INNOVATIVE CONCRETES FOR CIVIL ENGINEERING STRUCTURES: SCC, HPC AND RPC

By M. Collepardi

Synopsis: During the last decades, new cementitious materials were available. These represent a sort of technical revolution with respect to the traditional concretes. The most important innovative “High Tech” materials are: Self-Compacting Concrete (SCC), High Performance Concrete (HPC), and Reactive Powder Concrete (RPC).
In the present paper the compositions, the performances and some practical applications are shown. In particular, some performance improvements carried out in our laboratories are evidenced for these specific uses:

a) SCC for a Building Engineering application (S. Peter Apostle Church in Pescara, Italy) with white concrete characterized by a marble-like skin;
b) HPC in form of concrete with compressive strength over 90 MPa devoted to a work in the field of Civil Engineering (World Trade Center in San Marino);
c) RPC in form of a fiber-reinforced concrete with a high fracture energy (40 kJ/m^2) devoted to a special work in the area of Environmental Engineering (dumping of radioactive nuclear wastes).

Keywords: High Performance Concrete, Reactive Powder Concrete, Self-Compacting Concrete, Silica Fume, Superplasticizer.

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INTRODUCTION

With respect to the traditional concretes, the new cementitious materials [1], thanks to the availability of new raw materials, allow to reach much higher performances in terms of execution on job sites, useful service life, and mechanical strength. These new raw materials include:

- new synthetic polymers (poly-acrylates) which, with respect to naphthalene- or melamine-sulphonated polymers, are able to reduce even more effectively the amount of mixing water and then the water-cement ratio with all the consequent benefits [1];
- viscosity Modifying Agents based on Welan Gum to produce thixotropic mixes and then to obtain cohesive fresh concretes even when very fluid [1];
- polymeric metallic fibers to increase the ductility and the fracture energy of concretes which usually are brittle materials [1];
- mineral additions characterized by amorphous silica such as silica fume (waste from silicium-iron alloys) in form of very fine particles (size of some m/m) or UFACS (Ultra-Fine Amorphous Colloidad Silica) synthetically produced in form of particles (size of some nm)

EXPERIMENTAL AND DISCUSSION OF RESULTS

The term Self-Compacting Concrete (SCC) refers to a special type of concrete mixture, characterized by high resistance to segregation, that can be cast without compaction or vibration. With the advent of superplasticizers, flowing concretes with slump level up to 250 mm were manufactured with no or negligible bleeding, provided that an adequate cement factor was used, that is at least 350 kg/m^3. The most important basic principle for flowing and unsegregable concretes including SCCs is the use of superplasticizer combined with a relatively high content of powder materials in terms of portland cement, mineral additions, ground filler and/or very fine sand. A partial replacement of Portland cement by fly ash was soon realized to be the best compromise in terms of rheological properties, resistance to segregation, strength level, and crack-freedom, particularly in mass concrete structures exposed to restrained thermal stresses produced by cement heat hydration. Some other mineral additions, alternative to fly ash, have been taken into account for the three works presented in this paper: they are silica fume or ground limestone. However, when for architectural reason, white SCCs are needed, then fly ash and silica fume, both black coloured, cannot be used and only ground limestone is available.

The term High Performance Concrete (HPC), refers to cement mixtures with a water-binder ratio as low as 0.30-0.40, so that 28-day compressive strength as high as 70-100 MPa or even 1-day compressive strength as high as 45-55 MPa can be obtained. Due to these mechanical properties, the structural design of the modern reinforced concrete constructions, as well as the executing techniques, can be significant changed.

Reactive Powder Concrete (RPC) are even stronger than HPC since compressive strength can be as high as 200 MPa. However, due to the presence of metallic fibers embedded in a very dense cement matrix and substantially pore-free for the very low water-binder ratio (about 0.20), RPC is an extra-ordinary cementitious material for its ductility with respect to the brittleness of normal performance concrete (NPC). Moreover, RPCs are particularly adequate for special applications when ultra-durability requirements are needed for safety reasons as for instance, in dump of nuclear wastes.

In this paper three specific concretes are shown belonging to the SCC, HPC and RPC types: for an architectural concrete of the church of S. Peter Apostle in Pescara, the World Trade Center of San Marino, a dumping placement of radioactive nuclear wastes, respectively. For the mix-design of the three concretes, laboratory and field tests have been carried out. In the following sections the results for each of the three concretes are shown and discussed.

SCC MATERIAL

The properties required by the structural engineers of the construction may be summarized by the following data:

1) high fluidity in terms of **slump flow**: ≥ 650 mm after 1 hr at 30°C;
2) **characteristic strength**: $R_{ck} \geq 35$ MPa;
3) **impermeability** in terms of water penetration according to the ISO DIS 7031 test: ≤ 20 mm;
4) **marble-like effect** of the skin of the concrete placed in the absence of vibration.

