

# Micro Environmental Concrete

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**Abstract**—Reactive powder concretes (RPC) are characterized by particle diameter not exceeding 600  $\mu\text{m}$  and having very high compressive and tensile strengths. This paper describes a new generation of micro concrete, which has an initial, as well as a final, high physico-mechanical performance. To achieve this, we replaced the Portland cement (15% by weight) by materials rich in Silica (Slag and Dune Sand).

The results obtained from tests carried out on RPC show that compressive and tensile strengths increase when adding the additions, thus improving the compactness of mixtures via filler and pozzolanic effect.

With a reduction of the aggregate phase in the RPC and the abundance of dune sand (south Algeria) and slag (industrial by-product of blast furnace), the use of the RPC will allow Algeria to fulfil economical as well as ecological requirements.

**Keywords**—High mechanical strength, Reactive Powder Concrete, rheology, superplasticizer, workability

## I. INTRODUCTION

It is common to think of concrete as being a mixture of paste (Cement + water + additions + additives) and granular skeleton (aggregates+sand), which makes concrete heterogeneous material. The heterogeneity causes problems due to differences in hardness, chemical shrinkage, and thermal expansion of paste versus aggregate, which induces microcracks that weaken the concrete [1]-[11].

The removal of some aggregate, in the case of the RPC, leads to an improvement of the homogeneity of concrete [1].

In order to considerably improve the homogeneity, the compactness and even the ductility of the concrete, "Reactive Powder Concretes (RPC)" have been developed, which are considered as micro concretes that are characterized by a diameter of the particles not exceeding 600  $\mu\text{m}$ , a very low water to cement ratio (w/c) and very high compressive and tensile strengths, even higher than that of steel (350MPa) [11].

This paper describes micro concretes RPC containing materials rich in silica (silica fume SF, slag LH and dune sand SD very finely ground) to replace Portland cement by 15% by weight

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The principal objective is to characterize these RPC using mechanical tests (compression and tensile). The RPC were made at low W/C ratios by using two types of superplasticizers (with different chemical base). Two additives were used in order to control the workability of the RPC as long as was necessary for placing consolidating and completing specimen fabrication.

## II. MATERIALS

The materials used in this study are:

- Granular skeleton composed of fine sand (Algerian south): S
- Algerian cement CEM II/A: C
- Mineral additions: A
- Silica fume SF
- Blast furnace slag LH
- Dune sand finely ground SD

Chemical addition: two superplasticizers are used SP

- Superplasticizer containing Polysulfonates : SP1
- Superplasticizer containing Polycarboxylates : SP2

With the exception of the silica Fume SF, which is of Canadian source, the materials used are of local origins.

The physico-mineralogical, chemical and mechanical properties of materials used in this study are given in tables I to V:

TABLE I  
PHYSICAL CHARACTERISTICS OF CEMENT

|                                                  |                              |
|--------------------------------------------------|------------------------------|
| Real density ( $\text{g}/\text{cm}^3$ )          | 3.10                         |
| Apparent bulk density ( $\text{g}/\text{cm}^3$ ) | 1.04                         |
| Specific surface area ( $\text{cm}^2/\text{g}$ ) | 3152                         |
| Normal consistency                               | 0.27                         |
| Expansion in mm                                  | 0.72                         |
| Start and End of setting                         | BS = 1h57min<br>ES = 3h47min |

TABLE II  
PHYSICAL PROPERTIES OF THE ADDITIONS USED

| Addition                                               | SF               | LH               | SD               |
|--------------------------------------------------------|------------------|------------------|------------------|
| Real density ( $\text{g}/\text{cm}^3$ )                | 2.20             | 2.80             | 2.40             |
| Apparent bulk density ( $\text{g}/\text{cm}^3$ )       | 0.50             | 1.12             | 1.45             |
| Specific surface area ( $\text{cm}^2/\text{g}$ )       | 200 000<br>(BET) | 5000<br>(Blaine) | 6600<br>(Blaine) |
| Average diameter<br>of the particles ( $\mu\text{m}$ ) | 0.32             | 3.79             | 4.29             |

TABLE III  
MINERALOGICAL COMPOSITION OF CEMENT (BOGUE)

|                              |       |
|------------------------------|-------|
| $\text{C}_3\text{S}$         | 48.41 |
| $\beta\text{C}_2\text{S}$    | 20.58 |
| $\text{C}_3\text{A}$         | 8.68  |
| $\text{C}_4\text{AF}$        | 9.03  |
| $\text{C}\text{S}\text{H}_2$ | 5.33  |
| CaO free                     | 0.18  |

