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Recycled Aggregates (Recycled Sand) From High-Performance Concrete, Mechanical Strength Study

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Abstract

High Performance Concrete (HPB) is an innovative concrete that finds its place in modern constructions. New techniques for formulating and designing high-performance concrete have improved durability and achieved outstanding mechanical properties compared to conventional concrete, acause thanks to the improvement of its rheological qualities and its very limited porosity.

This has allowed to expand his field of employment especially in aggressive environments. Natural aggregates, frequently used, are now a non-renewable resource whose accessibility is continually declining.

Recycling of High Performance Concrete (HPC) waste in the form of recycled aggregates in the manufacture of a new range of high-performance recycled concrete with improved properties will lead to an understanding between performance and cost in order to achieve a resistant material with durability increased.

The aim of this study is to identify and analyse the characteristics of high performance recycled concrete aggregates based on two types of mineral additions (silica smoke, slag) which influence the properties of the concrete in a fresh and hardened state.

This study highlights the effects of substitution of natural aggregates by recycled aggregates (30% sand and gravel 25%, 50%, 100%) on the mechanical resistance of recycled high-performance concrete.

Examination of the results obtained has made it possible to establish the correlations between natural and recycled aggregates and on the physico-mechanical characteristics.

The analysis of these results also showed the interest of total or partial substitution of recycled aggregates based on silica smoke compared to recycled aggregates based on Algerian slag in the formulation of High Performance Recycled Concrete (HPRC) from the point of view of mechanical performance (strength).

Keywords: High Performance Recycled Concrete, Recycled Aggregates, Mechanical Strength, Silica smoke, Slag.

الخلاصة: الخرسانة عالية الأداء (خ ع أ) هي خرسانة مبتكرة تجد مكانها في المنشاءات الحديثة. أدت التقنيات الجديدة لصياغة وتصميم الخرسانة عالية الأداء إلى تحسين المتانة وحققت خصائص ميكانيكية بارزة مقارنة بالخرسانة التقليدية، وذلك بفضل تحسين صفاتها الريولوجية ومساميتها المحدودة للغاية. وقد سمح ذلك بتوسيع مجال عملها خاصة في البيئات العدوانية. الحصى الطبيعي، الذي كثيرا ما يستخدم، أصبح الآن موردا غير متجدد تتناقص إمكانية الوصول إليه باستمرار. سيؤدي استعادة نفايات الخرسانة عالية الأداء (خ ع أ) في شكل حصى معاد تدويره في تصنيع مجموعة جديدة من الخرسانة المعاد تدويرها عالية الأداء بخصائص محسّنة إلى البحث في التوافق بين الأداء والتكلفة من أجل الحصول على مادة مقاومة مع زيادة المتانة. الهدف من هذه الدراسة هو تحديد وتحليل خصائص الحصى المعاد تدويره للخرسانة العالية الأداء بإضافة نوعين من الإضافات المعدنية (دخان السيليكا والخبث) التي تؤثر على خصائص الخرسانة السائلة والصلبة. تسلط هذه الدراسة الضوء على تأثيرات استبدال الحصى الطبيعية بالحصى المعاد تدويره (الرمال 30٪ والحصى 25٪، 50٪، 100٪) على المقاومة الميكانيكية للخرسانة المعاد تدويرها عالية الأداء. وقد أتاح فحص النتائج التي تم الحصول عليها تحديد الارتباطات بين الحصى الطبيعي والمعاد تدويره وعلى الخصائص الفيزيائية - الميكانيكية. كما بين تحليل هذه النتائج فائدة الاستبدال الكلي أو الجزئي للحصى المعاد تدويره المصنوع من دخان السيليكا مقارنة بالحصى المعاد تدويره المصنوع من الخبث الجزائري في تركيبة خ ع أ م ت من وجهة نظر الأداء الميكانيكي (المقاومة).

