Journal of Materials and Engineering Structures

Research Paper

Study of concretes properties based on pre-saturated recycled aggregates

Tourkia Guerzou [a,]*, *Abdelkader Mebrouki* [a], *Joao Castro-Gomes* [b]

[a] *LCTPE, Civil engineering departement, Abdelhamid Ibn Badis University, Mostaganem, Algeria*

[b] *CMADE, Department of Civil Engineering and Architecture, 6201-001, Covilhã, Portugal*

ARTICLE INFO

Article history:

Received : 31 March 2018

Revised : 7 October 18

Accepted : 7 October 2018

Keywords:

Ordinary concrete

Recycled aggregates

Pre-saturation

Compressive strengths

ABSTRACT

The aim of this study was concretes waste recovery by replacing natural aggregates (NA) by recycled aggregates (RA) at rates of 0%, 50% and 100%. Recycled aggregates coming from construction and demolition waste (CDW) present a low quality compared to natural aggregates, the water absorption being their main drawback. Quantities of water absorbed and their variations in times were measured according to the European standard (EN 1097-6). Adding absorbed water during mixing have caused concretes segregations and an excess volume of water was observed at the surface of the concrete. The added water was not totally absorbed by aggregates. The pre-saturation of aggregates 24 hours before mixing and introducing them as a component in concrete was the best method. The initially saturated aggregates did not consume concretes mixture water. Workability by slump test and mechanical strengths developed with pre-saturated aggregates (100 % RA) and (50% RA - 50% NA) were measured on concretes, and then were compared to those of the reference concretes made with 100 % of natural aggregates.

1 Introduction

The building industries interest to recycle demolished constructions waste as new source of aggregates, this recycling can help to preserve natural sources and to protect environment. Recycled aggregates are obtained from concrete structures demolition. This industry waste valorization is an alternative solution which allows at the same time waste management and of the safeguarding of the natural resources [1, 2]. According to Oikonomou [3] and Douara [4] studies, the aggregates from demolition concrete can be used as aggregates in alternative to natural quarries aggregates, these aggregates are surrounded with an old cement paste, which is porous and would absorb an important water quantity.

The recycled concrete aggregates have like characteristics a lower relative density and a strong capacity for absorption water. This absorption is obviously the consequence of cement paste surrounding old natural aggregates, but more

* *Corresponding author. Tel.: +213 696768263.*
E-mail address: tourkia.guerzou@univ-mosta.dz

e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

particularly of its alveolar structure [5-7]. Cement paste interstices have the tendency to collect and to retain water [8 – 15]. Consequently, there would not be sufficient free water to hydrate cement grains. This criterion influences considerably the rheological behavior of the freshly-mixed concretes [16, 17].

Recycled aggregate density is less than that of natural aggregate [9, 10, 13, 14, 18]. This lower density is caused by the presence of the residual mortar [9, 18]. According to Etxeberria and al. [19] study, it is necessary to humidify the recycled aggregates before introducing them into the concrete in order to don't affect negatively the workability and to don't weaken the mechanical properties of the concrete because of the reduction in the interface paste-aggregate.

Measurement of recycled aggregate's absorption is a simple method which can be used to evaluate the quality of this one. Aggregates absorption is mainly due to the residual mortar. This particularly important property affects water quantities to be added to the mixture for a given handiness [20]. In saturated states, recycled aggregate water containing is greater than that of natural ones. A correction of added water quantity is necessary to maintain the same water/cement ratio.

Several methods were used to quantify recycled aggregates water absorption [21, 22]; as RAWA pycnometer method [23], hydrostatic method [24] and standard NF EN 1097-6 method [25].

The purpose of this experimental study is to measure absorbed water quantities and their variations in times according to the standard (EN 1097-6), to make ordinary concretes with 0%, 50% and 100% of recycled aggregates and to study fresh and hardened properties of the concretes made.

