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Original Article

Strength of glass powder based high performance concrete during the time

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ABSTRACT

Recycling waste glass and protection of the environment with decreasing of the cement use in building are the main context of this research work. The influence of waste Glass Powder very rich in silica SiO_2 as partial replacement of Algerian cement without additions based High Performance Concretes with superplasticizers is evaluated, varying the percentage of Glass Powder by 0%, 10% and 20% (by weight of cement). Compression and the three-point bending tests carried out on High Performance Concretes by fixing the water binder ratio and after water cement ratio at 0.35, the results show that the addition of Glass Powder improves the behaviour of the concrete material compared to the handling and the ease of implementation in an appreciable way. The study shows also that compressive and flexural strengths are significantly influenced by the substitution rate of Glass Powder, a drop is noticed at a young age for concrete with Glass Powder (7 and 28days) and strength gains at 90 and 365 days compared to the control concrete with 0%, this admitted that poozolanic and alkali silica reactions occurred from 28 days.

1. Introduction

It is well known that Portland cement production is an energy-intensive industry, being responsible for about 5% of the global carbon dioxide emissions worldwide according to Yang et al [1], for this reason an important contribution to sustainability of concrete and cement industries consists of using pozzolanic additions, especially if obtained from waste such as waste glass.

The concrete performance optimization is due to many in causes but recent technological evolutions of the admixtures allow formulations with a great reduction in the dosage of water while maintaining an adequate maneuverability and with the optional additional use of ultrafine compounds which complement the Viods of the granular skeleton between the cement grains with improved compactness detailed by Khudhair et al and Meziani et al [2, 3].

Supplementary cementing materials are often used in concrete mixes to reduce cement contents, improve workability, increase strength and/or enhance durability [4-6] through hydraulic or pozzolanic activity [7].

Utilization of these byproducts in cement/concrete not only prevents them from being environment contaminants (land-filled) but also enhances the properties of concrete in the fresh and hardened states. The use of additives cementitious such as silica fume [8-10], fly ash [11, 12] and slag [13] or others similar to Adanikin et al [14], is a common world activity in the composition of concrete conditions in each country.

Idir et al and She et al [15, 16] demonstrated that glass powder might has a pozzolanic activity and thus can pronvide advantage of partially replacing these cementitious materials [17], due to its vitreous nature and the content of some relatively appreciable amounts of silica, glass can has a pozzolanic activity specially if finely grounded [18]. Thus, GP could be used as a replacement for Portland cement in several materials for examples: in

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mortars [19] [20], in ordinary concretes or even reinforced [21, 22], in polymer concrete [23], in self-compacting concretes [24-26] and HPC reinforced with the fibers as the work of [27] and [28] shows.

Studies of Gahoi and Kansal [29] have shown that the color of the glass, size of the particles and the percentage of substitution plays a significant role on the mechanical properties (compressive and flexural) of the latter, also the work of Shekhawat [30] and Ali [31] which tried to compare the results of research carried out throughout these years on the glass powder in the concrete.

The glass can be incorporated into concrete using two approaches, in the form of aggregate (fine [32, 33] or coarse such as sand and gravel [34 -38]) or as a cementitious addition [39].

In literature incorporating glass as aggregates has the advantage of using large volumes of material and does not require fine crushing, but the main concern in such an application is the risk of alkali-aggregate reaction, as far as the additions of finely ground glass are concerned, they have the advantage of presenting pozzolanic activity, limiting the quantity of cement consumed, the authors substitute it for cement in proportions up to 40% by mass similar to Idir et al [15] and [18].

Algerian cement without additions CPA is the Portland cement composed of 95% or 100% clinker without additions, they are grayish enough, these cements are used in structures of civil engineering (bridges, large slender structures) or prefabrication; they allow a strength to the young age which allows a quick stripping. The choice of cement without additions CPA will allow us on one side to avoid the interaction between the additives used in the manufacture of other industrial cements and our main substitute the glass powder, on the other side to study the effect of this glass powder on the compression performance of high performance concrete.