TABLE IV  
CHEMICAL COMPOSITION OF CEMENT AND ADDITIONS USED  
(% PERCENTAGES BY WEIGHT)

|                                | Cement | SF    | LH    | SD    |
|--------------------------------|--------|-------|-------|-------|
| SiO <sub>2</sub>               | 19.82  | 96.00 | 40.53 | 94.90 |
| CaO                            | 60.40  | 1.58  | 39.89 | 0.90  |
| MgO                            | 1.09   | 0.20  | 1.30  | 0.97  |
| Fe <sub>2</sub> O <sub>3</sub> | 2.97   | 0.60  | 0.75  | 0.48  |
| Al <sub>2</sub> O <sub>3</sub> | 5.17   | 0.90  | 8.16  | 1.48  |
| SO <sub>3</sub>                | 2.48   | 0.45  | 2.00  | 0.03  |
| Na <sub>2</sub> O              | 0.41   | 0.17  | 0.16  | 0.10  |
| K <sub>2</sub> O               | 0.76   | 0.96  | 0.41  | 0.20  |
| CaO free                       | 0.18   | /     | /     | /     |
| LOI                            | 3.11   | /     | 1.01  | 0.50  |
| Cl-                            | 0.002  | /     | 0.005 | 0.003 |
| RIns                           | 4.23   | /     | /     | /     |

TABLE V  
MECHANICAL PROPERTIES OF CEMENT

|                            | 2d    | 7d    | 28d   |
|----------------------------|-------|-------|-------|
| Compressive strength (MPa) | 18.96 | 34.66 | 47.30 |
| Tensile strength (MPa)     | 2.91  | 4.47  | 5.73  |

In order to highlight the mineralogical nature of these particles an x-ray diffraction analysis has been used.

Their x-ray diffraction patterns show that [2]-[4]-[13]:

Silica fume SF has an amorphous structure near to that of Cristobalite

Blast furnace slag LH has an amorphous structure near to that of Melilite.

Ground dune sand SD has a crystallized structure of Low Quartz type.

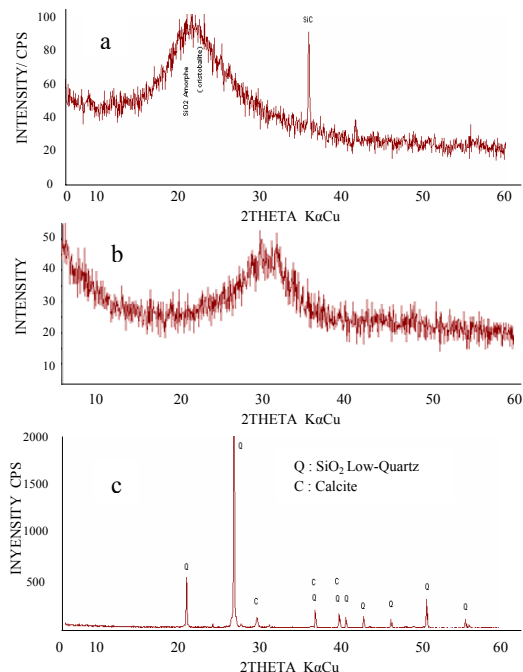


Fig.1 X-ray diffraction pattern:  
a)Silica fume, b) Slag furnace, c) Dune sand

### III. TESTS ON RPC

Several series of test-specimens, (4x4x16 cm at 20C°) of various material proportions, were tested.

Experimental results for the RPC in both fresh and hardened state are presented as follows:

- In the fresh state: Measurements of the workability by means of LCPC maniabilimeter and the density of the RPC have been conducted.
- In the hardened state: Compression and Tensile mechanical tests have been carried out.

In order to improve the workability of the RPC two types of superplasticizer (SP1 and SP2) were used. Additions of SF, LH and SD were incorporated at a rate of 15 % by substitution of the cement's weight to improve the compactness of the cementing matrix of the RPC, aiming of high strengths with a low water/cement ratio (W/C) [14]-[15]-[16]. The combinations used are presented in Table VI

TABLE VI  
COMPOSITION OF THE RPC CONTAINING SUBSTITUTION OF ADDITIONS [KG][2]

|         | W/B* | T**    | SP    | C   | S   | A   |
|---------|------|--------|-------|-----|-----|-----|
| RPC T** | 0.20 | 164.20 | 16.42 | 821 | 904 | 0   |
| RPC SF  | 0.17 | 139.57 | 16.42 | 698 | 904 | 123 |
| RPC LH  | 0.20 | 164.20 | 16.42 | 698 | 904 | 123 |
| RPC SD  | 0.20 | 164.20 | 16.42 | 698 | 904 | 123 |

\* B=C+Additives (A)      \*\* T : witness

Taking into account the lubricant role played by the silica fume (high fineness and amorphous structure), the W/B was reduced to 0.17 rather than 0.20 [5]-[6]-[7]-[10]-[12]

### IV. TESTS ON RPC IN A FRESH STATE

Results for fresh RPC made with the two varieties of superplasticizers, SP1 and SP2, are listed in Table VII.