2 Materials and methods

2.1 Materials

Materials used in this investigation include cement, natural aggregates, recycled aggregates, sand plasticizer and water. All of the materials used were produced locally in Algeria. The cement used is CPA- CEM I 42.5 R named "CRS" from ZAHANA cement factory (west of Algeria), presents a specific surface area (BET) of 4200 cm²/g and an absolute density of 3.1 g/cm3. Table 1 shows the cement chemical analysis.

The used cement is an ordinary cement Portland without additions CPA CEMI 42.5, presenting an average compressive strength about 44MPa at 28 days [NF IN 196-1]. Its Blaine specific area is of (4200cm^2/g) and its density is 3050 kg/m^3. Chemical and mineralogical compositions are given in Table 1. This cement contains a higher content in C2S, which is favourable for improving the long-term mechanical strengths.

Table 1- Cement chemical analysis

Oxyds	[%]	Minerals (Bogue)	[%]
SiO2	21,12	C2S	34,5
CaO	63,84	C3S	38,5
Al2O3	6,42	C3A	10,7
Fe2O3	3,74	C4AF	11,3
MgO	0,21	Gypsum	4,5
Na2O eq	0,14	Others	0,5
SO3	0,51		
L.I 1	2,41		

1 (L.I) is Loss on Ignition (% by mass).

Natural aggregates were received from (Sidi Belabes, Algeria) career. Recycled aggregates were obtained from an old building demolition. All aggregates (natural RN and recycled RA) physical characteristics are showed in Table 2.

Table 2- Aggregates physical characteristics

Characteristics	Natural aggregate 3/8 (NA 3/8)	Natural aggregate 3/8 (NA 8/16)	Recycled aggregate 3/8 (RA 3/8)	Recycled Aggregate 8/16 (RA 8/16)
Absolute density [g/cm3]	2.56	2.67	2.38	2.35
Apparent density [g/cm3]	1.38	1.38	1.27	1.28
Water absorption [%]	1.8	1.44	9,93	5,80

Table 2 shows that recycled aggregates (both RA3/8 and RA8/16) absorptions are upper than those of natural aggregates. This absorption is due to the nature of these aggregates that are formed by solid grains surrounded by an old porous cement paste.

Grain size distribution analysis was measured for both natural and recycled aggregates by mechanical sieving Fig. 1 show particle size distribution curves of aggregates 3/8 and the fig.2 show the curves of aggregates 8/16.