1.1 Abbreviations

Glass Powder: GP
Algerian cement without additions: CPA
High Performance Concretes: HPC
Water binder ratio: W / L
Water cement ratio: W / C

2. Materials and experimental Methods

2.1. Plant Materials

2.1.1. Cement

The cement used for the manufacture test pieces is a cement CPA type CEM I 52.5 without any addition (95% clincker + 5% gypsum), produced by the industrial group (GICA) located in Bouira (Algeria) and conforms to the norm NF EN 197-1 [40] whose clinker is produced and crushed together with gypsum by the group GICA. The constituents of cement, according to the Bogue formula are: C_3S at 60.61%, C_2S at 15.36%, C_3A at 6.6%, C_4AF at 10.61% and finally gypsum at 5%. Its starting time of setting is at 2h08 min and its end time of setting is estimated at 5Hh13 min. For the mechanical characteristics, a compressive strength is 56 MPa at 28 days. The chemical composition and physical characteristics of this cement are given in Table 1.

Table 1. Chemical and physical characteristics of cement and glass powder.

Oxides (% par mass)	Cement CPA	Glass Powder
SiO_2	21.29	70.50
Al_2O_3	4 .72	1.42
Fe_2O_3	3.49	0.10
CaO	64.68	8.43
MgO	0.44	4.01
Na_2O	0.17	15.28
SO_3	2.06	0.25
Loss on ignition	1.93	0.22
Specific gravity (kg/m^3)	3470	2120
Specific surface(cm^2/g)	253	3600

2.1.2 Glass powder

This powder comes from the recovery of glass bottles in roadside dumps and scattered in nature. The glass powder is obtained by selecting only the green and white bottles. These are cleaned to remove the paper labels, dried, crushed and finely ground (Fig. 1) with a specific surface area of 3600 cm^2/g. The valorization of using crushed glass in concrete could be constitute an interesting a feasible alternative from the environmental point view, avoiding its landfill. However, from a technical point view, bottle glasses contain significant quantities of alkalis which can cause detrimental effects on the concrete in relation to the alkali-silica or alkali-aggregate reactions. The chemical composition is shown in Table 1 and the granulometric characteristics are measured with the Laser granulometer are shown in Fig. 2, the results reveal that the granulometric distribution is between 0,832 µm and 549 µm, the maximum particle size recorded is about 600µm.

Fig 1. Transformation of waste glass into glass powder

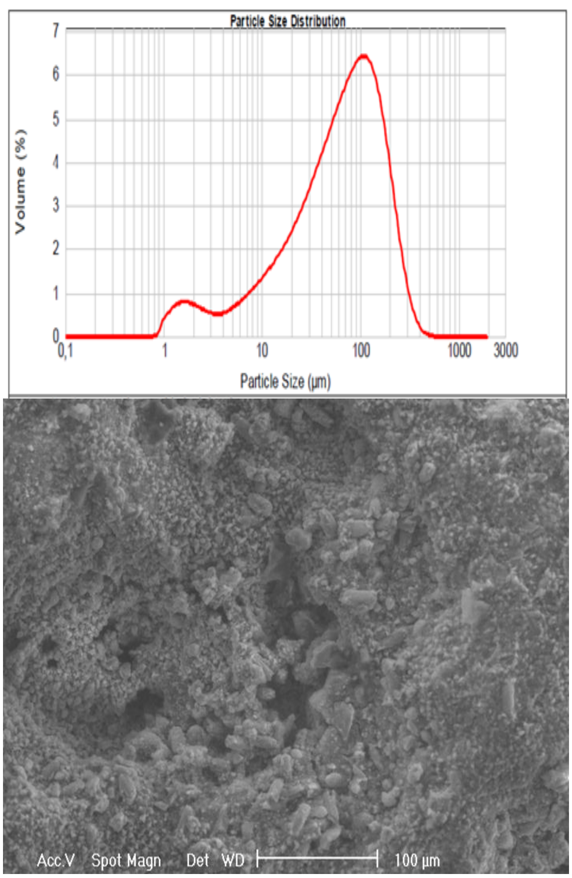

Fig 2. Particle size distribution and MEB image of glass powder

2.1.3 Aggregates

The sand used in this study is a mixtures of two different kinds, the first is a fine sand of Boussaâda (Algeria) having 6.6% of the total mass and the second is crushed, natural limestone rock of the Sidi Slimane region of 93.4% of total mass while the modulus of final fineness after homogenization is 2.60.

Gravels are crushed aggregates of the same mineralogical nature as crushed sand, the principal characteristics of the used aggregates are given in Table 2.