1. INTRODUCTION

Concrete is one of the most widely used materials in the world. However, concrete constructions are not eternal. Every year, works are demolished to make way for new structures, producing tons of waste, called waste of C&D (construction and demolition). A European Union report estimates that 3 billion tons of construction and demolition waste are produced each year in Europe. Waste, which used to be of little interest or concern, began to be an economic and ecological problem. The enormous quantities of waste that are constantly being generated are increasingly tying up large area for storage and thus reducing the availability of land and pollution. The production of recycled aggregate meets the need for a source of aggregate and the reduction of waste volumes.[1]
It is well known that the construction sector consumes huge amounts of natural aggregates (NA), which represent about 70-90% of the volume of traditional engineering materials, such as concrete [2]. Faced with this situation, many alternatives have emerged to try to increase the sustainability of this sector, among which the use of waste in the manufacture of these materials stands out [3]. It has even been shown that the performance of recycled aggregate is suitable for the production of unconventional concrete, such as high-performance concrete (HPC), characterized by both its high strength and optimal durability properties [4].
The high mechanical properties of HPC are obtained by increasing the cement content, low water-to-cement ratio (w/c) and correct packaging of aggregates [5]. In addition, the use of appropriate quantities of mineral additions (for example, fly ash or silica smoke) in addition to ordinary Portland cement further improves the hardened performance of this type of concrete [6]. The ultimate goal of this design is to achieve a dense microstructure that maximizes both the strength and durability of the concrete [7]. Nevertheless, all these aspects lead to a genetic reduction in the handling of HPC, a problem that can be solved by adding superplasticizers [8]. Some mineral additions also balance the fresh and hardened behaviour of this type of concrete [9].
With respect to the incorporation of AR into HPC, it is expected to impede its mechanical properties, as in conventional concrete [10]. However, its high microstructural density reduces this decrease compared to conventional concrete. Thus, the use of 20-50% of a single fraction of AR resulted in a decrease in compressive strength of only 3-7% [11,12]. The joint use of small quantities of the two fractions showed the same trend, with a decrease in compressive strength of about 5% for the coarse and fine AR content of 50% [4]. In addition, in various studies, the resistance of HPC from coarse recycled aggregates was higher than that of the reference mixture (100% NA) for the constant p/c ratio and the volume of coarse and fine aggregates [13]. This unexpected situation is generally attributed to the high microstructural density of HPC [14].
Our project has two objectives, the first concerns the effect of recycled aggregates on the physico-mechanical behaviour of BHP based on blast furnace slag from El-Hadjar (Algerian product) in total replacement of silica smoke (European product). The second objective is the recovery of recycled aggregates (slag) in order to manufacture a new range of High Performance Recycled Concrete (HPRC) which meets the requirements of resistance and durability.
In order to provide answers to these concerns, an experimental study on the evolution of the mechanical and physical properties of the material over time has been developed and presented in this article.

2. MATERIAL PROPERTIES

2.1. Research Methodology

The properties of the concretes were mainly studied in order to formulate them by a judicious choice of their constituents. we present in this paragraph, which is divided into two parts, the characteristics of the materials used and the compositions of the tested concrete, we investigated the impact of the recycled aggregate factor and mineral additions on the behaviour of high-performance recycled concrete of similar formulations. Thus, we chose a natural sand, two sands obtained by crushing two types of BHP (slag-based, and silica smoke) and four types of gravel of different nature including an aggregate type (sand, gravel) and the other three types are recycled aggregates (slag, GRANITEX silica smoke). Before carrying out the experimental study, it is essential to characterize and rigorously identify all the constituents used in the formulation of the BHP and BHPR studies, detailing the test campaign conducted to characterize these materials, through their particle size, mechanical (fragmentation, resistance), physical (density, and water absorption) properties.
We start with the non-aggregated materials: cement, slag, silica smoke and mixing water.

2.2. CEMENT

The cement used is a BISKRIA limestone portland cement of type NA 442-CEM I 42.5R conforming to EN 197-1[15], of the BISKRIA CEMENT PLANT. This cement had a density of approximately 3.1 Mg/m3 and a clinker content of approximately 98%. In addition, a commercial limestone charge (density of approximately 1.1 Mg/m3) was used in the manufacture of HPC and HPRC.

2.3. SLAG

The slag used is a by-product of the manufacture of the font, from the factory of El-Hadjar Annaba (Algiers). It is a sand of 0/3 mm particle size, granulated slag cooled by water jet, vitrified, that is amorphous. It is ground to a large specific surface area compared to cement. El-Hadjar slag has the advantage of being rather acidic (the CaO/SiO2 ratio varies within the limits of 0.95-1.04), it is relatively stable in accordance with NFEN 15167-1 [16].

2.4. SILICA SMOKE

The silica smoke used in this study is supplied by the Algerian company GRANITEXT of commercial name MEDAPLAST HP, in the form of a fine powder of grey colour conforming to NFEN 13263-1 [17].