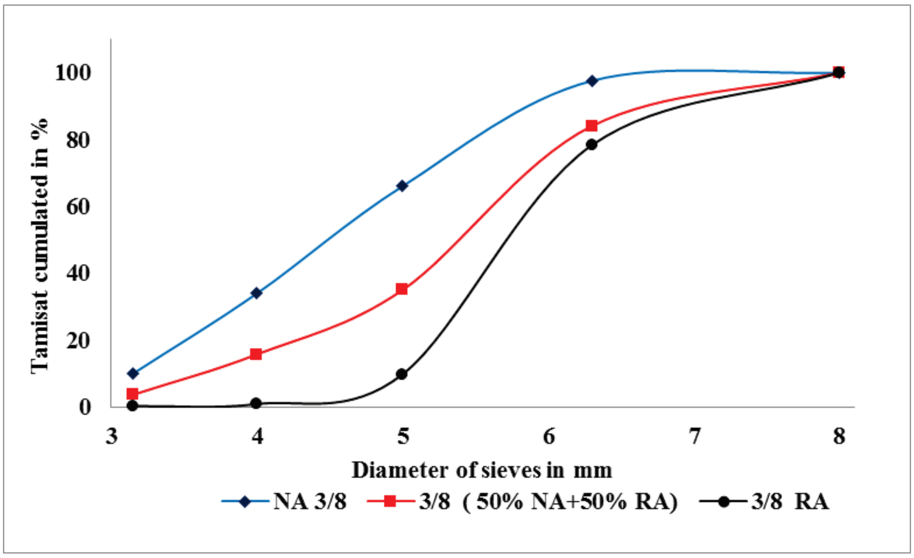

Fig 1- Grading curves of aggregates 3/8

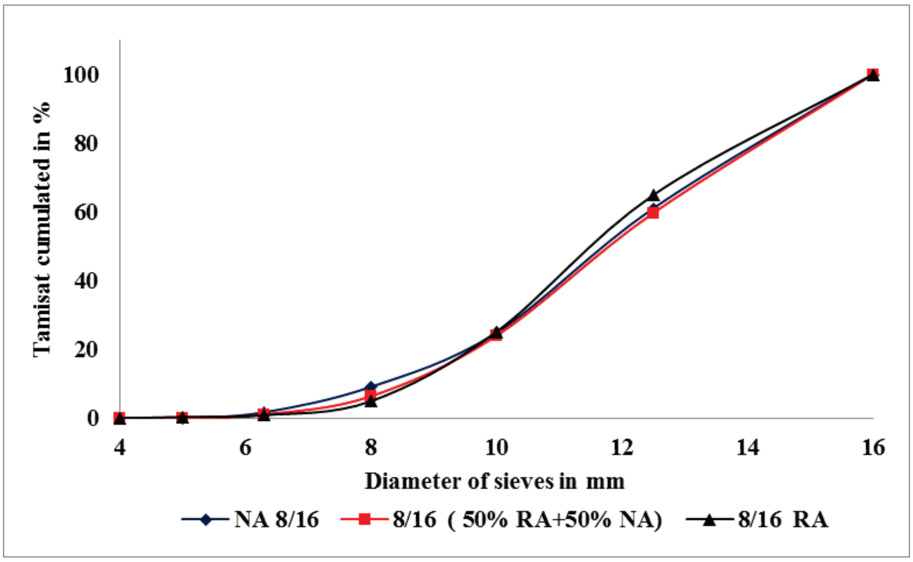

Fig 2- Grading curves of aggregates 8/16

Table 3- Recycled Aggregates chemical characteristics

Oxyds	Na_2O	MgO	Al_2O_3	SiO_2	SO_3	CaO	Fe_2O_3	K_2O	TiO_2
[%]	**0.75**	**1.27**	**5.73**	**34.48**	**1.28**	**50.85**	**4.50**	**0.80**	**0.34**

It's noticed from Fig.1 that the recycled aggregates 3/8 are coarser than natural aggregates, and the grading curve of the aggregates 8/16 in fig. 2 shows that all aggregates have a similar size distribution. This is possibly because of the crushing mode. The cement paste surrounding the natural aggregate is much in the 3/8 than the 8/16 recycled aggregates.

Two sand types were used. A silicate calcium sand from (Sidi-Lakhder - Mostaganem, Algeria) career and a sea sand for the granular correction. Physical characteristics of these sands are presented in the Table 4.

Table 4- Physical characteristics of Sand

Characteristics	Sea sand (SM)	Career sand (SC)
Absolute density [g/cm3]	2.63	2.5
Apparent density [g/cm3]	1.5	1.43
Sand equivalent [%]	91	80
Finesse modulus	1.2	3.9
fines (<80 µm) [%]	0,009	0.005
Water absorption [%]	0.64	1.82

Sand particle size distribution curves are presented below. Fig. 3 shows corrections made on sands size distributions, career sand was corrected by sea sand based on finesse modulus method.

