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JOSÉ M. V. GÓMEZ-SOBERÓN

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RELATIONSHIP BETWEEN GAS ADSORPTION AND THE SHRINKAGE AND CREEP OF RECYCLED AGGREGATE CONCRETE

AUTHORS´ AFFILIATIONS

Gómez-Soberón, José M. V. is Ph.D. by the Technical University of Catalonia, Spain, studied the M.Eng. (Construction) at the National University of Mexico and Civil Engineer of the Autonomous University of Puebla in Mexico. He has published numerous papers on the area of Recycled Concrete in International Journals and Conferences and works as consulting engineer. josemanuel.gomez@upc.edu

ABSTRACT: In this work, it is described an experimental analysis of specimens of recycled concrete (RC) with replacement of natural aggregate with recycled aggregate originating from concrete (RCA). An experimental analysis to obtain the shrinkage and creep properties (basic and by drying) of RC was carried out. The replacement fraction of natural aggregate with RCA were 0%, 15%, 30%, 60% and 100% and the test conditions were 50% RH and 20 °C. The results of these trials were compared with mercury intrusion porosimetry tests (MIP) and gas adsorption (nitrogen), at 90 days. In the results, an increase in the shrinkage and creep properties of the RC with respect to conventional concrete was observed, while porosity values increased. However, the deformation evolution in the time is similar to conventional concrete.

KEYWORDS: Creep, Gases adsorption, Mercury intrusion porosimetry, Porosity, Recycled concrete, Recycled concrete aggregate and Shrinkage.

Nomenclature

φ - Coefficient of creep

$\varepsilon_{c\ basic}$ – Deformation by creep basic (mm/m)

$\varepsilon_{c\ drying}$ – Deformation by creep due to drying (mm/m)

$\varepsilon_{sh\ basic}$ – Deformation by shrinkage basic (mm/m)

$\varepsilon_{sh\ drying}$ – Deformation by shrinkage due to drying (mm/m)

D_s – Dry density (kg/m^3)

D_{sss} – Dry surface saturated density (kg/m^3)

N_2 – Gas nitrogen

RH – Relative humidity (%)

T – Temperature (°C)

t_o – Initial reference age for measures of creep (days)

Technical Terms

MIP – Mercury intrusion porosimetry tests

NA – Natural aggregate

OC – Original concrete

RC – Recycled concrete

RCA – Recycled aggregate originating from concrete

W/C – Relationships water – cement

INTRODUCTION

Recycled concrete may be considered as being porous [Gómez-Soberón, Agullo and Vazquez August 2001], with average total porosity values up to 35% higher than conventional concrete (depending on the age of the specimens and the replacement fraction of natural aggregate with recycled concrete aggregate or RCA). The general behavior observed is a decrease in mechanical and physical properties when the fraction of RCA present in the RC is increased [Gómez-Soberón, Vazquez and Agullo August 2001, Gómez-Soberón, Agullo and Vazquez July 2001].

Capillary pores (50 nm to 10 nm) and gel pores (< 10 nm) play an important role in water movement and affect shrinkage and creep properties due to drying [John, Poole and Sims 1994]. These pores can be characterized by either their total volume or their size distribution using mercury intrusion porosimetry techniques (MIP) or by gas adsorption.

Five types of concrete with different RCA content are presented in this study. The behavior of the concrete used to obtain the RCA is also given. The concrete samples were prepared for the study of their physical, mechanical, strain and porosity properties. bulk

EXPERIMENTAL DETAILS

Original Concrete

In this study 4 m^3 of original concrete (OC) was used. The concrete was made in a plant of ready-mixed and was cast into wooden formwork frames measuring 0.40 m x 0.20 m x 0.10 m. Fifty cylinders measuring ϕ 0.15 m x 0.30 m and four cubes measuring 0.10 m x 0.10 m were used to study the porosity and mechanical behavior of the OC. Twenty-four hours after casting, the specimens were removed from the formwork and submitted to a curing process (similar to the cured of concrete in constructions outdoor) for 150 days (see Table 1, where the specific characteristics of this concrete are given). The specimens were then passed once through a semi-fixed roller grinder with an inlet width of 0.45 m and a maximum outlet size of 0.025 m. Finally, the resulting material was classified into sizes (in mm): 0-5, 5-10, 10-20, 20-25. The 5-10 and 10-20 fractions were used as RCA in this work.

Recycled Aggregate and Natural Aggregate

The designation used by sizes was: for RCA, gravel 10-20 mm and fine gravel 5-10 mm; and for the natural aggregate (NA), gravel 12-20 mm and fine gravel 5-12 mm. The criterion used was the compacted maximum density (which reduced the possible influences of different particle size). These were: (a) for RCA the combination was 55% gravel and 45% fine gravel and (b) for NA the combination was 70% gravel and 30% fine gravel.