TABLE VII  
WORKABILITY AND DENSITY OF THE STUDIED RPC 2

|        | W/B  | t (s) | d (g/cm <sup>3</sup> ) | t (s) | d (g/cm <sup>3</sup> ) |
|--------|------|-------|------------------------|-------|------------------------|
| RPC T  | 0.20 | 100   | 2.156                  | 39    | 1.884                  |
| RPC SF | 0.17 | 20    | 2.289                  | <1    | 1.975                  |
| RPC LH | 0.20 | 104   | 2.166                  | 38    | 1.676                  |
| RPC SD | 0.20 | 105   | 2.173                  | 35    | 1.688                  |

The LCPC maniabilimeter time of the RPC made with SP2 was found to be less than that of the RPC made with SP1.

The increase in workability allowed a very easy placing of RPC.

In terms of workability the results show that:

Independent of the type of cement replacement, the use of the SP2 instead of the SP1, improves significantly the workability of various RPC (SF, LH, SD and T). This improvement is due to the different chemical nature of superplasticizers (SP1 and SP2).

Table VII shows that the densities of the RPC made with SP2 are lower in a fresh state compared to those of the RPC made with SP1. This reduction implies

The repulsion of the grains between them and thus the improvement of the workability of the RPC in a fresh state.

Although the SP2 makes RPC more workable, it was not possible to reduce the W/B ratio to values lower than 0.20 for (LH, SD, T) and 0.17 for SF.

Once more, the obtained results confirm the superplasticizer role played by the silica fume; by the finesse of this last one, with has a lubricant effect to reduce the LCPC maniabilimeter time [9]-[12] ]-[17]-[18].

V. TESTS ON RPC IN A HARDENED STATE

A. Compressive strength

Table VIII and Fig. 2 show the RPC compressive strengths with time.

TABLE VIII  
RPC COMPRESSIVE STRENGTHS (MPa) [2]

|     |     | RPC T | RPC SF | RPC LH | RPC SD |
|-----|-----|-------|--------|--------|--------|
| 3d  | SP1 | 41.88 | 63.44  | 40.50  | 31.25  |
|     | SP2 | 32.10 | 56.33  | 30.22  | 25.88  |
| 7d  | SP1 | 55.21 | 86.25  | 51.15  | 40.63  |
|     | SP2 | 45.66 | 82.66  | 43.66  | 36.44  |
| 14d | SP1 | 66.64 | 100.00 | 66.28  | 63.95  |
|     | SP2 | 55.36 | 97.32  | 53.33  | 52.20  |
| 28d | SP1 | 74.75 | 112.50 | 73.65  | 71.98  |
|     | SP2 | 85.85 | 120.66 | 83.58  | 80.45  |
| 90d | SP1 | 87.50 | 130.25 | 94.71  | 93.82  |
|     | SP2 | 98.22 | 143.75 | 106.25 | 105.13 |