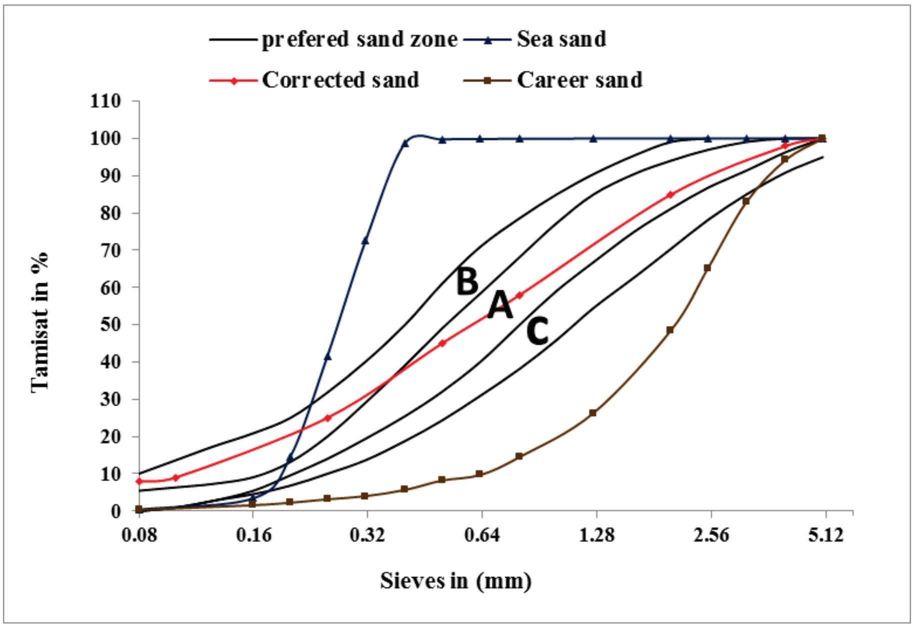

Fig 3- Grading curves of sand

2.2 Methods

Before formulating the ordinary concretes, absorbed water quantities were measured for the two classes recycled aggregates.

2.2.1 Pre-saturation

It was measured according to NF EN 1097-6 standard following steps below:

- Weigh a quantity (M1) of recycled aggregates (size ranges 3/8 and 8/16) after having them to steam with 80°C (to no calcinate cement past).
- Weigh the mass (M2) corresponding to pycnometer filled with water
- Weigh the mass (M3) corresponding to the recycled aggregates put in the pycnometer and filled with water.

Follow and measure water absorption in time intervals: 5 min, 10 min, 15 min, 30 min, 1h, 2h, 6h, 12h, 24h and 72 h. For these measurements, spread out the recovered aggregates of the pycnometer over a dry fabric. Lets them dry in free air until the visible water films disappear and then notes the mass (M4). Absorption ratio (Ab) can be calculated by the following relation:

$$Ab\% = \frac{100.(Ma\text{-}Mb)}{Ms} \qquad (1)$$

With:

Ma: mass of the sample soaked by water (wet).

Ms: mass of the dry sample after drying oven with 80 °C.

Drying with 80°C is selected to avoid the deterioration of the paste surrounding the aggregates.

2.2.2 Formulation of ordinary concretes

All ordinary concretes were formulated using DREUX-GORISSE method based on abacuses and the initial parameters were fixed as below:

water–cement ratio (W/C) for all concrete mixtures was kept constantly of 0.5, binder material content is 350 kg/m^3, compressive strength to reach was fixed at 30 MPa (28 days), concrete class S3 and aggregates maximum diameter Dmax=16 mm.

Concretes mixture compositions (corresponding to 1 m^3 concrete) are summarized in Table 5.

Table 5- Proportions of concretes mixtures

Materials	100% NA	100% RA	50% RA+50% NA
Cement [Kg]	350	350	350
Water [l]	175	175	175
Sea sand [Kg]	149.80	153.86	149.80
Career sand [Kg]	427.18	438.73	427.18
Size 3/8 [Kg]	136.45	133.85	150.6
Size 8/16 [Kg]	978.47	833.62	903.58
Fine [Kg]	49.53	50.88	49.53
Superplacticizer (%)	3.5	3.5	3.5

3 Results and discussion

Here discussion on results of tests carried out in the laboratory to investigate the various properties such as water absorption, workability, compressive and flexural strengths.

3.1 Results on fresh concrete state

3.1.1 Absorption

For both two classes of recycled aggregates (RA 3/8 and RA 8/16) water absorptions were measured. Fig. 4 shows variation of theses quantities in time.