Table 2 gives the properties of the aggregate used. The RCA used in this study can be considered as being within the RILEM recommendation for TYPE II RCA (absorption ≤ 10% and $D_s \geq 2000$ kg/m^3); for the Belgian recommendation GBSBII (absorption < 9% and $D_s >$ 2100 kg/m^3); and in the Japanese case they comply with the absorption requirement (≤ 7% and $D_s \geq 2200$ kg/m^3) in the fractions used [Rilem 1994, Hendriks 1994, Vycke and Rousseau 1993, Kasai 1993]. Consequently, the RCA employed in this study may be used in both plain and reinforced concrete if its application and mechanical behavior is taken into account.

Mixture of Recycled Concretes

Due to the difficulty in determining the real W/C (water/cement) because of the high variation of absorption in the RCA, it was decided to use the ACI Standard Mixture Proportioning Method with the following criteria:

1. The substitution of RCA for NA was done using equal bulk volume fractions with the following condition (equation 1):

$$r = RCA_{coarse} / (RCA_{coarse} + NA_{coarse}) \qquad (1)$$

$0.00 \leq r \leq 1.00$

Where:

r = fraction of NA replaced by RCA, by volume

RCA_{coarse} = 55% recycled gravel + 45% recycled fine gravel

NA_{coarse} = 70% natural gravel + 30% natural fine gravel.

The replacement fraction for the five samples were: r = 0.00, 0.15, 0.30, 0.60 and 1.00. As fine aggregate (0-5 mm), 100% crushed natural limestone sand from the Garraf quarry, Barcelona, was used.

2. The RCA showed an increase in absorption proportional to the time spent in water. For the mixture was taken 20 minutes of immersion of the aggregates, reaching 97% of the absorption for fine gravel and 77% of the absorption for gravel, in both cases with comparison of absorption after 24 hours.

3. The amount of water absorbed by the aggregate was taken into account separately, in addition to its wetness before mixing and the free water that formed part of the mixture. The above aspect is justified in criteria that were emphasized in previous publications of the

authors [Gómez-Soberón, Vazquez and Agullo August 2001, Gómez-Soberón, Agullo and Vazquez September 2001, Gómez-Soberón, Vazquez and Agullo May 2001].

With the established mixing time and the required amount of water, the order of mixing the materials permits (as far as possible) the immobility of the water and an improvement in the transition zone (reduction of the porosity). The following sequence of mixed was adopted: (a) all of the coarse aggregate and water was introduced in the mixer; (b) these were mixed for 2 minutes; (c) the mixer was switched off for 3 minutes; (d) stages b and c were repeated twice; (e) the cement was introduced and mixed for 3 minutes; and (f) the sand was added and mixed for another 3 minutes.

The mixes are given in Table 3. The variation in consistency and volumetric weight of the RC with different fractions of aggregate replaced are within tolerable limits (slump 0.1 ± 0.03 m and concrete with volumetric weight normal).

Properties of the Concretes

The tests on the different concretes including the physical properties of absorption, density, and porosity; and the mechanical properties of compression, tensile strength, and Young’s modulus. Table 4 shows the results of the tests, in which the Spanish Norm Union were used. For more details of the previous trials, consult other publications of the authors [Gómez-Soberón, Vazquez and Agullo August 2001, Gómez-Soberón, Agullo and Vazquez July 2001].

Shrinkage and Creep

This test were determined using eight ϕ 0.15 m x 0.45 m cylinders for each one of the variables considered above. The strain measurements were carried out with embedded MM series EGP-type gauges fitted in the center of the concrete specimens. The specimens were kept in a curing chamber for 28 days (T = 20°C ± 2 and RH = 95% ± 5), after which they were moved to a climate chamber (T = 20°C and RH = 50%) until the end of the test period (90 days). Strain measurements were started at the following times: for basic (autogenous) and drying shrinkage, t_0 = 24 hours after the specimens had set; for basic and drying creep, t_0 = 28 days. When the specimens were moved to the climate chamber, the surfaces of four of the samples for each variable under study (two for basic shrinkage and two for basic creep) were sealed with paraffin (3-mm-thick layer) and than wrapped in three sheets of aluminium foil to prevent seepage of water from the concrete to the chamber environment. In Table 5, the values of compressive strength, test stress values for the different concrete samples and instantaneous and final strain values for the different variables in the study are shown. For more details of the trials of shrinkage and creep, consult previous publication of the authors [Gómez-Soberón, Vazquez and Agullo August 2001].