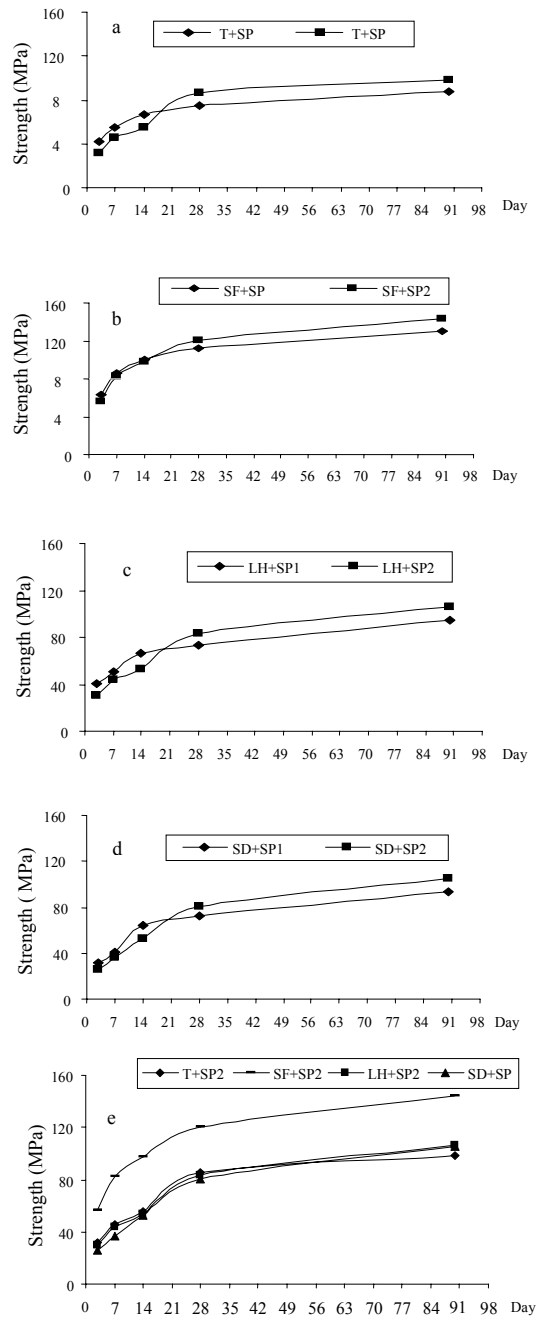


Fig.2 Compressive strength (MPa) of the studied RPC [2]

- a) Compressive strength of RPCT for W/C=0,20.
- b) Compressive strength of RPCSF for W/B=0,17
- c) Compressive strength of RPCLH for W/B=0,20
- d) Compressive strength of RPCSD for W/B=0,20
- e) Compressive strength of RPC Studied used SP2

The comparative study between two superplasticizers shows that:

- The SP1 leads. *at early ages*. To higher strengths than those obtained with the SP2. Furthermore. At later ages (>28d) the order is reversed. It can be concluded that the SP2 is more appropriate for RPC durability improvement.
- Fig.2 shows that. Independent of the addition and superplasticizer. The RPC compressive strengths of specimens made with (SF. LH. SD) are definitely higher than those of RPC T. *At later ages* ( $\geq 90$  d) this difference is more evident with the use of the SP2.
- Given the very great pozzolanic reactivity of SF. highlighted by XRD [2]-[4] analysis. The RPC mechanical strength made with **SF** are higher than those of the **RPC T** at already the 3<sup>rd</sup> day.
- The RPC's increase in compressive strength of dune sand is less significant than that of ground slag, since the latter has an amorphous structure, unlike ground dune sand, which is crystallized.
- The application of pressure, thermal cure and the introduction of fibers can improve the RPC's mechanical strengths and performance

B. Tensile strength

Table IX and Fig.2 show the **RPC** tensile strengths as a function of time.

TABLE IX  
RPC TENSILE STRENGTHS [MPa] [2]

|     |     | RPCT | RPCSF | RPCLH | RPCSD |
|-----|-----|------|-------|-------|-------|
| 3d  | SP1 | 3.88 | 4.54  | 3.77  | 3.76  |
|     | SP2 | 2.62 | 3.33  | 1.82  | 1.88  |
| 7d  | SP1 | 5.69 | 6.55  | 6.21  | 6.20  |
|     | SP2 | 4.26 | 5.12  | 3.63  | 3.22  |
| 14d | SP1 | 6.75 | 8.26  | 7.02  | 7.11  |
|     | SP2 | 7.55 | 8.66  | 6.62  | 6.36  |
| 28d | SP1 | 7.19 | 9.76  | 7.98  | 7.50  |
|     | SP2 | 8.52 | 10.52 | 7.88  | 7.58  |
| 90d | SP1 | 7.63 | 10.37 | 8.21  | 7.98  |
|     | SP2 | 8.88 | 11.12 | 8.86  | 8.65  |