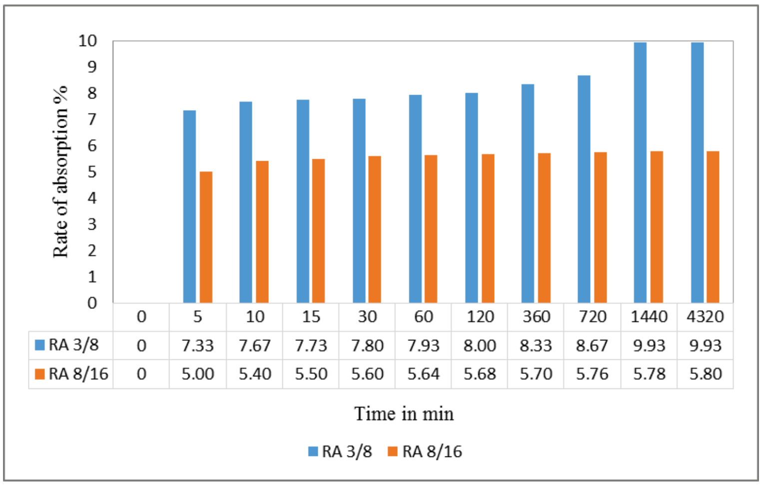

Fig 4- Diagram of water absorption according to time

Fig. 4 shows clearly two phases of evolution. The big absorption of water was in the five first minutes, followed by a second slower phase. Both curves evolve in the same way. The quantity of water absorbed by (RA3/8) is bigger than that of the (RA 8/16), this must be due to their important contain of old cement paste surrounding small natural gravels. For the two recycled aggregates, complete saturation was observed after 24 hours.

3.1.2 Workability

Four concretes were prepared for determining the workability at the fresh state. Slump flow tests results are shown in Fig. 5 below. For each concrete, slump flow was measured using Abrams cone.

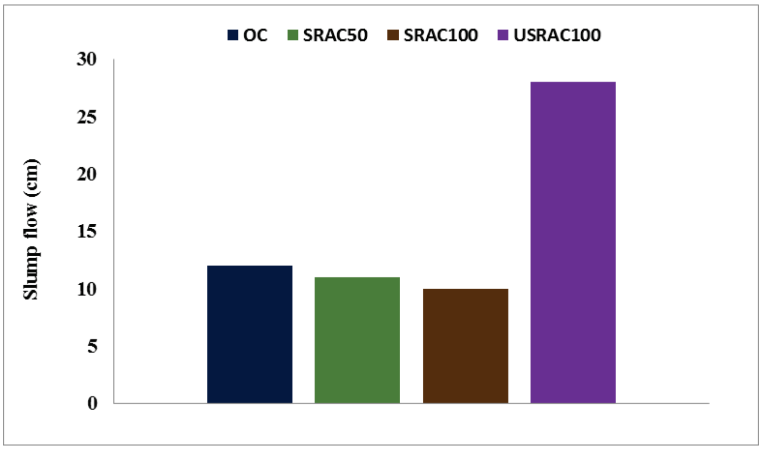

Fig 5- Slump flow of concretes

Notice that:

OC: Ordinary concrete made with 100% of natural aggregates (100% NA), as control mix.
SRAC50: Saturated recycled aggregates concrete (RA 50% + NA 50%).
SRAC100: Saturated recycled aggregates concrete (100% RA).
USRAC100: Unsaturated recycled aggregates concrete (100% RA).

Fig. 5 shows clearly according that to European norm EN 206-1, three concretes belong to the class S3 (slump flow 10 - 15 cm), only the concrete mixed with 100% unsaturated recycled aggregates is contained in the class S5 (slump flow > 22 cm) and is very fluid compared to the (OC) concrete because of the amount of absorbed water added to the mixing. Concretes made with 100% unsaturated recycled aggregates have the best workability because of their contained water quantity. There is a direct relationship between workability and mechanical strengths of concretes made with unsaturated recycled aggregates [26].