Porosimetry by Mercury Intrusion

The methodology applied in this technique, as well as the number, type and specimens specification have been published in a previous paper [Gómez-Soberón, Agullo and Vazquez August 2001].

The replacement factor r of the RC presented a correlation with total volume and the pore size, its influence being more important at lower ages and diminishing as the concrete ages. The most significant differences of the studied specimens are seen in two parameters: (a) The greater pore radius threshold as the replacement of natural aggregate by RCA is increased. (b) The detection of zones of major quantitative changes seen in the increase of the pore volume from pores with radius < 30 nm.

Finally, the results for specific surface area together with total porosity are those which better describe and correlate the results of the mechanical properties of the studied concrete.

Nitrogen (N_2) Adsorption

The N_2; adsorption technique is appropriate to characterize the sizes and distribution of pores in the region of capillary pores (50 to 10 nm) and gel pores (< 10 nm). Furthermore, it is these regions of pore size that, according to previous studies [Gómez-Soberón, Agullo and Vazquez August 2001], show significant variation in RC when the RCA content is increased. As there is a direct relationship between pore size and shrinkage and creep phenomena [John, Poole and Sims 1998], the following series of experiments were carried out [Willis, Abbell and Lange 1998].

Experimental

The procedures that were followed for each of the seven samples tested (OC, Natural Aggregate, r = 0.00, r = 0.15, r = 0.30, r = 0.60 and r = 1.00) are described below.

Cubic samples (h = 0.10 m) were placed first in a curing chamber for 28 days (T = 20°C ± 2 and RH = 95% ± 5) and then in a climatic chamber (RH = 50 and T= 20 °C) for 90 days. The cubic samples were then passed through a laboratory roller grinder with the inlet size set to its lowest value. The ground samples were passed through a sieve to obtain sample sizes ranging from 12.7 mm to 9.52 mm.

The sieved samples were put into test tubes and were degassed. This process involved temperature desiccation and gas elimination using a vacuum. After the samples were degassed, they were saturated (at atmospheric pressure) using an inert gas (nitrogen). Thereafter, they were sealed using a plug. The sealed tube was opened for the subsequent analysis process. This consisted of extracting the inert gas and starting the test. Finally, during the testing process the sample was covered with a cell that guaranteed constant thermal conditions throughout the test.

Equipment used for N_2 adsorption

In the N_2 adsorption tests a Micromeritics™ [(1)] Model ASAP 2010 analyzer was used with the following specifications and detection range [Micromeritics Instrument Corporation, 2002]: 0.01 m^2/g < specific surface area < 3000 m^2/g. 0.35 nm < pore diameter < 300 nm. 0 mm Hg < average pressure < 950 mm Hg. Equipment capacity (4 samples in total). Preparation of two simultaneous samples. Analysis phase (one sample port and saturation pressure pipe). The transmission pipes for the samples used were ϕ = 12.7 mm with a sample pumping capacity of nine cm^3. The gas used was nitrogen (N_2).

The equipment used is shown in Figs. 1 and 2, where the test tubes containing some of the samples in the preparation process and the analysis process in the thermal cell are seen.

RESULTS

[1] Copyright 1995-2002. Micromeritics Instrument Corporation. Norcross, GA, U.S.A.

The following section shows the results and analysis of the N_2 adsorption tests carried out on the different concrete samples in this study. Fig. 3 shows the average pore diameter distribution in the N_2 adsorption stage. In this figure, the following points are worthy of note.

1. NA is an aggregate with a practically non-existent pore diameter distribution, which indicates that its average pore diameter (see Table 6) can be considered as constant, with a very small standard deviation throughout the aggregate. Furthermore, for the region where this pore diameter distribution is found, this aggregate has quite a low porosity (0.001516 expressed in cm^3/g) in comparison with the rest of the samples studied.
2. The RCA used in this study as a substitute for the NA shows an average pore diameter that is 40% higher than NA (it has a higher standard deviation), and the test (ϕ= 45 nm) pore diameter increases inversely to its diameter and follows a distribution curve that is similar to an logarithmic curve.
3. The remaining samples corresponding to the replacement factor $\boldsymbol{r}$ under study show a common pore diameter distribution region. This region may be located at $\phi \geq 50$ nm. From this region the increase in the replacement factor $\boldsymbol{r}$ causes the pore diameters to increase their volume (which vary from 0.0213 cm^3/g when $\boldsymbol{r} = 0.00$ to 0.0330 cm^3/g when $\boldsymbol{r} = 1.00$ See Table 6); Thus, as the pore diameter increases, the pore volume also increases. This behavior is attributed to the mortar content that adheres to the RCA; in other words, as RCA is a partial mixture of natural aggregate and old mortar, which increases the factor $\boldsymbol{r}$, the result is an increase in mortar (increase in the factor $\boldsymbol{r}$ = increase in mortar = increase in the volume of the pores, which in addition are inversely proportional to diameter size).
4. The relationships that are seen between the different replacement factors $\boldsymbol{r}$ can be summarized by the similarity shown by the parities between $\boldsymbol{r} = 0.00$ and $\boldsymbol{r} = 0.15$,

followed by the variables between $\boldsymbol{r}$ = 0.30 and $\boldsymbol{r}$ = 0.60, and finally at a considerable distance from the rest of the factors when the factor is $\boldsymbol{r}$ = 1.00