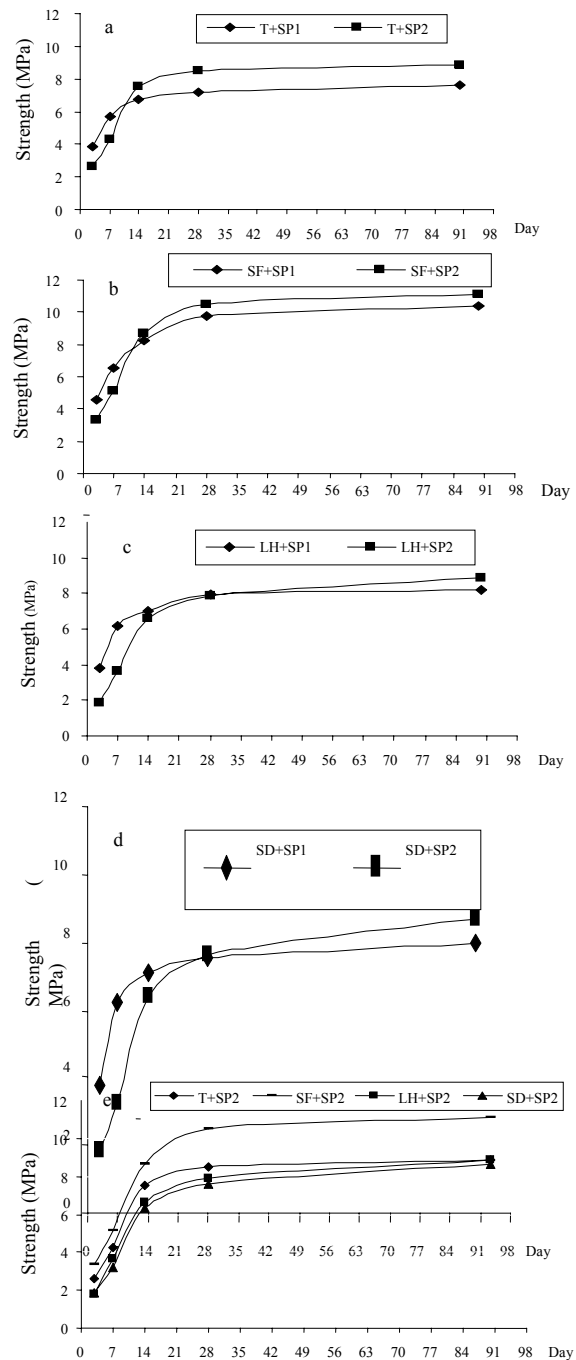


Fig. 3 Tensile strength (MPa) of the studied RPC [2]

- a) Tensile strength of RPCT for W/C=0,20
- b) Tensile strength of RPCSF for W/B=0,17
- c) Tensile strength of RPCLH for W/B=0,20
- d) Tensile strength of RPCSD for W/B=0,20
- e) Tensile strength of RPC studied used SP2.

From the compressive and tensile strength results. The following observations can be made:

Superplasticizers SP1 and SP2 delayed the hardening of RPC, which led to demolding the specimens after 24 hours.

- For all the studied RPC, the compressive and tensile strengths increase with age and the type of superplasticizer (SP1, SP2). The RPC containing SF develop their strengths very quickly at already the 3 day's age.

At the of 3 days. The compressive and tensile strengths obtained for all the RPC containing SP2 are definitely lower than those of the RPC containing SP1.

At the 7 days. The RPC compressive and tensile strengths made of SF and SP2 approach those made of SP1.

At later ages. 28 and 90 days. The RPC strengths with and without additions. But using SP2 exceeds the strengths obtained with SP1.

The lower strength of RPC made with superplasticizer SP2 at the very early ages explains its more significant retarding effect on hardening than that caused by superplasticizer SP1.

The pozzolanic reaction of the used cement replacement additives [2]-[4] is once more confirmed. Because the mechanical strengths are even higher than that of the RPC T so the materials rich in silica contribute by their pozzolanic reaction to increase the mechanical strengths.

## VI. CONCLUSION

*The investigation that has been carried out led us to withdraw the following conclusions:*

The mechanical strengths at later ages (90 days), of the RPC containing additions (SF, LH, SD) are higher than those of the RPC T, which means that these incorporated additions have a pozzolanic role resulting in the formation of CSH II of second generation. The kinetics of formation of these CSH II depends on their smoothness, on the cement part replaced, on their silica content and more particularly on their amorphous structure [2]-[4].

The use of the SP2 allows a significant improvement of the workability which results in a reduction in the time measured using a LCPC maniabilimeter compared to that of the SP1.

The mechanical strengths of the RPC using the SP2 are definitely higher than those containing SP1 at later ages.

The highest RPC mechanical strengths (110 MPa in compression and 8 MPa in tension) are reached when using the SP2 with the following ratios: S/C = 1.1 and W/B = 0.20.

In addition to the appreciable performances (simplicity of implementation, high mechanical strength and high compactness and very good aspect of surface) offered by this new born RPC, its use will allow Algeria to fulfil the requirements of sustainability.

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