In order to rach all these requirements, the composition adopted for the concrete mixture was that shown in Table 1.

The performances really obtained are shown in Table 2 and they are all capable to meet the above first three performances required by the structural designer.

As far as the marble-like effect of the skin is concerned – which was very important for the work from an architectural point of view – it was visually assessed by comparison of two white concretes, both placed without any vibration: the former at a fluid consistency S5, and the later in form of SCC. Figure 1 shows, for instance, the marble-like effect of the skin obtained only in the case of the SCC. Then, thanks to the special rheological properties of the SCC in the fresh state, even the fourth requirement needed by the architect was met.

HPC MATERIAL

For the World Trade Center in San Marino, a special concrete was required with the typical properties of SCC as shown in the previous section and, additionally, with a high compressive strength. These are the requirements needed for the work:

1) high fluidity in terms of **slump flow**: ≥ 600 mm after 1 hr;
2) **compressive strength** ≥ 65 MPa at 21 days and ≥ 80 MPa at 28 days;
3) **dynamic elastic modulus**: ≥ 40.000 MPa;
4) **drying shrinkage**:≤ 500 m/m at two months;
5) **uniformity** in terms of specific mass, elastic modulus, and compressive strength measured on cored specimens through field tests.

Table 3 shows both the adopted composition and the performances of the concrete. These agree with the first four requirements.

One cylinder specimen was cored from the un-vibrated concrete placement 1500 mm thick, and then the following measurements were carried out: specific mass (M_v) and dynamic elastic modulus (E_d) shown in Fig. 2, and compressive strength shown in Fig. 3.

The data obtained on different parts of the cored material indicated that the results obtained for the concrete of the structure are reproducible and agree very well with those obtained for the specimens cast in laboratory. Then, even the fifth requirement (about uniformity) is met.

RPC MATERIAL

This material was studied for a research devoted to obtain a very durable concrete structure as reliable container for radioactive wastes from disused nuclear plants. These are the properties required particularly challenging mainly for strength and ductility:

1) **compressive strength** (R_c): ≥ 200 MPa;
2) **flexural strength** (R_f): ≥ 50 MPa;

3) **compressive elasic modulus**: ≥ 60 GPa;
4) **fracture energy** determined by the stress-strain curve: ≥ 40 kJ/m^2;
5) **long terms durability** on the concrete structure in contact with a sulpahtic soil.

The adopted composition to reach all these objectives in shown in Table 4. A low-C_3A Portland cement was adopted because it is by itself sulpahte-resistant. This cement, combined with a very low water-(cement+silica fume) ratio of 0.20 is capable of meeting the required durability.

The obtained mechanical data can be summarized in terms of 205 MPa for the compressive strength, 60 MPa for the flexural strentght, 65 GPa for the static elastic modulus, and 45 kJ/m^2 for the fracture energy. These data fully meet all the required performances.

Figure 4 show the strain-stress curve of the adopted RPC in comparison with those a mormal performance concrete (NPC) and of the high performance concrete (HPC) studied in the previous section.

The greates ductility of the RPC with respect of that of HPC and NPC is mainly due to the presence of steel fibers with an aspect ratio (length/diameter=L/d in Table 4) of 72 embedded in a cement matrix substantially pore-free (Fig. 5).

CONCLUSIONS

The results obtained in the present paper show the extra-ordinary properties which can be obtained by using the innovative concretes recently developed.

In particular, SCC appears to be very succesful because it is easy to place the concrete in a safe way independently of the quality and reliability of the workmanship today available on the jobsites. The SCC presented in this paper is a very special concrete even for the excellent surface (white and with marble-like aspect) required for architectural reasons.

On the other hand, the HPC and specially the RPC can be considered as market niches in the field of Civil Engineering. Moreover the RPC could find interesting applications in the field of Mechanical, Chemical and Environmental Engineering; that studied in the present work is devoted to the area of environmental engineering in order to produce a container for radioactive wastes, coming from disused nuclear plants, which should be placed in safe and reliable concrete structures even if in contact with potentially aggressive soils for their high sulphate content.