Fig. 4 shows the average pore diameter distribution in the N_2 desorption stage. The following should be noted in this stage:

1. The distribution of the curves has the same order (with reference to the factor $\boldsymbol{r}$) as the adsorption stage the adsorption stage (except for OC, which increases for the reason possible of the phenomenon of hysteresis).
2. As could be expected, analogously with the extrusion stages in the MIP tests (where effects such as hysteresis are seen, causing changes in the curve distributions), in the N_2 adsorption tests (desorption stage) it is also possible that the test process alters the samples to some extent, and therefore the curves should only be interpreted as a guide. In the event of two curves very similar (adsorption stage), the desorption may differentiated in this variables (differentiating, for example, between factors $\boldsymbol{r}$ = 0.30 and $\boldsymbol{r}$ = 0.60); which are significantly similar in the adsorption curves and are clearly differentiated in the desorption curves.

Fig. 5 shows the graph of the results for the surface area for the seven specimens tested and the values shown in Table 6. The general behavior seen is an increase in the surface area which is directly correlated with the replacement factor $\boldsymbol{r}$ (it should be pointed out that when $\boldsymbol{r}$ = 1.00, a value that is 65% greater than the reference concrete is reached $\boldsymbol{r}$ = 0.00), while the OC is located in the intermediate region with reference to the factor $\boldsymbol{r}$; and finally, the NA is the specimen with the lowest specific surface area (only 0.7712 m^2/g).

Finally, in Figs. 6 and 7, the graphs that represent the relationship between the pore volume found in the N_2 adsorption tests and the values for shrinkage and creep of the different RC studied are shown. As can be seen, there is a clear correlation between the increases of the strains due to the various mechanical effects and the increase in the pore volume detected. These correlations are considerably more significant in the properties associated with drying in the specimens (either for shrinkage or creep properties). The best correlation is found in creep due to drying versus pore volume.

In view of the above, it is true that this porosity (capillary pore and gel pore zone) seems to be closely related to the phenomena of shrinkage and creep; however in the case of RC they are the cause of the increase in the values of these properties. This means that increasing the amount of RCA in the RC causes an increase in the mortar content of the concrete. This mortar is clearly more porous than a natural aggregate.

Another factor that has not been taken directly into account in the present study, but which is clear from the mechanical results previously presented on RC and also the Los Angeles coefficient tests done on RCA used in the present study [Gómez-Soberón, Vazquez and Agullo August 2001], is that the RC with RCA can reach lower stress levels than the concrete with natural aggregate (NA), resulting in concrete with corresponding shortcomings in stress. In the case of shrinkage and creep, the possibilities of restrictions in stress that may be seen in aggregate used in the concrete under study are (obviously after the mortar factor) the most important factor to be taken into account (as regards material used) when these properties are evaluated.

CONCLUSIONS

Based on the research and results presented in this paper, the following conclusions are reached:

- Total porosity to water increases significantly in recycled concrete aggregate (RCA) in comparison with the porosities shown by natural aggregate (NA).
- There was an increase in the shrinkage and creep for the recycled concretes and these are related to the properties of the recycled aggregate, originating from the original concrete

(high porosity, possibility of water absorption and a decrease in density). These properties increased with an increase in the amount of natural aggregate being replaced.

- The tests carried out using mercury intrusion porosimetry shows that the factor r shows correlation not only with total porosity but also with pore size radius (pore radius in the zone < 30 nm considerably increases its volume when the factor r is increased). These tests also showed the reduction of the pore volume with ageing of the concrete.
- Finally, the N_2 adsorption results show the pore diameter size distribution in the smaller size zones (capillary and gel zone). It can be concluded from these tests that.
  a) Natural aggregate (NA), used in this investigation, is not very porous and has a practically constant pore diameter.
  b) The RCA used is a more porous aggregate than NA and the difference is due to the increase in the pore volume as its diameter decreases.
  c) The NA replacement factor for RCA (r) correlates with the increase in total pore volume that is found as of the $\phi \geq 50$ nm zone. These increases are due to the mortar that adheres to the natural aggregate in the RCA.
  d) The increase in the specific surface area shown in the RC directly correlates with the factor r.
  e) The effect on the increase in shrinkage and creep (which are more pronounced in comparison with the drying process) can be attributed to the presence of RCA. This aggregate provides an extra amount of mortar to the RC which in turn leads to an increase in porosity (especially in the $\phi \geq 50$ nm zone), and thus to the possibility of increased in shrinkage and creep strain.

