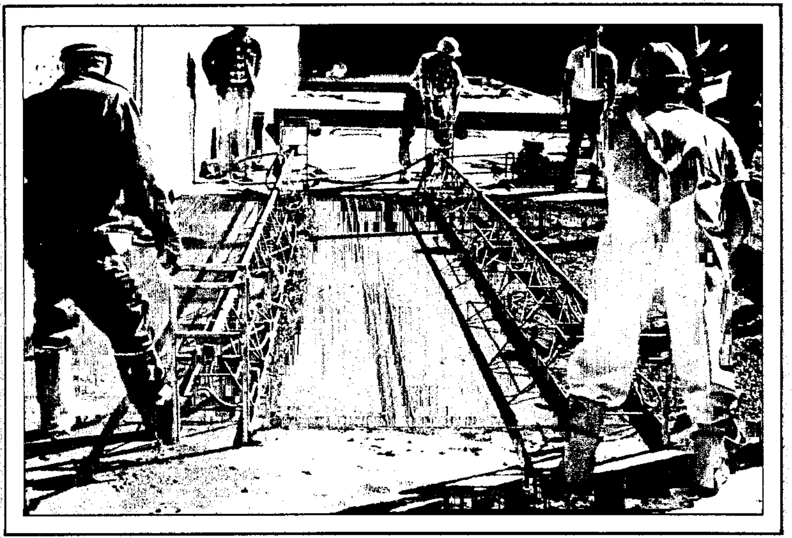

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TERENCE C. HOLLAND SYMPOSIUM
ON
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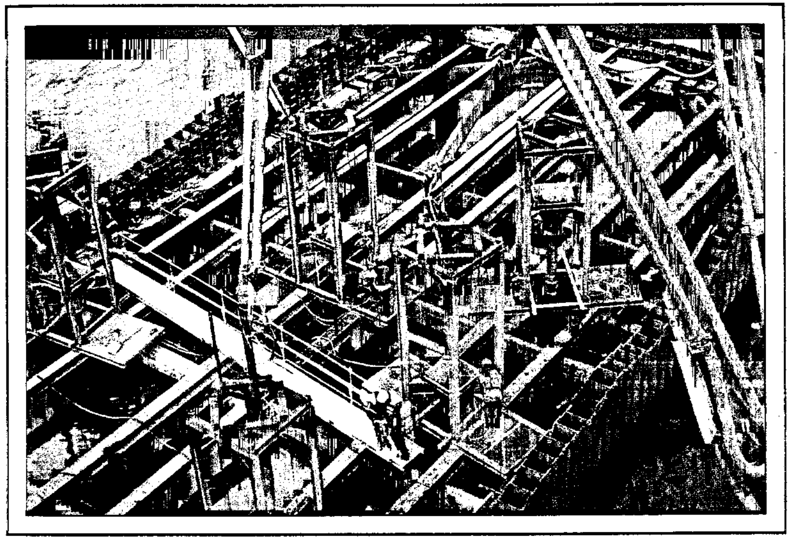

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MECHANICAL PROPERTIES OF SELF-COMPACTING AND FLOWING CONCRETES

by M. Collepardi

Synopsis: A flowing concrete and two self-compacting concretes were manufactured, at given Portland cement content (400 kg/m3) and water-cement ratio (0.45), in order to obtain the same 28-day compressive strength.

Ground limestone or fly ash was used in to manufacture self – compacting concrete (SCC). A polycarboxylate-based superplasticizer was adopted to produce SCCs with a slump-flow of about 750 mm and a flowing concrete with a slump of 200 mm.

Compressive strengths of SCCs were higher than that of the flowing concrete. This can be explained by the pozzolanic activity of fly ash in addition to the cement content. However, ground limestone is not a pozzolanic material and then its action can be related with a change in the microstructure of the cement matrix caused by the small particles of limestone. The change in the microstructure can also explain why the steel-bond strength is much higher in the two SCCs than in the flowing concrete.

Keywords: Bond-strength, Compressive strength, Fly ash, Limestone filler, Segregation, Self-Compacting Concrete.

ACI member **Dr. Mario Collepardi** 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.