3.2 Results on hardened concrete state

Compressive and flexural strengths of concretes made with (100% NA), (50% NA + 50%RA), (100% unsaturated RA) and (100% pre-saturated RA) were measured on concretes at 2, 7, 14 and 28 days, according to European EN 206-1 norm.

Concrete made with 100% NA Concrete made with 50% NA and 50% RA Concrete made with 100% RA

Fig 6- Concretes appearance

Fig. 6 shows clearly the difference in surface appearance of each concrete. The 100% NA concrete has a compact surface and low porosity. However, the 50% NA and 50% RA concrete has minimum pores but the small aggregates fill the voids well. The 100% RA concrete has several pores but it is denser than the others.

3.2.1 Compressive strength

Fig. 7 shows variation of compressive strength measured at 2 to 28 days. It can be seen that this strength increases with increase in curing age. Compressive strength was measured on cubes of 10 x 10 x 10 cm^3. These tests were made according to European EN 206-1 norm.

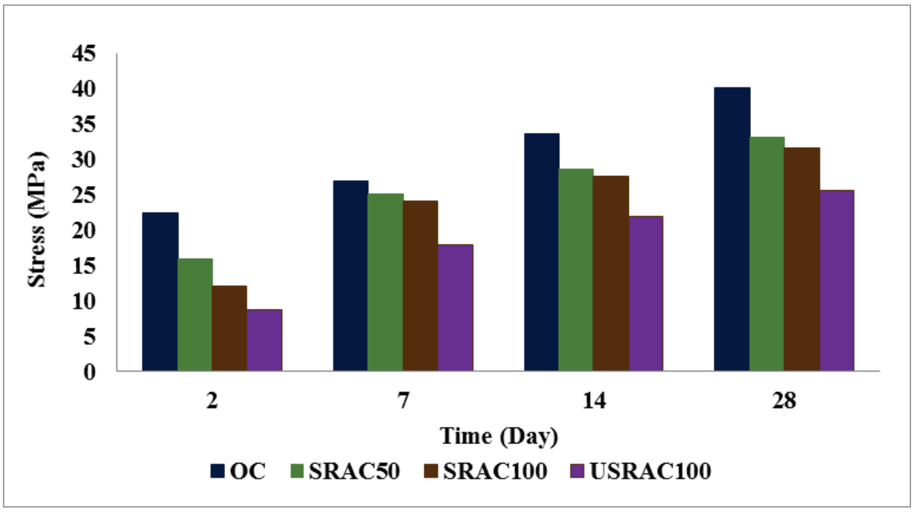

Fig 7- Variation of compressive strength

For each type of concrete, compressive strength increase from 2d to 28d. All concretes with saturated aggregates and for any time, developed lower compressive strengths compared to (OC) concrete. Whereas these concretes allowed obtaining good initial strength (2d, 7d).

According to results obtained (Fig. 7), from 2d to 28d of curing, compressive strength decreases as the addition of recycled aggregates increases in mixing concretes. Concretes containing unsaturated recycled aggregates have developed the lower strength but they developed the higher workability at slump test (Fig. 5).

By saturating recycled aggregates, with 50 % and 100 % of replacement, compressive strengths developed are similar and obtained concretes developed acceptable (for ordinary constructions) compressive strength (more than 25 MPa at 28d) without considering the chosen substitution rate. These confirm results obtained by similar research, Butter's study [8] showed that concrete made with saturated recycled aggregates developed a good compressive strength. These results are, however, different to some other researches. Works' results of Exteberria [19] and Ferreira [25] showed that concretes made with recycled aggregates initially pre-saturated, had less good characteristics in the fresh and hardened states than those having undergone a compensation of water during mixing.

3.2.1 Flexural strength

Flexural strengths were measured on cylindrical concrete test tubes 7×7×28 cm^3. Results obtained are shown in (Fig. 8) below. These tests were made according to European EN 206-1 norm.