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TABLE 1 Mixtures used for original concrete.

COMPONENT	OC
Cement, kg/m^3 (1)	380
Water, kg/m^3	168
Fine gravel (5-12 mm), kg/cm^3 (2)	252
Gravel (12-20 mm), kg/cm^3 (2)	773
Sand (0-5 mm), kg/m^3 (2)	784
W/C	0.44
Coarse A / Fine A, Vol.	1.3
Additives, Plastifier (L/m^3)	2.69

(1) CEM I 42.5 R
(2) Limestone aggregate, Garraf quarry, Barcelona

TABLE 2 Properties of recycled and natural aggregate.

PROPERTY	RCA			NA(1)		
	10-20	5-10	0-5	12-20	5-12	0-5
Dry specific gravity, kg/m^3	2280	2260	2170	2570	2640	2570
Specific gravity (surface dry), kg/m^3	2410	2420	2350	2590	2670	2600
Water absorption, %	5.8	6.8	8.2	0.9	1.1	1.5
Total porosity, %	13.42	14.86	…	2.70	2.82	…
Shape index	0.363	0.466	…	0.364	0.576	…
Flakiness index	6	15	…	8	19	…
Modulus of fineness	7.2	6.2	3.8	6.9	5.0	3.3
Sand equivalent, %	…	…	93.6	…	…	93.8
Particles < 200μ, %	0.06	0.29	9.85	0.50	2.46	9.24

(1) Limestone aggregate, Garraf quarry, Barcelona

TABLE 3 Mixtures used for recycled concrete.

COMPONENT		*r* = 1.00	*r* = 0.60	*r* = 0.30	*r* = 0.15	*r* = 0.00
Cement, kg/m^3 (1)				400		
Water, kg/m^3				207.6		
RCA, kg/cm^3	Fine gravel (5-10 mm)	406	258	134	69	…
	Gravel (10-20 mm)	497	315	164	84	…
NA, kg/cm^3	Fine gravel (5-12 mm) (2)	…	268	488	604	710
	Gravel (12-20 mm) (2)	…	115	209	259	304
Sand (0-5 mm), kg/m^3 (2)				662		
W/C				0.52		
Coarse Aggregate/ Fine Aggregate, Vol.				1.53		

(1) CEM I 52.5R Spanish Normalization Association and Certification: Cements. Definitions, classifications and specifications (UNE 80 301 96 RC/97)
(2) Limestone aggregate, Garraf quarry, Barcelona

TABLE 4 Mechanical and physical properties of recycled concrete.

AGE[(1)] / FACTOR	TENSILE STRENGTH, MPa			COMPRESSIVE STRENGTH, MPa			YOUNG'S MODULUS, GPa			ABSORPTION, % [(2)]	WATER POROSITY, % [(2)]	D_s, kg/m^3 [(2)]	D_{sss}, kg/m^3 [(2)]
	7	28	90	7	28	90	7	28	90				
r =0.00	3.6	3.7	3.9	33.3	39.0	42.1	27.6	29.7	32.4	8.40	18.0	2130	2310
r =0.15	3.3	3.7	3.9	33.9	38.1	41.6	27.2	291	30.1	8.60	18.5	2140	2360
r =0.30	3.3	3.6	3.9	34.8	37.0	39.5	26.5	27.8	29.4	8.60	18.5	2150	2330
r =0.60	3.2	3.4	3.7	30.6	35.8	38.3	25.5	26.6	27.6	9.00	19.2	2120	2320
r =1.00	3.5	3.3	3.6	30.7	34.5	37.5	26.9	26.7	26.4	9.60	20.1	2090	2290
OC	3.2	3.8	…	35.2	38.4	…	33.0	33.7	…	5.90	13.4	2270	2410
OC[(3)]	4.1	4.1	4.2	45.1	45.4	47.0	35.2	34.5	34.6				

(1) Days

(2) D_s = Dry specific gravity, D_{sss} = Specific gravity (surface dry). Spanish Normalization Association and Certification. Concrete tests. Toughened concrete. Determination of the density (UNE 83.312/1990)

(3) 150 days curing process + 15 days process of RCA manufacture + 7 days curing room = 172, 150 days curing process + 15 days process of RCA manufacture + 14 days curing room = 179, and 150 days curing process + 15 days process of RCA manufacture + 97 days curing room 255 days of age

TABLE 5 Shrinkage and creep of recycled concrete.