INTRODUCTION

Self-Compacting Concrete (SCC), is a segregation-free concrete although it is so fluid that it can completely fill any area of the formwork in the absence of any compaction effort. The main characteristic of SCC is the higher cement matrix-aggregate ratio with respect to an ordinary concrete. On the other hand, the volume of the aggregate - in particular the coarse aggregate - must be reduced in terms of both volume and maximum size , to improve the mobility and the segregation-resistance of the fresh mixture. Figure 1 summarizes these changes on a quantitative basis by comparing the volume of the ingredients in an ordinary concrete and in the corresponding SCC at the same water-cement ratio (w/c).The following rules should be followed to be successful in manufacturing SSC(1):

- excessive values of cement and filler volumes (Vc+Vf) make the mixture too viscous and reduce its mobility; on the other hand, too low values in (Vc+Vf) increase the segregation risk;
- a value in the water volume(Vw) to fine volume (VwVw/(Vc+Vf higher than 1.20 increases the risk of segregation, whereas a value lower than 0.85 makes the fresh concrete too viscous.
- volume and maximum size of the coarse aggregate must be lower than 340 L/m3 and 25 mm respectively, in order to avoid segregation and collision among aggregate particles that can block the concrete flow.

The purpose of the present work was to study the mechanical properties, in terms of compressive strength and steel-concrete bond, of an ordinary fluid concrete (OFC) at a slump of 200 mm and those of SCCs at given w/c and Portland cement content.

EXPERIMENTAL: MATERIALS AND METHODS

Materials

Concrete mixtures with a w/c of 0.45 were designed (Table 1). The composition of an ordinary flowing concrete (slump 200 mm) and that of two self-compacting concretes with fly ash (F-SCC) or ground limestone (LSCC) as fine mineral addition(0.1-45 mm), were manufactured at a given portland cement content (400 kg/m3) and at a given amount of mixing water (180 kg/m3). The maximum size of the coarse aggregate for all the mixtures was 20 mm and then compatible with the limit required by SCC for the coarse aggregate size (< 25 mm).

The water-binder ratio of the fly-ash-SCC (F-SCC) is 0.34 if one takes into account the amount of fly ash (135 kg/m3) to act as a cementitious material. On the other hand, if one considers the amount of ground limestone (160 kg/m3) just as the finest fraction of the aggregate, then the particle size distribution of the aggregate is changed with respect to that of the OFC. Figure 2 shows the particle size distribution of the aggregate used in the OFC (42% of sand; and 58% of gravel) and that adopted for the L-SCC (9% of ground limestone; 45 % of sand; and 46% of gravel), both compared with the Bolomey's standard curve.

The amount of superplasticizer, based on acrylic polymer, was: 0.6% for OFC (slump = 200 mm); 1.1% for the L-SCC (slump flow = 750 mm); and 1.3 for the F-SCC (slump flow =740 mm). The viscosity-modifying admixture, VMA(2), was 0.25% for L-SCC and 0.20% for the F-SCC. Figure 1 shows the volume of the two SCCs in comparison with that of the ordinary flowing concrete: with respect to this concrete the two SCCs contain more volume of fine material and less volume of the coarse aggregate, whereas there is no difference in the volume of cement, water, sand and air.

Methods

The OFC was placed in cubic formworks and fully vibrated. The two SCCs were poured into the formworks without any vibration at all. All the concrete mixtures were wet cured at 20°C and the compressive strength was measured from 1 day to 28 days.

Reinforced concrete specimens, devoted to the measurement of the steel-concrete bond, were manufactured as shown in Fig.3$^{(3)}$. Again the two SCCs were placed without any vibration, whereas for the OFC three vibration times were adopted: 0-15-30 seconds. These reinforced specimens were wet cured at 20°C and then the steel-concrete bond was measured at 28 days by pulling-out the metallic bar as schematically shown in Fig.3.

Some cement matrix was taken from the concrete specimens at 28 days and was examined by scanning electron microscopy in order to study the microstructure of the OFC in comparison with that of the two SCCs.