2.5. Superplasticizer

In our study, we used a high water reducing superplasticizer. It is based on synthetic polymers and its use in concrete makes it possible to obtain a very low E/C ratio. It is of commercial name GRANITEX MEDAFLOW RE 25 conforming to the standard NF EN 934-2 [18] has been added to offer great maneuverability to the HPC and HPRC.

2.6. mixing water

The mixing water used to make the various mixtures comes from the public drinking water distribution system of the town of Tiaret where this research work was carried out, it contained no harmful compounds for the fresh or hardened behaviour of the concrete.

2.7 Agrégat

2.7.1. Natural Agrégat

The aggregates to be used in the manufacture of concrete must allow the construction of a granular skeleton with a minimum of voids.

The gravel used in the manufacture of the HPC and HPRC concrete are of classes (3/8) and (8/15) come from the quarry of "Ben Brahim" located in RECHAIGA located in the South region of Tiaret (Algeria). While the class sand (0/4) of limestone origin of the river "GUELTET SIDI SAAD" of the same region.

2.7.2. Recycled aggregates (RA)

The recycled high-performance concrete was made from recycled parent concrete aggregates already prepared in the Civil Engineering Laboratory of the Department of Tiaret University, various crushed samples. The same materials, cement and sand, were used and natural aggregates were replaced with recycled aggregates based on slag concrete and silica smoke with

The production of recycled aggregates has gone through several stages: fragmentation of the blocks of the demolition concrete (cylindrical concrete specimens already compressed) and by means of a hammer, the fragments of the concrete have been broken to suitable dimensions, then ground with a manual crusher, then proceeded with sieves to separate the different granular classes 3/8 and 8/15 for recycled gravel and the fraction (0/4) for recycled sand, the grinding and sieving mentioned were carried out at an age of high performance concrete parent HPCP 28 days figure 1.

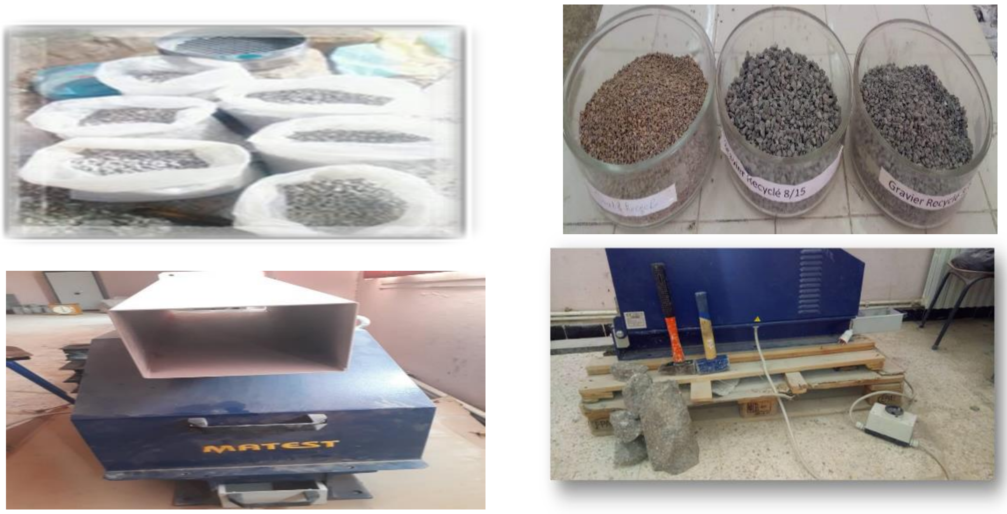

Figure 1

Preparation of recycled aggregates sand (0/4) and gravel (3/8 , 8/15)

First, the PHPC parent high performance concrete was manufactured with 100% AN according to the composition indicated in Table 1. BHPP had a compressive strength of 38.863 MPa at 7 days , 53.619MPa at 14 days, 59.74 MPa at 28 days and 61.228 MPa at 56 days for slag-based parent concrete. In addition, Granitex silica smoke-based parent concrete has a compressive strength of 45.865 MPa at 7 days, 47.005MPa at 14 days, 48.79 MPa at 28 days and 54.26 MPa at 56 days.