COMPONENT PROPERTIES		r = 1.00	r = 0.60	r = 0.30	r = 0.15	r = 0.00	OC
Compressive strength (28_{days}), MPa		34.5	35.8	37.0	38.1	38.8	46.1[(1)]
Stress level for creep, MPa [(2)]		12.08	12.53	12.95	13.34	13.58	16.14
$\varepsilon_{sh\ basic}$, (90_{days}), mm/m		0.0138	0.0310	-0.0040	-0.0080	-0.0220	-0.260[(3)]
$\varepsilon_{sh\ drying}$, (90_{days}), mm/m		0.4029	0.4104	0.3524	0.3763	0.3740	0.1940[(3)]
$\varepsilon_{c\ basic}$	Instantaneous, mm/m	0.1370	0.1470	0.1645	0.1350	0.1430	0.1180[(3)]
	φ (90_{days}, 28_{days})	0.85	0.72	0.55	0.81	0.44	0.34[(3)]
	$Specific_{c\ basic}$, 1/MPa	0.021	0.020	0.020	0.018	0.015	0.012[(3)]
$\varepsilon_{c\ drying}$	Instantaneous, mm/m	0.1580	0.1530	0.1380	0.1350	0.1600	0.1265[(3)]
	φ (90_{days}, 28_{days})	4.04	3.85	3.65	3.55	2.90	0.1265[(3)]
	$Specific_{c\ drying}$, 1/MPa	0.076	0.068	0.057	0.054	0.051	0.028[(3)]

(1) The age of the test was 200 days

(2) 0.35 Compressive strength (28_{days})

(3) Shrinkage (262 days, 172 days) and φ (262 days, 172 days)

TABLE 6 Results for the N_2 adsorption tests.

COMPONENT	BET SURFACE AREA, m^2/g	AVERAGE PORE DIAMETER, nm		AVERAGE PORE DIAMETER (4v/A), nm	VOL. ADSORBED, cm^3/g STP
		Adsorption	Desorption		
NA	0.77	9.22	12.42	…	0.0015
OC	4.75	13.08	13.20	…	0.0155
r = 0.00	3.15	30.16	21.12	27.03	0.0213
r = 0.15	3.31	25.05	19.87	16.74	0.0214
r = 0.30	4.60	23.30	14.63	22.00	0.0255
r = 0.60	4.06	25.21	20.80	16.93	0.0259
r = 1.00	5.18	24.70	20.03	16.80	0.0330

FIG. 1 – Testing equipment for N_2 adsorption.

FIG. 2 – Detail of the N_2 adsorption equipment.

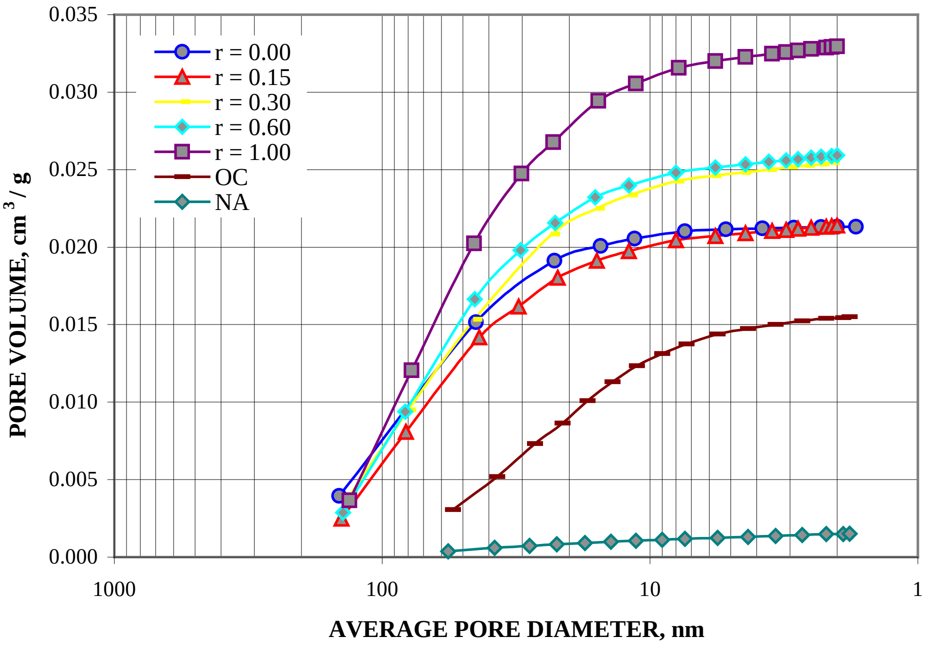

FIG. 3 – Pore adsorption distribution. Cumulative pore volume.

