of portland cement by 50% of slag and/or fly ash. In particular, the chloride penetration in the slag SCC at 1 year is about 3 mm and a little higher in the other two SCCs. By assuming a linear trend [5] for the chloride penetration depth (*x*, in mm) versus the square root of time ($\sqrt{t}$, in $year^{1/2}$) according to equation (1)

$$x = k \cdot \sqrt{t} \qquad (1)$$

the *k* value is about 3 $mm \cdot year^{-1/2}$ and therefore can be assessed by extrapolation the theoretical time (*t*) taken by Cl^- ions to fully penetrate a 30mm-thick cover (*x*) of the slag SCC:

$$t = (x/k)^2 = (30/3)^2 = 10^2 = 100 \text{ years}$$

Drying Shrinkage. Figure 5 show the results of drying shrinkage tests of concrete specimens cured 7 days and then exposed to air at 20 °C with RH of 50%. These results indicate that the drying shrinkage at 6 months is about 450 micro-strains for the SCC with slag or composite cement and lower, by about 15% less, for the concrete with pozzolanic cement.

CONCLUSIONS

The results of this work indicate that high performance SCCs (characterized by low heat of hydration, high compressive strength (80-85 MPa at 90 days), very low permeability in environments containing chloride ions or CO_2, and relatively low drying shrinkage) can be manufactured with portland cement replaced by 50 % of slag and/or fly ash and a water-cement ratio as low as about 0.30.

The mobility of SCC with slag or slag-fly ash is much higher than that of SCC with fly ash. The latter appears to be very cohesive and thus slower than the other mixtures.

The thermal heating in quasi-adiabatic conditions is about 30 °C with a slightly lower temperature increase of 28 °C for the SCC with pozzolanic cement.

The compressive strength of SCC with slag or slag-fly ash is higher than that of the concrete with fly ash, particularly at early ages.

The penetration of CO_2 and in particular of chloride ions is very low due to the water-tightness of all these SCC with a w/cm of about 30 mm and the presence of slag and/or fly ash which strongly retard the diffusion of Cl- through the cement matrix of these concretes.

The drying shrinkage is relatively low for these SCCs (less than 450 micro-strains in very dry environments with RH of 50%) and even lower for the SCC with pozzolanic cement.

REFERENCES

[1] Troli, R., Ogoumah Olagot, J.J., Monosi, S., and Collepardi, M., “Low Heat Development in SCC for Massive structures”, Proceedings of the Seventh CANMET-ACI International Conference on Superplasticizers and Other Chemical Admixtures, Berlin (Germany), pp.103-112, 2003.

[2] Uomoto T. and Ozawa K., “Recommendation for Self-Compacting Concrete”, Japanese Society of Civil Engineers, Shinjyuku, Tokyo, pp.1-70, August 1999.

[3] McGrawth, P.F., Hooton, R.D., Influence of Binder Composition on Chloride Penetration Resistance”, Proceedings of the Fourth CANMET-ACI International Conference on Durability of Concrete, Sydney (Australia), pp.331-348, Editor V.M. Malhotra.

[4] Borsoi, A., Collepardi, S., Coppola, L., Troli, R. and Collepardi, M., Superplasticized Concretes with Slag-Fly Ash-Portland Cement” Supplementary papers of the Sixth CANMET-ACI International Conference on Superplasticizers and Other Chemical Admixtures, Nice (France), pp. 93-103, 2000.

[5] Collepardi,M., Marcialis, A. and Turriziani, R., “Penetration of Chloride Ions in Cement Pastes and in Concretes”, Journal of American Ceramic Society, Vol.55, pp 534-535, 1972.

Table 1 – Chemical composition of Portland cement, fly ash, and slag used to produce blended cements

Oxyde (%)	Portland cement	Fly Ash	Slag
SiO_2	21.25	59.94	36.50
Al_2O_3	4.33	22.87	11.67
Fe_2O_3	1.85	4.67	1.01*
TiO_2	0.13	0.94	0.20
CaO	64.30	3.08	38.95
MgO	1.81	1.55	8.08
SO_3	3.70	0.35	1.00**
K_2O	0.71	2.19	0.42
Na_2O	0.17	0.62	0.34
l.o.i.	1.50	3.34	1.28

*as FeO **as S

Table 2 - Composition of blended cements (Blaine fineness of about 400 m²/kg)

Blended cement	Portland	fly ash	ggbfs	EN
(Type)	(%)	(%)	(%)	terminology
Slag	50	-	50	CEM III
Pozzolanic	50	50	-	CEM IV
Composite	50	25	25	CEM V

Table 3 - Composition of the concrete mixtures all at w/cn of 0.31

Cement (type)	Cement (kg/m³)	Sand (kg/m³)	Gravel (kg/m³)	Water (kg/m³)	SP* (kg/m³)
Slag	508	893	950	254	3.71
Pozzolanic	498	876	947	249	6.47
Composite	500	879	955	250	5.00