2.8 Mix design

The formulation of a concrete thus corresponding to the process of selection of components and their proportions in order to produce a material as economical as possible with certain precise minimum properties, in particular with regard to maneuverability, resistance, and durability.
Despite the absence of a recognized method of formulating high-performance concrete, some observations can be based on. First, since manoeuvrability can be controlled by an appropriate superplasticizer dosage, the water dosage must be determined from the water/cement ratio required to meet the strength requirements.
With high-performance concretes, compressive strength is sometimes specified for an age greater than 28 days, which should be clearly taken into account in relation to the strength criterion.
After a detailed characterization of the different constituents, we will present in the following the procedure and the formulation method chosen to determine the optimal composition of High Performance Concrete (HPC, HPRC) of our study NF EN 197-1 [19]. Three experimental tests are used to adjust and correct the handling and compactness of the chosen formulations.
Optimizing the formulation of a BHP involves optimizing the granular skeleton to improve compactness and minimize porosity. Several methods of formulation of concretes are proposed. We will use the adjusted grout method for the formulation of study BHP.
Two sets of HPC were manufactured, one containing HPCSS silica smoke and the other containing HPCS slag. An optimal amount of silica smoke, 8% of the cement mass, and another 12% of the cement weight of slag allows 450 kg/m3 of cement to be used to achieve a strength of 60 MPa at 56 days. The reduction in the amount of water is obtained by adding a superplasticizer dosed at 0.6% for HPCS and 0.9% compared to the cement mass for HPCSS, this made it possible to make the mixture fluid. The two sets of formulated concretes are summarised in Table 1. Finally, an effective W/L ratio equal to 0.32 was defined, as a function of water absorption in 24 hours of AN (mixing time). This low W/L ratio, insufficient to obtain a high manoeuvrability, was compensated by the addition of a high-water reducing superplasticizer and by the mixing process.
After defining the reference mixture, 50% and 100% of coarse AN were replaced by RA and 30% natural sand by recycled sand. The water content when RA was added was adjusted for their water absorption in 24 h (Table 3). Four mixtures were produced with RA: HPCS50%, HPCS100%, HPCSS50%, HPCSS100% and HPCS0%, HPCSS0%.

Table 1 The series of formulated concretes.

Components	BHPL0%	BHPFS 0%	BHPL 50% GR	BHPL100% GR	BHPFS 50% GR	BHPFS 100% GR
Cement	450	450	450	450	450	450
Weter	176	176	176	176	176	176
Sand (0/4)	715	715	500.5	500.5	500.5	500.5

RSand (0/4)	/	/	214.5	214.5	214.5	214.5
Gravel (3/8)	432	432	216	/	216	/
RGravel (3/8)	/	/	216	432	216	432
Gravel (8/15)	528	528	264	/	264	/
RGravel (8/15)	/	/	264	528	264	528
Silica Smoke	/	36	/	/	36	36
Slag	54	/	54	54	/	/
Superplasticizer (SS)	/	4.05	/	/	4.05	4.05
Superplasticizer (S)	2.7	/	2.7	2.7	/	/
Slump (cm)	15	14	17.5	18.5	16	17
W/B	0.35	0.36	0.35	0.35	0.36	0.36

In this experimental programme, only one type of mould was used, cylindrical (16 x 32) cm NF EN 12390-1[20]. Table 2

Table 2 Tests in the hardened state.

Tests	Norm [20]	Age (days)	Specimen type
Hardened density	EN 12390–7	7, 14, 28, 56	Cylindrical specimens 15x30 cm
Compression strength	EN 12390–3	7, 14, 28, 56	Cylindrical specimens 15x30 cm

2.9 Mixing process

The mixer used for the manufacture of concrete is vertical axis with a capacity of 50 liters. The mixing sequence chosen is as follows:

- Prepare the moulds needed for the various tests, check their number and that they are well greased in order to facilitate subsequent removal;
- Ensure all equipment is available and materials are properly dried;
- Prepare the amount of water needed for the waste, for the preparation of the HPC;

- The superplasticizer is added to the first half of the mixing water;
- Pour the components into the tank: first the gravel, then the sand, cement and addition;
- Turn mixer on to homogenize dry mixture for 5 minutes:
- Add water while the mixer is running;
- Leave the mixer running and gradually add the first half of the mixing water (the one containing the adjuvant) and mix, then add the remaining water.

The concretes made, were placed in cylindrical moulds (16x32) cm2 are then vibrated vertically, Figure 2.

Figure 2 Vibration, Mould Filling and Implementation mode

The test pieces must be removed from the mould after 24 h ± 1 hour in a room maintained at a temperature of 20°C ± 2°C. The mould shall be marked with the serial number of the test piece.