Table 2. Physical characteristics of aggregates

Charactéristics	Sand	Gravel 3/8	Gravel 8/15
Absolute density (g/cm^3)	2.7	2,63	2,77
Bulk density (g/cm^3)	1.6	1,42	1,38
Porosity	/	1,05	1,50
Absorption	/	0,42	0,13
Module of fineness	2.6	/	/
d/D	0/4	3/8	8/15

2.1.4. Superplasticizers

The admixture used is a no-chlorinated, new generation polyvalent water-based superplasticizer based on polycarboxylate copolymer according to standard NF EN 934-2 [41] with a density of 1.060 ± 0.020 g / cm^3. pH = 5.5 ± 1.0, chloride ion content ≤ 0.1%, content of Na_2O Eq. ≤ 2.5% and dry extract = 29.5% ± 1.4% The recommended range of use varies from 0.1 to 5.0% of the weight of the binder.

2.2. Methods

The composition of the HPC adopted consists of a mixture of two sands (6.6% fine sand of Boussaâda and 93.4% coarse sand), two fractions of limestone gravel (3/8 and 8/15), 1.6% superplasticizer And a variable substitution rate of the glass powder for 0 to 20% of the amount of cement CPA.

In order to verify, understand and explain the effects of glass powder on the properties of concretes HPC, a control BHP with 0% GP (HPCR) without addition was formulated as a comparative study.

Based on this control composition, HPC (with an W / L = 0.35 and W / C = 0.35 ratio) were formulated by introducing the glass powder (GP) at a rate of 10 and 20% With respect to the mass of the cement, wherein L represents the binder which is equal to the sum of the cement and the glass powder (L = C + GP). The various compositions are summarized in Table 3.

Table 3. Compositions of different HPC

	Unit	HPCR	HPCL1	HPCL2	HPCC1	HPCC2
% de GP	%	0	10	20	10	20
Cement	Kg/m^3	450	405	360	405	360
GP	Kg/m^3	0	45	90	45	90
Water	l/m^3	157.5	157.5	157.5	141.75	126
W/L*	/	0.35	0.35	0.35	/	/
W/C**	/	0.35	/	/	0.35	0.35
Sand	Kg/m^3	602	602	602	602	602
G 3/8	Kg/m^3	210	210	210	210	210
G 8/15	Kg/m^3	995	995	995	995	995
SP	l/m^3	9	9	9	8.1	7.2

***L: binder, L=C+GP** ****C: cement**

2.2.2. Preparation of test specimens

The specimens were prepared according to the standard NF P 18-400 [42], the mixing of the concrete is carried out in a cement mixer with a capacity of 30 liters. The glass powder is mixed with the cement alone and dumped at the same time, without any precaution and at random. The total mixing time 5min (1 minute of dry mixing and 4 minutes of wet mixing). Compaction was carried out on a vibrating table for one minute. After 24 hours storage of the molds in open air, the specimens were demoulded and stored in a tank of fresh water under laboratory condition at 25 °C (saturating humidity HR = 100% and an ambient temperature).

3. Results and Discussion

3.1. Analys of fresh result

3.1.1 Density

In order to follow the evolution of the density of our concrete affected by the addition of GP, we followed its evolution in the fresh and hardened state; the average results of every three sample are grouped in Table 4.

Table 4. Density of the various concretes HPC

State of concrete	**Designation**	**Density (Kg/m^3)**		
Fresh	*HPCR*	2560.2		
	HPCL1	2531.5		
	HPCL2	2478.8		
	HPCC1	2545.8		
	HPCC2	2493.2		
		7 day	**28 day**	**90 day**
Hardened	*HPCR*	2550.6	2555.4	2560.3
	HPCL1	2545.8	2550.6	2574.5
	HPCL2	2536.2	2541.0	2564.9
	HPCC1	2531.5	2545.8	2570.4
	HPCC2	2536.2	3550.6	2562.3

For the fresh state, the addition of 20% glass powder decreased the density of HPC compared to the control concrete, but for the cured state the density increased throughout the time, the concretes based on glass powder had the same behavior as the control one except that they are more dense at 90 days.

3.1.2. Fluidity

Slump test was carried out in accordance with standard NF P 18-451 [43] and the results are summarized in Table 5

Table 5**.** Concretes subsidence HPC studied

Désignation	**subsidence (cm)**
HPCR	1
HPCL1	2
HPCL2	4
HPCC1	2
HPCC2	3

It can be seen that the use of 2% superplasticizer (point saturation on superplasticizer) by the cement mass for the reference concrete gives a very firm concrete (1cm of subsidence), but the substitution of the cement by the glass powder with 10% and 20% at increase the subsidence of these last from 2cm to 4cm and always gives a concrete more at least firm than the HPCR. For the ratio W / C = 0.35 (HPCC1 and HPCC2) the concrete is viscous and requires more vibration than the two concretes HPCL1 and HPCL2. The workability of concrete is increased with the use of glass powder, because of their fineness which can fill the space between the cement grains instead of being occupied by (greater amount of free water going Fluidize the concrete).