RESULTS

Compressive Strength

Figure 4 shows the compressive strength values at 1-3-7-21-28 days of the two SCCs in comparison with that of the OFC. At a given w/c of 0.45, the two SCCs were stronger (by about 20%) than the OFC at early and later ages. The mechanical behavior of the F-SCC could be expected on the basis of the pozzolanic activity of the fly ash. Indeed, the water-binder ratio of the F-SCC (0.34) is lower than that of the corresponding OFC at the same w/c of 0.45.

On the other hand, the mechanical behavior of the L-SCC is surprising since limestone is not considered to act as a pozzolanic material. Then, its enhancing effect on the strength of the SCC, with respect to that of the corresponding OFC at equal w/c, should be ascribed to a physical rather than to a chemical effect. The fine particle of the ground limestone could act as filling material for the voids of the cement matrix in the SCC. On the other hand, fly ash could act as both filling and pozzolanic material and this could explain why the strength of the F-SCC is slightly higher than that of the corresponding L-SCC, particularly at early ages.

Microstructure and Steel Bond

The microstructure of the cement matrix shown in Fig. 5-7 confirm the above hypothesis to explain the filling effect of the ground limestone. The presence of C-S-H on the surface of the fly ash particles (Fig. 7) indicate the pozzolanic effect in addition to the filling one. This microstructural characteristics can also explain why the steel-bond of the two SCCs are much better (by about 70%) than that of the OFC (Fig.8). Moreover, an excessive vibration (from 15 to 30 seconds) of the OFC reduces the steel-bond probably for the presence of the bleeding water at the interface of the steel-concrete interface: Fig. 9 schematically shows how the filling action of ground limestone or fly ash can improve the steel bond interface in SCC with respect to that of the OFC.

CONCLUSIONS

Two SCCs concretes (slump flow about 750mm) with fly ash or ground limestone as fine materials have been studied in comparison with the corresponding ordinary flowing concrete (slump of 200 mm) at the same w/c (0.45) and cement content (400 kg/m3). The results of the present work indicate that compressive strength and steel-bond strength in SCCs with fly ash or ground limestone are higher than in the corresponding ordinary flowing concrete.

In particular, the absence of vibration in placing the SCCs significantly improves the steel-bond strength with respect to that of the OFC; the latter can be damaged by an excessive vibration for the formation of bleeding water at the steel-concrete interface.

The mechanical behavior of the SCC with respect to that of the ordinary flowing concrete could be ascribed to the filling effect of the fine particles of ground limestone or fly ash in the micro-voids of the cement matrix. The additional pozzolanic effect can explain why the strength of the fly-ash-SCC is slightly higher than that of the limestone-SCC particularly at early ages.

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Table 1 – Composition and workability of Ordinary Flowing Concrete (OFC) and SCCs.

Ingredients/Properties		MIX		
		OFC	L/SCC	F/SCC
CEM I 52.5R (kg/m^3)		400	400	400
Filler (kg/m^3)		----	Limestone 160	Fly Ash 135
Aggregate	Sand (0-4 mm) kg/m^3	760	785	785
	Gravel (4-20 mm) kg/m^3	1040	845	845
Water (kg/m^3)		180	180	180
Superplasticizer* (kg/m^3)		2,4	4,5	5,2
VMA** (% cem)		----	0,25	0,20
water/cement ratio		0,45	0,45	0,45 (0,34)***
Slump (mm)		180	----	----
Slump flow (mm)		----	750	740

* Polycarboxylate-based superplasticizer

** VMA = Viscosity Modifying Agent

***Within brackets the value of water-binder ratio with fly ash as cementitious material

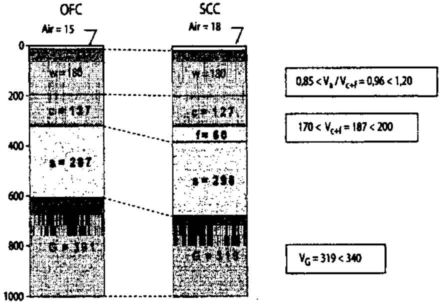

Fig. 1 – Composition in volume (L/m^3) of the ingredients in the Ordinary Fluid Concrete (OFC) and SCC.