Figure 3 Demolding of test pieces

The release test pieces are kept at a temperature of 20°C 2°C in water according to NF EN 12390-2 [21].

Figure 4 Preservation of test pieces in water

After 7, 14, 28 and 56 days of curing, the samples were subjected to the compressive strength test.

3.EXPERIMENTAL PROCEDURE

3.1 Physical and mechanical testing of aggregates

This section presents the essential elements of component characterization (the physical and mechanical properties of natural and recycled aggregates).
All NA and RA test results are presented and compared in Table 2 according to NF EN 933-1, NF EN 933-2 [22-23].

Table 3 Physical and mechanical properties of aggregates.

Properties	Norm [23,24]	NA-S	NAG-3/8	NGA-8/15	RA-SS	RA-SSS	RAG-3/8 S	RAG-3/8SS	RAG-8/15 S	RAG -8/15 SS
Apparent density (AD)	NFP 18–554	1.430	1.010	1.458	1.312	1.251	1.278	1.185	1.290	1.221
Absolute Density (ADs)	NFP 18–554	2.444	2.616	2.631	2.372	2.407	2.458	2.445	2.636	2.542
Water absorption rate 24 h	NFP 18–555	4.5	4.00	4.00	3.5	4.0	4.0	3.5	4.0	4.0
Los Angeles Test (LA %)	NF EN 933-2	/	17.4	18.6	/	/	26.8	35.4	26.6	34.6
Micro Deval Test (MD %)	NF EN 933-2	/	8.00	6.00	/	/	4.00	2.00	7.20	3.00

3.2 Test on HP concrete and HPR concrete

a) In fresh state

Workability for high-performance concrete is a fundamental quality that must be seriously considered in the composition study. This criterion can, in general, be defined on the basis of plasticity by the slemp of Abrams. Abrams cone sag shall be carried out in accordance with the requirements of NF EN 12350-2 [25].

It makes it possible to determine the consistency of a fresh concrete by measuring the slemp which is nothing other than the difference between the height of the truncated mould used

Figure 5 and the highest point of the collapsed test body.

Figure 5 Slump test

The slump measurement values are given in Table 4 and are shown in Figure 7.

Table 4 Slump and W/L ratio of mixtures.

Mélanger	Slump(cm)	W/C ratio	W/Beffectif
HPCS0%	15	0.39	0.35
HPCSS0%	14	0.39	0.36
HPRCSS50%	16	0.39	0.36
HPRCSS100%	17	0.39	0.36
HPRCS50%	17.5	0.35	0.35
HPRCS100%	18.5	0.35	0.35

b) In hardned state

The compression test shall be carried out on 2 (16x32) cm standard cylindrical test pieces; NF EN 12390-1, [20]. The loading speed is constant. The test machine is a class "B" force press with a maximum capacity of 1500 KN in accordance with NF EN 12390-2 [21].

The test shall be carried out as follows: the test piece, once rectified, must be centred on the test press with an error of less than 1% of its diameter. Loading should be done at 0.5 MPa with a tolerance of ±0.2 MPa. For 16x32 cm test pieces, this means a load increase of 10 KN/s ±4 KN/s. The breaking load is the maximum load recorded during the test. Compressive strength is the ratio between the breaking load and the cross-section of the test piece.

 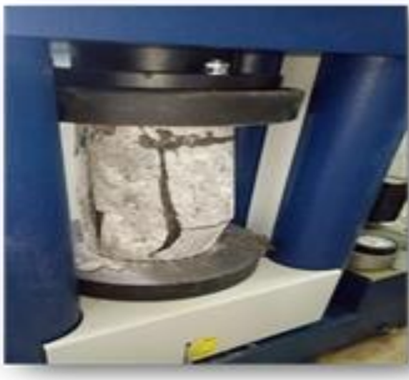

Figure 6 Loading and breaking of cylindrical test pieces

4. RESULTS AND DISCUSSION

4.1 Physical and mechanical properties of aggregates

According to Table 3: The volume weights of both apparent (Mvapp) and absolute (Mvabs) recycled aggregates are significantly lower than those of natural aggregates. This can be explained by the existence of cement paste glued to recycled aggregates which is porous on the one hand and the nature (density) of the source rocks of these aggregates on the other hand.
It can also be concluded that the water absorption rates of natural and recycled aggregates are very low (< 5%) which confirms the good compactness of these aggregates. This is mainly due to their mineralogical and morphological nature.