3.2. Analysis of hardened results

The compositions of the concretes with and without glass powder retained for the experimental program are reported in Table 3. It should be noted that the contents of the addition of glass powder (GP) and of Superplasticizer after optimization, are respectively: 10% and 20% of the cement mass.

The physical, mechanical and microstructural characteristics of concrete with and without glass powder are compared.

3.2.1. *Influence of glass powder substitution rate on compressive strength NF EN 12390-3 [44]*

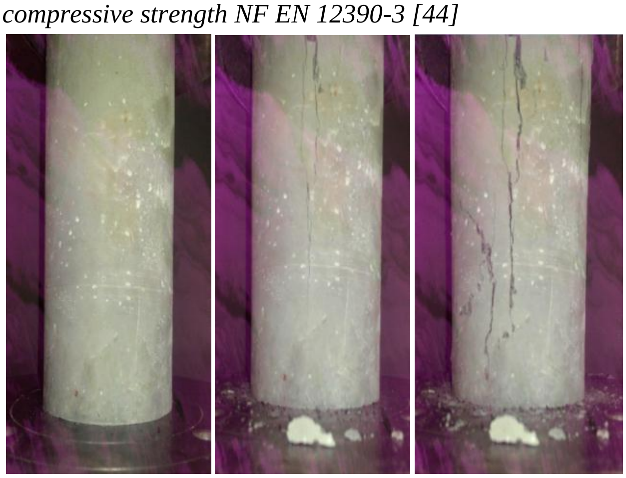

Fig 3. Behavior of cylinder concrete during a simple compressive test

The compressive tests which are carried out using the cylindrical (11 × 22) cm dimensions and the flexural tensile tests are determined on prismatic specimens (7 × 7 × 28 cm^3). For both companions five types of concrete were chosen to determine the influence of the GP level. These concretes are denoted by: HPCR, HPCL1, HPCL2, HPCC1 and HPCC2.

Fig. 3 show the behavior of HPC cylinder during a compressive test and the result is summarized in Fig. 4, It can be seen from the results that compressive strength propagates as a function of time and deteriorates with the increase in the percentage of the glass powder at 7 and 28 days compared to the control concrete HPCR (48.4 MPa). Until 28 days, the compressive strength of concretes with glass powder increased (90 and 365 days) to even exceed the strength of HPCR, which is explained by the pozzolanic reaction [15] of the glass powder which manifests at long term. Idir et al [15] say that for fine glass with particle size range under 41 µm and mean particle size of 7.8 µm obtained similar results concluding that the general trend is for replacement of cement by glass to lead to a decrease in compressive strength demonstrated in the work of . Saribiyik et al and She et al [23, 16]. On the other hand it is observed that similarly, these results show that the W / L and W / C ratio affects the resistance of these concrete, the good compressive strength are obtained for concrete by working with W/L ration (Fig.5), but the strength of HPCC1 and HPCC2 at 365 days still remain higher than that of HPCR.

The high compressive strength is obtained at 365 days, the optimum glass content was found to be 20% GP (HPCL2) for which compressive strength was achieved 68.3 MPa higher than the control concrete HPCR by working with our CPA class 52.5.

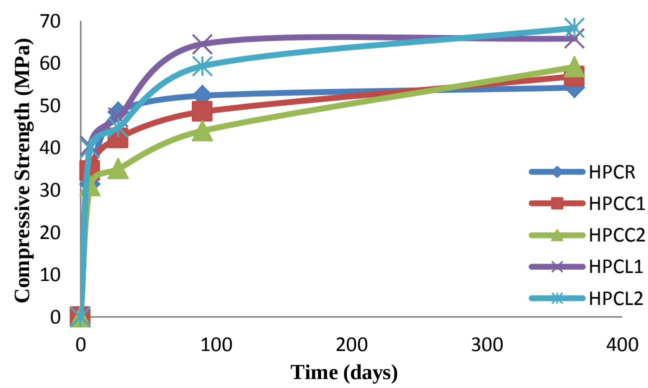

Fig 4. Evolution of the hardening kinetics according to the glass powder proportioning