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Table 1 – Composition of SCC

INGREDIENT	**kg/m^3**
WHITE Portland Cement CEM/II B-L 32.5R	400
COARSE CRUSHED MARBLE (2-16 mm)	875
FINE CRUSHED MARBLE (0-4 mm)	440
VERY FINE CRUSHED MARBLE (0-2 mm)	430
GROUND LIMESTONE	100
WATER	180
ACRYLIC SUPERPLASTICIZER	9.6
VISCOSITY MODIFYING AGENT	0.12
W-C RATIO	0.45

Table 2 – Performances of SCC

Specific Mass (fresh mix) (kg/m^3)		2417
Concrete Aspect		Cohesive
Slump Flow (mm) at 30°C after:	0 min.	700
	30 min.	680
	60 min.	650
Compressive Strength (MPa) at 20°C as a function of time (days)	1	17.2
	7	35.3
	14	39.4
	28	43.0
Water penetration (ISO-DIS 7031)		6 mm

Table 3 – Composition of HPC

Portland Cement (CEM I 42.5 R)	465 kg/m^3
SILICA FUME	65 kg/m^3
WATER	175 kg/m^3
GRAVEL (15-22 mm)	195 kg/m^3
GRAVEL (6-15 mm)	720 kg/m^3
SAND (0-6 mm)	710 kg/m^3
ACRYLIC SUPERPLASTICIZER	4.6 kg/m^3
water/(cement+silica fume)	0.33 kg/m^3
Slump flow at 5 and 60 min. (mm)	73-60
R_{cm} (MPa) a: 1 d	50
28 dd	95
Drying shrinkage at 60 days (µm\m)	380
Dynamic elasatic modulus at 28 days	≥ 45.000 MPa

Table 4 – Composition of RPC

CEMENT ferric type (CEM I 42.5R)	880 kg/m^3
SILICA FUME	220 kg/m^3
SAND (0-0.6 mm)	970 kg/m^3
Steel Fibers (L/d=72)	180 kg/m^3
WATER	220 kg/m^3
DRY ACRYLIC SUPERPLASTICIZER	12 kg/m^3
water/(cement+silica fume)	0.20

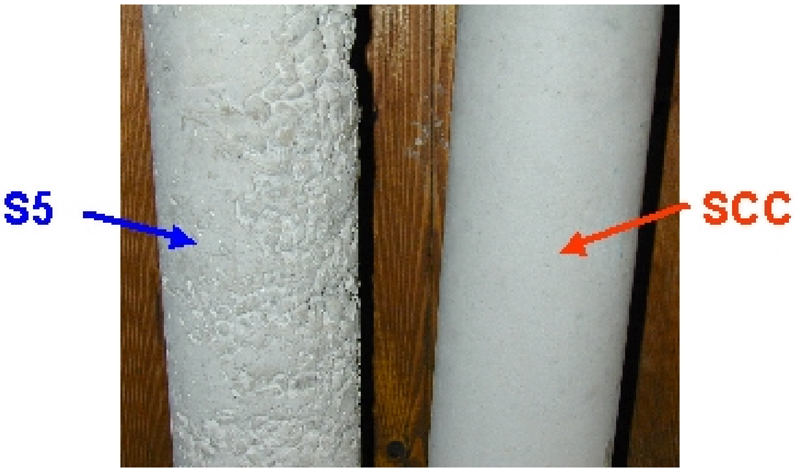

Fig. 1 – Skin effect marble-like of SCC with respect to a traditional concrete at a superfluid consistency (S5), both placed without compaction.

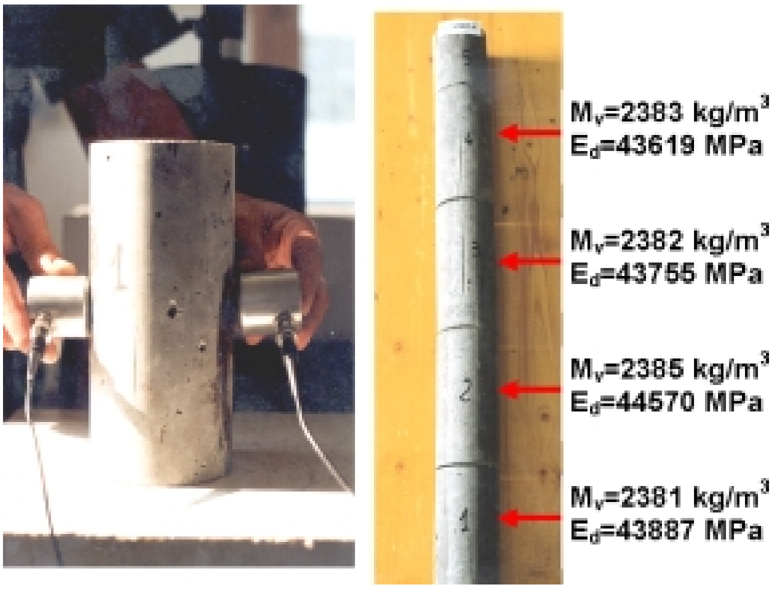

Fig. 2 – Specific mass (M_v) and dynamic elastic modulus (E_d) on cored concrete.