The mechanical properties of resistance to fragmentation and wear were determined by the Los Angeles and Micro Deval tests according to NF EN 933-2 [23].
The Los Angeles test shows that natural aggregates are mechanically stronger than other types of recycled aggregates.
The values obtained for the Micro Deval test are lower than the higher specific value required by this type of concrete (20%) confirming good wear resistance

4.2 Fresh properties of HPC and HPRC

a) Workability

The values of the slump obtained in Table 4, correspond to a concrete of plastic consistency, these vary from 14 to 18.5 (cm) the concrete is class S1 according to EN 12350-2 [25].
By their porous and absorbent nature, recycled aggregates affect the manoeuvrability of BHPR compared to BHPN with more compact and less porous natural aggregates.Figure 7. Silica-based BHP are slightly less manageable compared to slag-based BHP. This is mainly due to the spherical morphology of the silica smoke particles, which gives the BHP a certain viscosity and a lower flow rate than the slag BHP, which has more or less angular shapes [26].

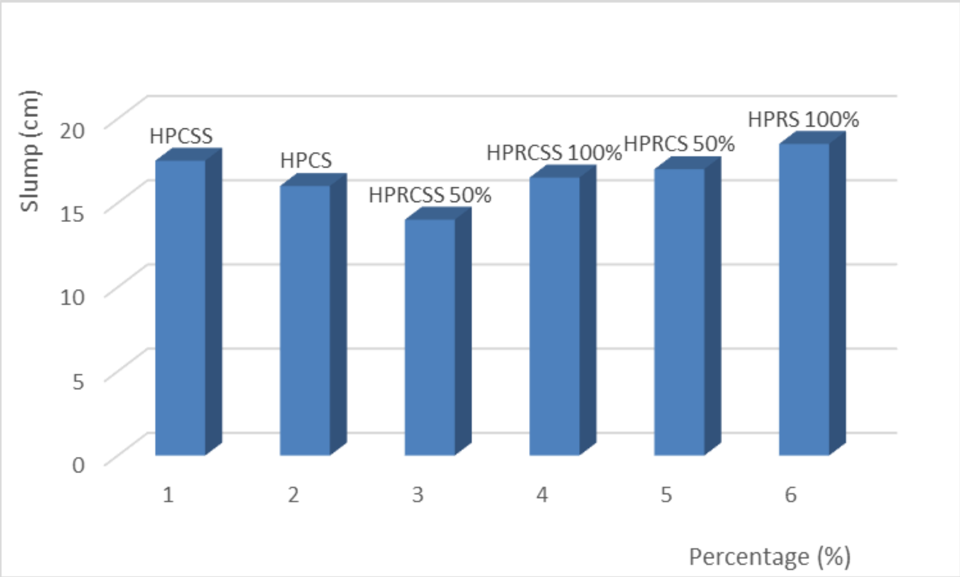

Figure 7 Slump as a percentage of recycled aggregate (0%, 50%, 100% gravel) and 30% sand

4.3 Mechanical properties

a) Hardened density

This test makes it possible to adjust the formulation studied for the same type of aggregate by comparing the experimental volume with the theoretical volume and to see the effect of the nature of the aggregates on the variation in density. The density of the concrete in the hardened state shall be measured from the mass of the test piece in relation to its volume after 28 days of hardening according to NF EN 12390-1 [20]. The test pieces used are cylindrical in size (16x32) cm.

Table 5 Hardened density of mixtures.

Mixtures	Hardenes density kg/m3)			
Days	7	14	28	56
HPCS0%	2.430	2.368	2.393	2.450
HPCSS0%	2.428	2.425	2.427	2.481
HPRCSS50%	2.341	2.435	2.348	2.430
HPRCSS100%	2.292	2.335	2.318	2.475
HPRCS50%	2.312	2.344	2.399	2.399
HPRCS100%	2.358	2.315	2.357	2.346

From Table 5 and Figure 8 it can be seen that for the same type of aggregate the hardened density of HPRC with addition of silica smoke is generally higher than that of HPRC with addition of slag. This is mainly due to the difference in the density of the two mineral additions used. The results also show that the nature of the aggregates significantly influences the hardened density of the HPC. Two cases are noteworthy: the first case concerns the effect of the mineralogical nature of natural aggregates. HPRC with silica smoke aggregate has the highest hardened density of all ages (7, 14, 28 and 56 days) compared to HPRC with slag aggregate. The second case concerns the influence of the introduction of recycled aggregates as a substitute for natural aggregates, it can be seen that the hardened densities of HPC with recycled aggregates of sleg are higher than those of HPC with silica smoke aggregates at the age of 56 days. This is due to the highest density of recycled slag aggregates (50%, 100%) [27].