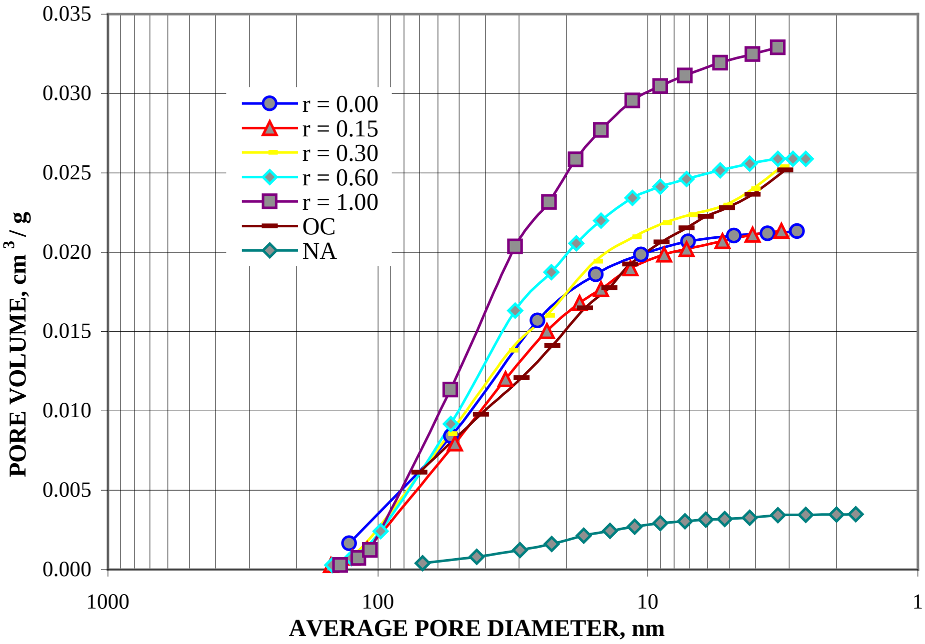

FIG. 4 – Pore desorption distribution. Cumulative pore volume.

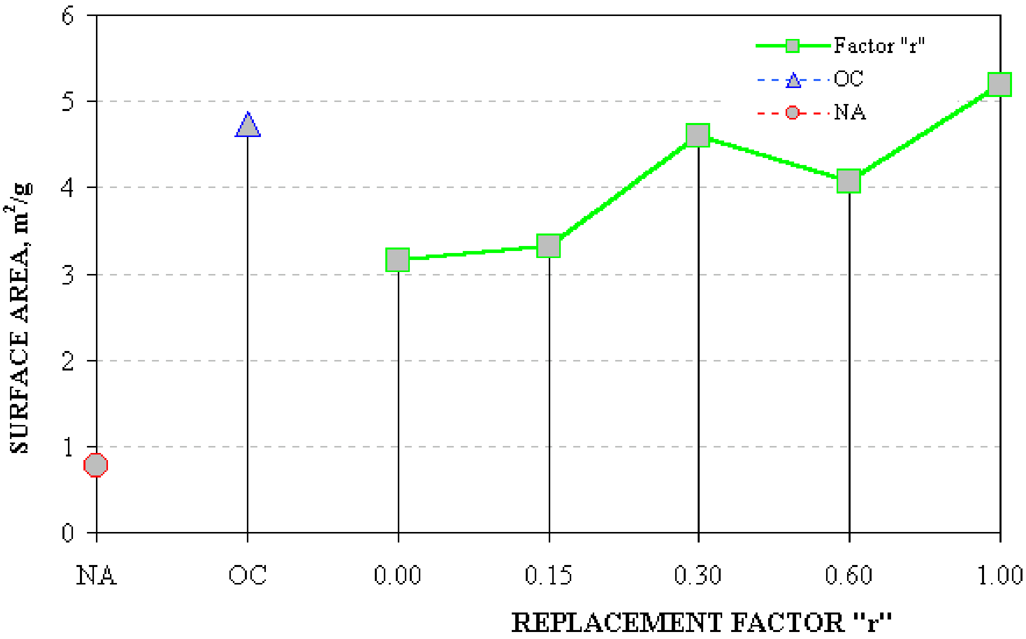

FIG. 5 – Surface area of the different test specimens.