*Superplasticizer

Table 4 - Slump-flow, V-funnel and U-box tests of SCC

SCC (with cement)	Slump-flow		U-Box	V-funnel
	Diameter (mm)	Time (sec)	Time (sec)	Time (sec)
Slag	745	35	15	17
Pozzolanic	740	100	36	40
Composite	750	35	12	15

Table 5 - Times and difference in level (ΔH) of SCC in the L-box test with vertical bars

SCC (with cement)	Times (in sec.) taken to reach:				ΔH (mm)
	200 mm	400 mm	End	Rest	
Slag	1	3	5	21	15
Pozzolanic	7	8	15	60	10
Composite	1	3	5	24	0

Table 6 - Times and difference in level (ΔH) of SCC in the L-box test with horizontal bars

SCC (with cement)	Times (in sec.) taken to reach:				ΔH (mm)
	2nd bar	4th bar	End	Rest	
Slag	2	7	19	57	70
Pozzolanic	6	12	47	100	100
Composite	2	4	10	60	10

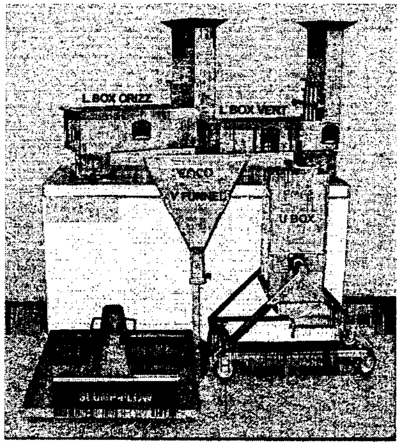

Fig. 1 –Equipments for the rheological assessment of SCCs.

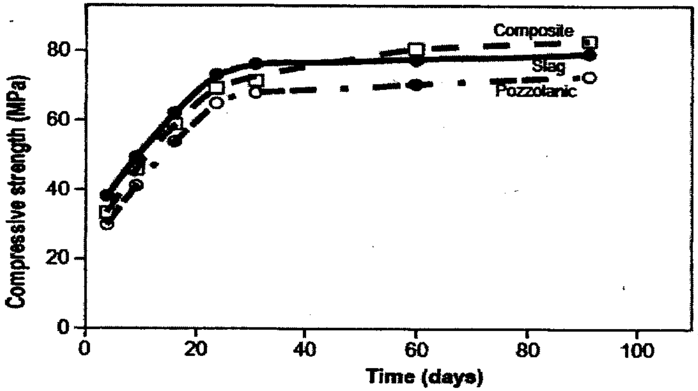

Fig. 2 – Compressive strength of SCC with slag cement, pozzolanic cement, and composite cement.

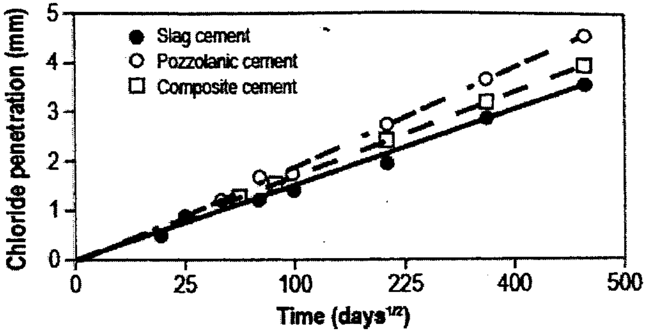

Fig. 3 – Chloride penetration in SCC (w/c = 0.3 N) with different cements as a function of time.

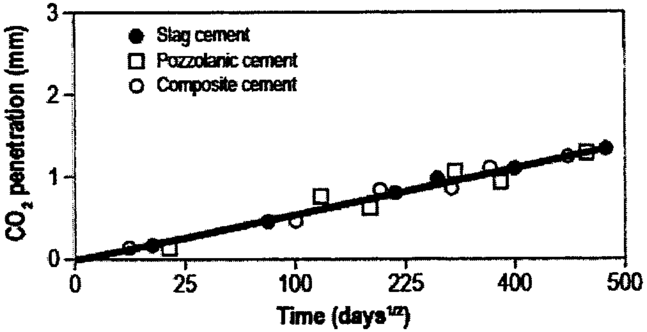

Fig. 4 – Carbonation depth of SCCs with different cements.

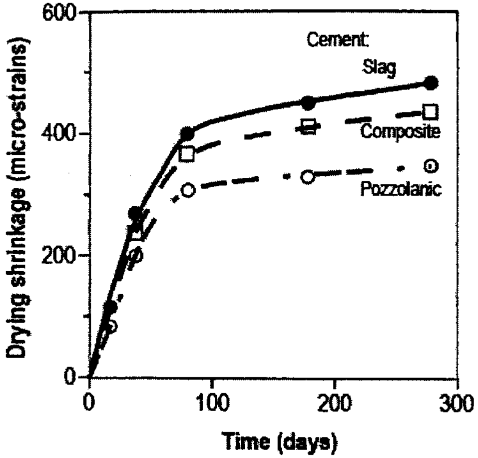

Fig. 5 – Drying shrinkage at RH of 50% of the SCCs with different cements.