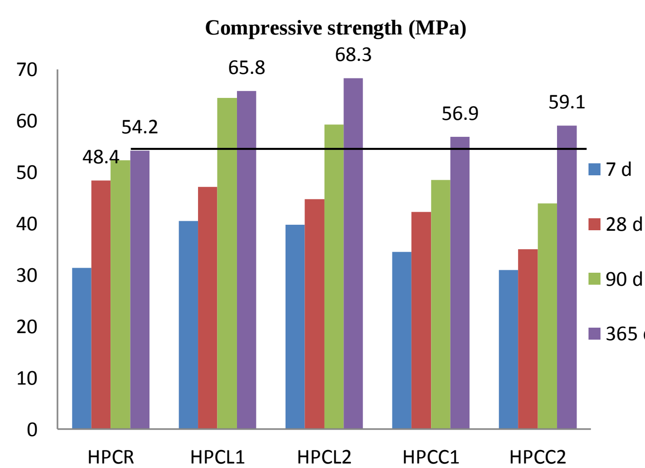

Fig 5. Influence of the addition dosage on the compressive strength at different ages

3.2.2. Influence of the substitution rate of glass powder on the three-point bending strength NF EN 12390-5 [45]

The results of the flexural strength for concretes as a function of time are given by the curves in Fig 6 From these results it can be seen that the flexural strength increases with age for all the different HPC, At a young age (28 days) the resistance of the HPCR is higher than those of the other HPCL and HPCC, but beyond this age at 90 days, those of the glass-based concretes increases and exceeds the resistance of the HPCR which shows that the glass powder exerts a physical and chemical effect [18] **(**pozzolanic and alkali-silica reactions).

We note a considerable increase in the flexural strength between 28 and 90 days is observed, it increases with the increase of the GP content, Phenomenon can be explained by the low adhesion between the grains of the cement and sand. We see at 365 days that the flexural strength decreased for all HPC unlike the behavior of these HPC in compression (Fig 5).

For the effect of the ratio W/L in the cement, it is noted that the compressive strength decreases by increasing the quantities of water (W/C= 0.35).

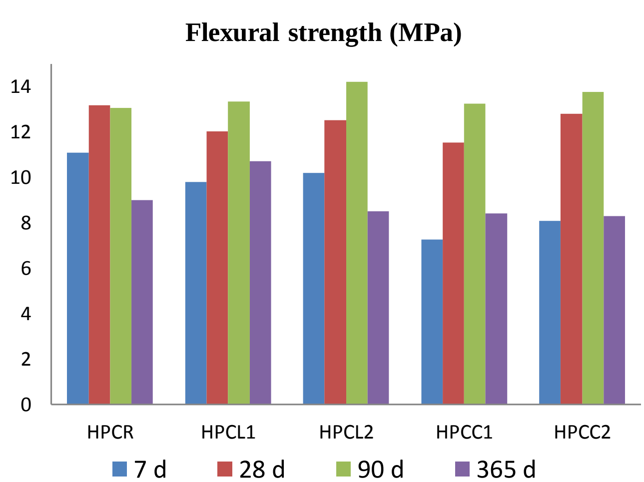

Fig 5. Influence of the addition dosage on the compressive strength at different ages

3.2.3. Microstructure analysis

It is important to note that this study is mainly comparative, we present in this paragraph the observations made at the MEB at the interface area paste cement aggregate samples from crushing specimens in compression, From the age of 7, 28 and 90 days (see Fig. 7). The results obtained must be taken with care given the method of preparation of the sample and possible experimental artefacts.