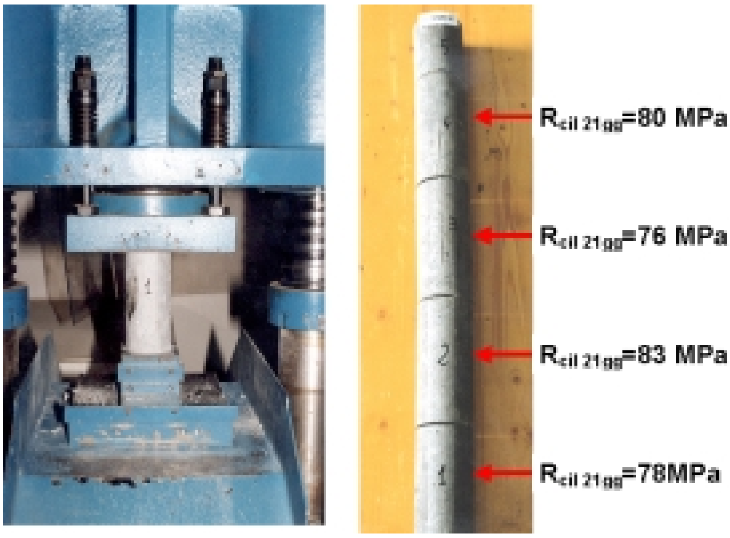

Fig. 3 – Compressive strength on cylinder specimens ($R_{cil21days}$) from cored concretes.

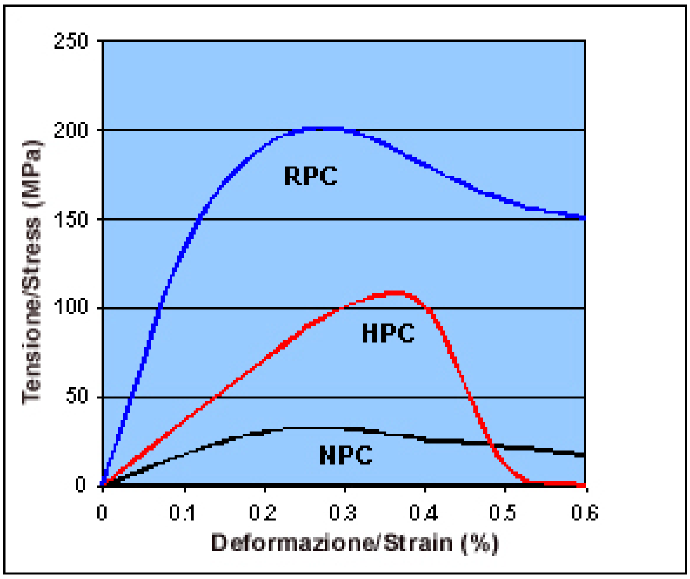

Fig. 4 – Stress-strain behaviour of RPC with respect to normal (NPC) and high performance concrete (HPC).

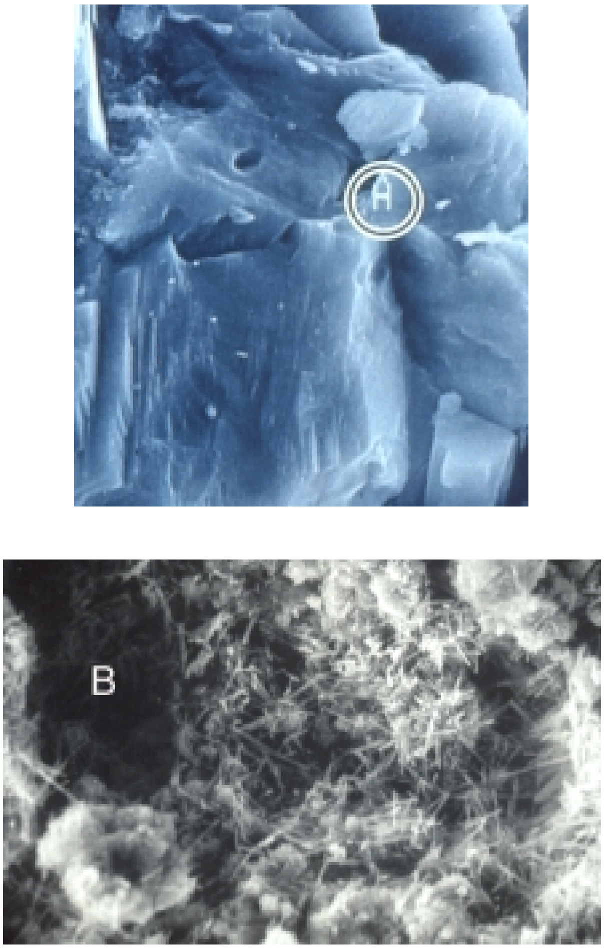

Fig. 5 – SEM microstructure of a traditional and porous cement matrix (B) and a very dense cement paste of RPC (A) [7].