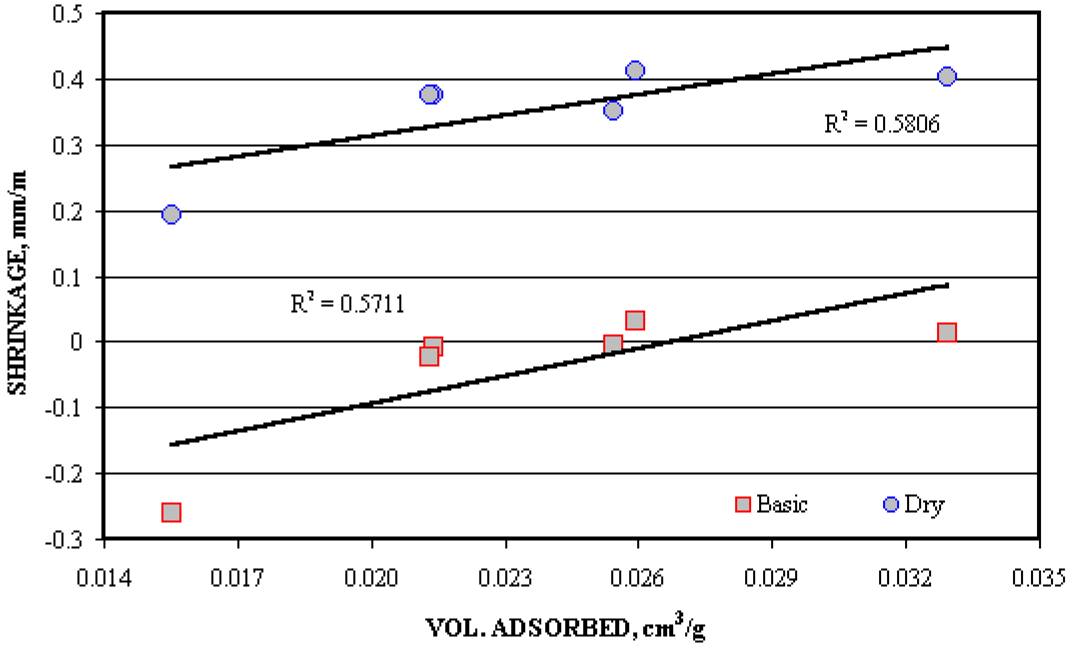

FIG. 6 – Porosity volumes found in N_2 tests and their relationship with shrinkage in RC.

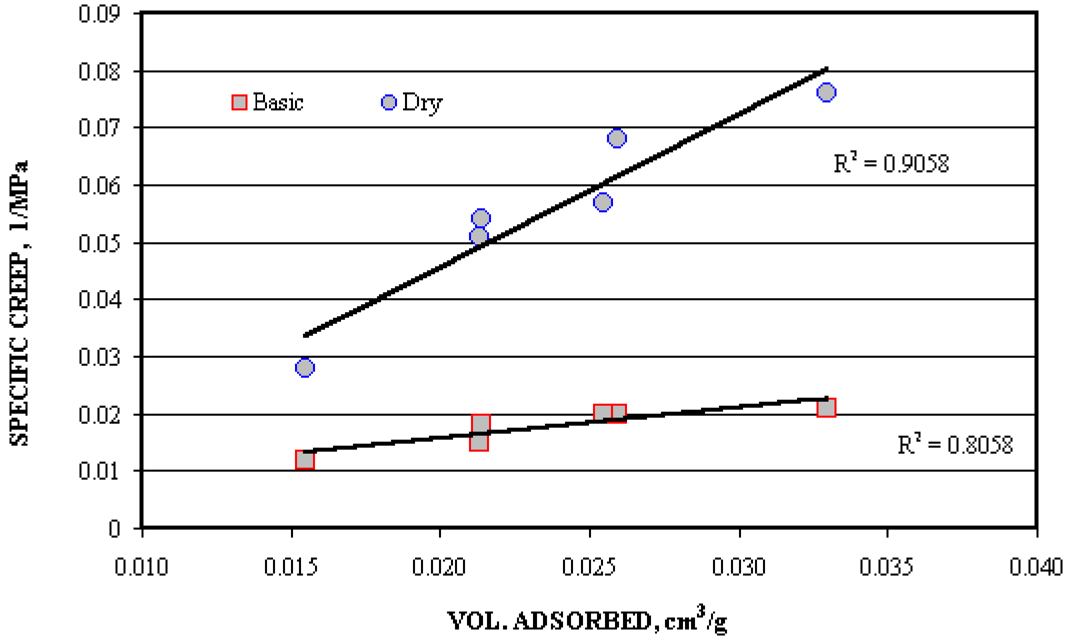

FIG. 7 – Porosity volumes found in N_2 tests and their relationship with specific creep in RC.