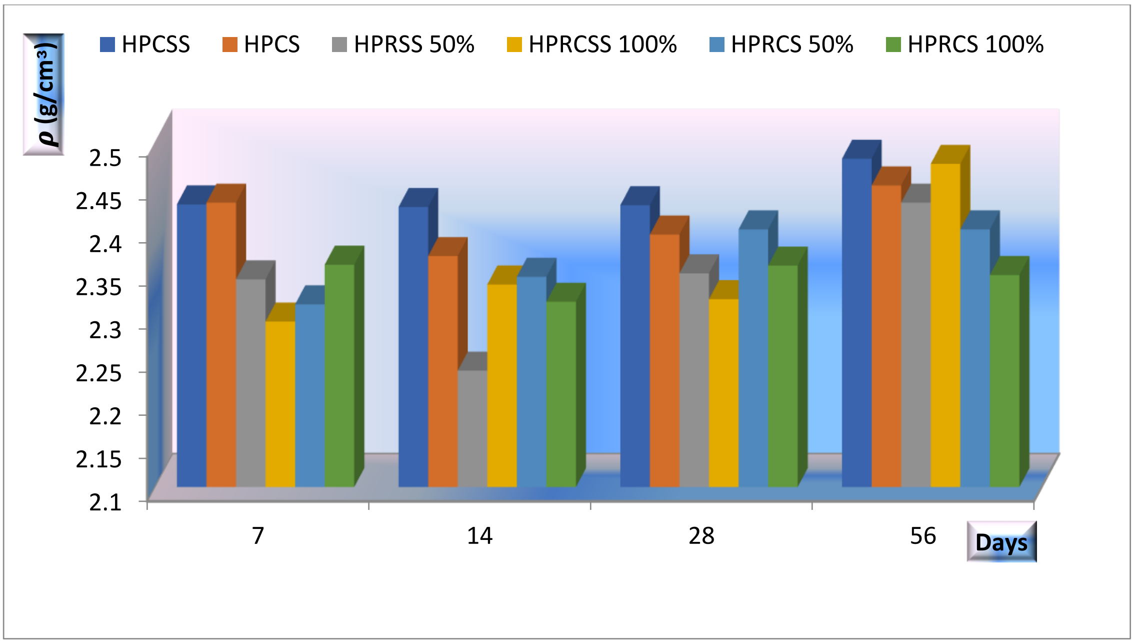

Figure 8 Determination of the hardened density of the mixtures according to the RA content.

b) Compressive strength

Mechanical resistance in compression is an essential characteristic of concrete and one of the fundamental parameters of our study. Therefore, its determination and evolution were followed for all HPC and HPRC compositions studied in this study. The Water/Cement ratio that governs the strength of ordinary concrete in simple compression is no longer the only parameter that influences the strength of high-performance concrete. The latter is characterized by the effect of mineral additions and the nature of the aggregates used. The compression tests were carried out in order to show the effect of two parameters: the nature of the aggregates and the mineral additions on the mechanical resistance in compression. In order to study the effect of these two parameters, three types of aggregates (one natural and two recycled) with two types of mineral additions, namely silica smoke and slag, are used. Compression strength results at (7, 14, 28 and 56) curing days are shown in Figure 9.