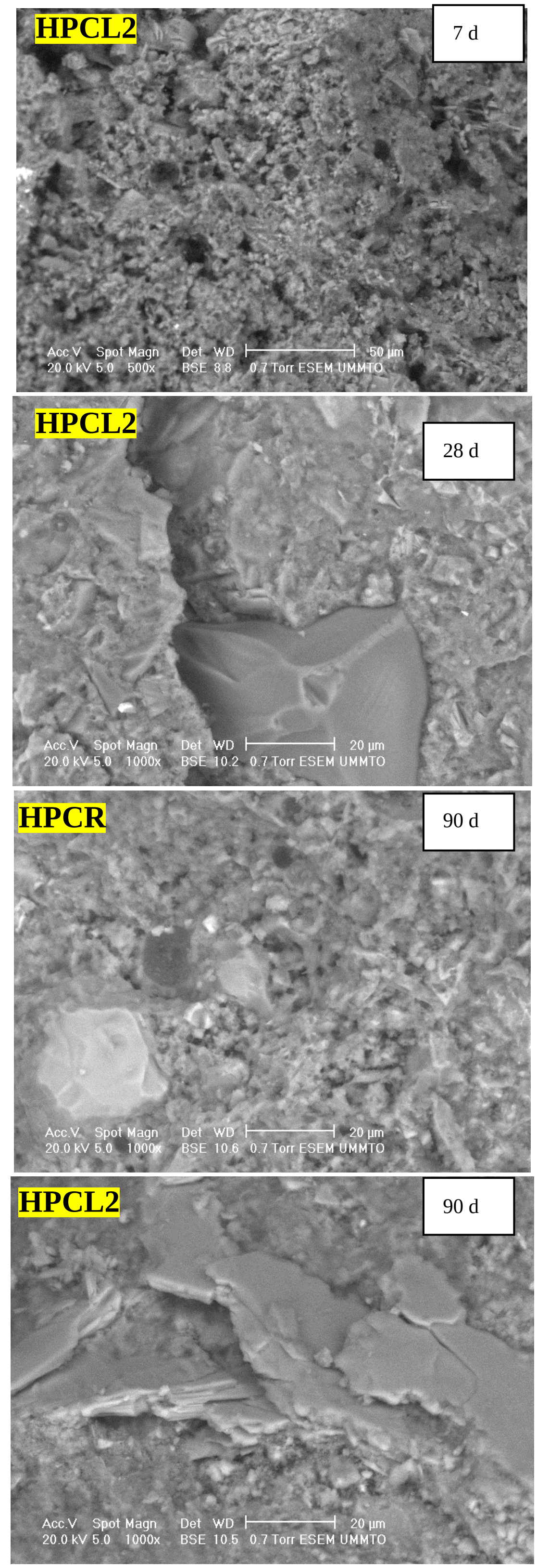

Fig 7. Micrographs of the intern surface obtained by SEM, at different ages (X 1000*)*

In fact, the sample is polished in order to obtain a more or less smooth and flat surface. During this operation, it is possible to form a network of microcracks or a separation between the aggregates and the cement paste. However, it can be assumed that the appearance of microcracks in the cement paste is mainly related and the tensions produced on the specimens from whom the samples are derived. We have chosen to illustrate the overall analysis that we carried out with the most representative images of the state of the microstructure, we note that the portlandite crystals are well composed with lengthened forms, they are smaller for the mortars with glass powder than those without glass powder and it is also shown in the work of Redden and Neithalath [46].

4. Conclusion

The results obtained showed the advantage of replacing the cement by recycled glass powder in proportions of 10 and 20% in High-Performance Concrete.

The density of concretes with glass powder has the same behaviour as the reference except that they are more dens at 90 days than it.

The workability increases with the increase of the substitution rate of the cement CPA by the glass powder; it is reflected by the variation of the specific surface of the fresh concretes thanks to the great fineness of the glass powder (3600 cm ^{2}/g) compared to the cements and therefore a decrease in demand for water.

The addition can have an effect both on the fresh concrete by the improvement of the subsidence in relation to the dosage but who gives a firm HPC, as well as on the concrete hardened by the increase of the mechanical strength with this composition.

The HPCR with 0% of GP at 28 days is more strong than that with GP, this may be due to the substitution of a percentage of cement by the GP, which affects the hydration and thus the resistance; but this strength increases to reach values which can even exceed that with 0%, in fact, at 90 and 365 days relative to the control concrete (HPCR).

An addition of 10% and 20% of Glass Powder improves the mechanical compressive strength of the HPC studied, the compressive strength is considerably deferred, a decrease in the strength as a function of the percentage increase in Glass Powder and a shelf life increase for CPA cement which shows that the glass powder exerts a physical and chemical effect (pozzolanic and alkali-silica reaction).

Finally results also showed that the best strength values were obtained by working with the W / L ratio and not with the W/ C ratio for these HPC. The W/L ratio affected the strength of the CPA based concretes in a considerable way that confirms high performance formulations by decreasing this ratio but working with the W/L ratio where L represents the binder that contains cement and glass powder.

However, it is necessary to validate the sustainability of the recovery of glass powder in cementations matrix materials by other works like physical and chemical durability.

Conflict of Interest

The authors declare that they have no conflict of interest

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