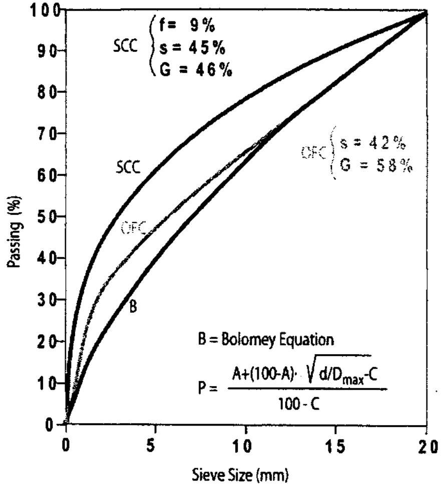

Fig. 2 – Particle size distribution of the aggregate in L/SCC or Ordinary Flowing Concrete (OFC) in comparison with the Bolomey equation; f= ground limestone; s= sand; G = gravel.

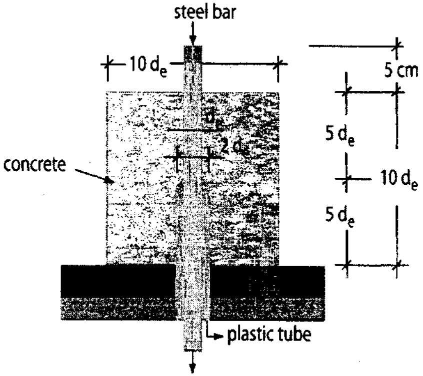

Fig. 3 – Reinforced specimen for the steel-concrete bond test according to RILEM-CEB [2]

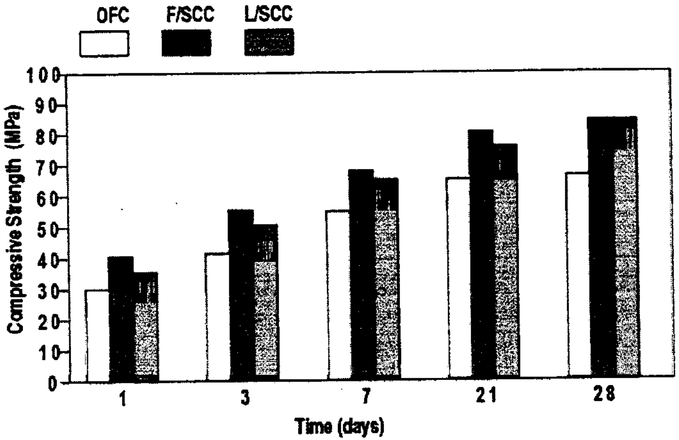

Fig. 4 – Compressive Strength of OFC, L/SCC and F/SCC

Fig. 5 – SEM micrograph of the cement matrix of OFC (by D. Salvioni, Mapei).

Fig. 6 – SEM micrograph of the cement matrix of L/SCC (by D. Salvioni, Mapei).

Fig. 7 – SEM micrograph of the cement matrix of F/SCC (by D. Salvioni, Mapei).

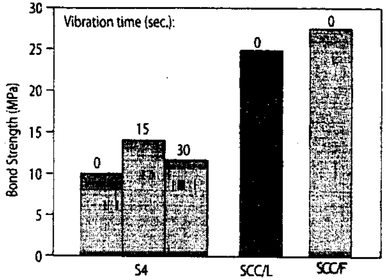

Fig. 8 – Steel bond-strength of OFC and SCCs. The figures indicate the vibration time.

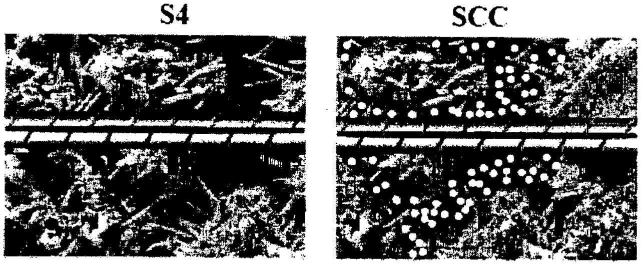

Fig. 9 – Schematic model of strength-concrete area in ordinary flowing concrete and in SCC.