It can be seen from the graph that all strengths evolve in the same way that those of control concrete (OC) made with natural gravels. For all concretes, regular increase of strengths was observed between 2 and 28 days. Concretes made with 100% unsaturated recycled aggregates (USRAC100) have developed the lower flexural strength.

Strength value achieved is approximatively similar than that of control mix (OC). Thus, replacement of natural aggregates by saturated recycled aggregates gives positive results and improved flexural strength.

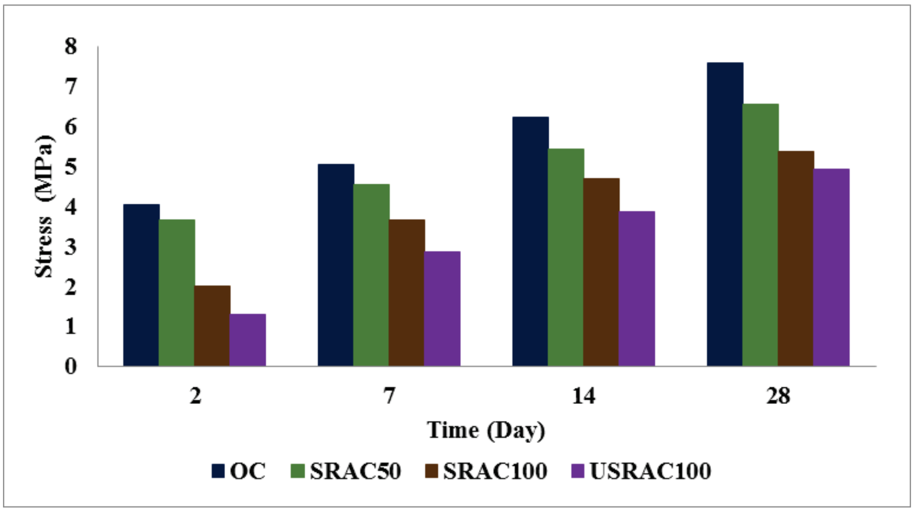

Fig 8-Variation of flexural strength

4 Conclusions

The main aim of this study was to measure water absorbed quantities by recycled aggregates crushed at 3/8 mm and 8/15 mm classes and to improve concrete characteristics. The determination of these various water quantities was followed by the mechanical compressive and flexural strengths of the ordinary concretes. Besides a control concrete made with 100% natural aggregates, concretes with recycled aggregates were developed. These concretes were formulated using two methods. The first is to add the absorbed quantity of water as compensation during mixing, the second was to pre-saturate the gravels 24 H before introducing them into the concrete. This study can be considered as part of strategy of waste recovery. According to the experimentation results, it’s noticed that the recycled aggregates 3/8 mm absorb more water than the recycled aggregates 8/16 mm because of their important containing of old cement paste surrounding small natural gravels. For unsaturated aggregates, add of absorbed quantity of water as compensation during mixing give concretes with not desired characteristics, water rejection phenomenon was observed during mixing concrete, causing consequently an increase in workability and a decrease of the strength compressive. With initially saturated recycled aggregates, recycled concretes have presented very acceptable results on workability and mechanical strengths. By replacing 50% initially saturated recycled aggregates, established the best formulation for recycled concretes, and the obtained results on workability and strength were similar to those of reference concrete made with 100% natural aggregates.

Based on the results, it can be concluded that it is recommended to introduce pre-saturate recycled aggregates into the concrete in order to obtain resistant ordinary concretes containing the recycled aggregates. This method ensures that the recycled aggregates do not absorb the effective quantity of water for the concrete. The USRAC100 concrete has the best slum flow but it has the worst flexural and compressive strength, we can use it as a filler concrete, printed concrete, pavements edges realization, floating flagstone and sealing coat.

Acknowledgements

The authors thank to (LCTPE) research laboratory and (LMPC) laboratory at the Faculty of sciences and Technology, University Abdelhamid Ibn-Badis of Mostaganem (UMAB), Algeria, and C-MADE laboratory, Covilhã Portugal, for their technical support.

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