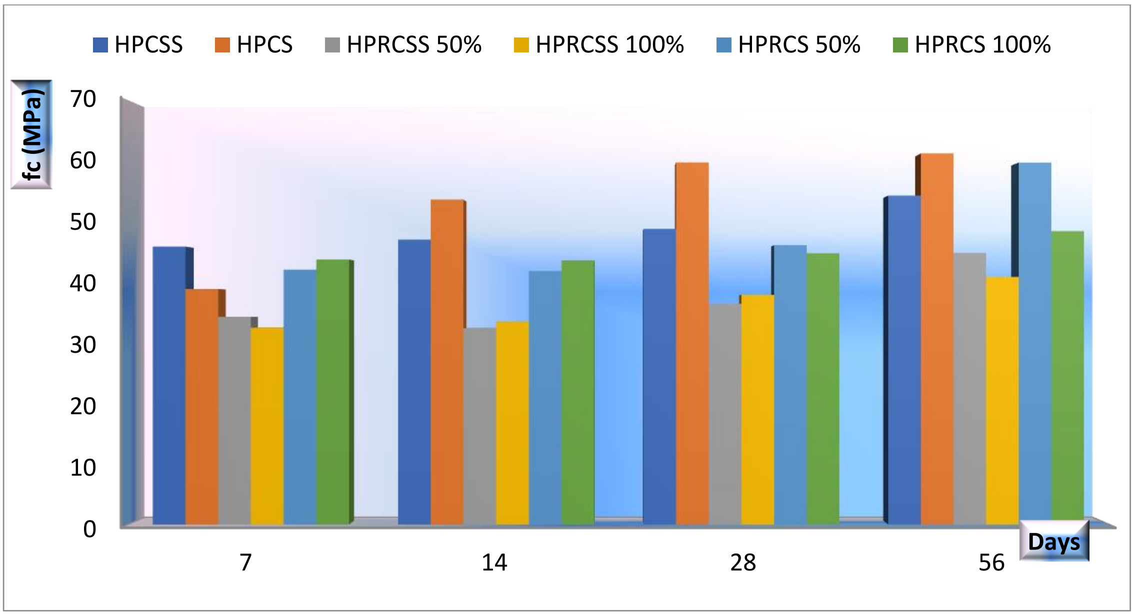

Figure 9 – Compressive strength as a function of time of different mixtures.

According to the values of the resistance evolution from 7 to 56 days, the HPRC based on slag aggregates have the best compression resistance compared to those based on silica smoke aggregates. This is attributed to double attached mortar, and low porosity of HPC formulated with mineral additions and therefore excellent mechanical behavior. Obtaining a high compressive strength of concrete therefore does not seem to be solely dependent on that of the aggregate used. The quality of the aggregate/cement matrix interface could also play a role [11,28].

5. CONCLUSION

Our main objective in this study is to formulate a high-performance concrete based on recycled aggregates (slag, silica smoke), developing its performance in order to use it in the construction of reinforced concrete structures, with better mechanical resistance than possible and lower blow. In order to achieve this aim, we based our work on the bibliographic synthesis that allowed us to create a scientific and technical context for our work. We were able to know the important problems of HPC and HPRC such as maneuverability, compatibility superplasticizer cement, and especially the water/cement ratio introduced in HPC and HPRC. These parameters acting directly on the rheological behavior then mechanical and in the end affects the durability of these concrete HP. The main difficulty encountered in the formulation of high-performance concrete HPC and HPRC consists in choosing the most effective cement-superplasticizer couple to achieve maximum water reduction, good workability and satisfactory rheology of the concrete during the implementation time. The experimental programme presented consists of two series of NHPC and four series of HPRC formulated with two additions of slag and silica smoke. An attempt was made to obtain the optimum workability of the HPC and HPRC on the basis of the lowest water/binding ratio and especially with the means available from the laboratory to make mechanical improvements to the HPRC material to be used in the construction. This study allowed us to carry out a physico-mechanical characterization of the different materials used, to choose the appropriate formulation methods and to see the influence of the nature of the aggregates on the properties of the concrete in the fresh and hardened state. Based on the results of the physical and mechanical tests carried out during this experimental work in these different phases, we can conclude the following:

- The densities of natural and recycled aggregates are very close, it is noted that natural aggregates have high densities compared to recycled aggregates, This is mainly due to their mineralogical natures which differ from that of recycled aggregates (presence of the mortar attached to the parent HPC);
- The water absorption coefficient values of natural and recycled aggregates are very low, confirming the good compactness of these aggregates;
- The Los Angeles test shows that natural aggregates are mechanically stronger than recycled aggregates (gravel, sand);
- Natural aggregates affect the manoeuvrability of HPRC compared to more compact and less porous recycled aggregates;
- HPC based on silica smoke are slightly less manageable compared to those based on slag. This is mainly due to the spherical morphology of the silica smoke particles, which gives the HPCSS a certain viscosity and a less flow than the slag HPCS, which have more or less angular forms;
- HPRC based on slag aggregates have the best compression resistance (61.228 MPa N, 59.710 MPa HPRC 50% and 48.109 MPa HPRC 100%) compared to HPRC based on silica smoke aggregates (54.26MPa N, 44.813MPa HPRC 50% and 40.848MPa HPRC 100%) at 56 days.

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