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Influence of cement type and chemical admixtures on the durability of recycled concrete aggregates

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Abstract. This study investigates the effect of replacement of natural aggregates with recycled concrete aggregates on the durability of concrete. Three different combinations of cement and chemical admixtures were considered, and the produced mixtures were assessed for their durability performance. The obtained results show a significant increase in the porosity of the mixtures with increasing in the percentage of recycled sand substitution, whereas the porosity increase was less pronounced for the natural gravel substitution. In addition, increasing the percentage substitution of recycled aggregates results in a decrease in density. However, this decrease is more pronounced in the case of substitution with recycled sand than for recycled gravel. Finally, the diffusion depth of the chloride ions increases with the increase of recycled gravel, regardless of the cement/admixture couple. This rise is less pronounced than in the case of concrete made with recycled sand.

1. Introduction

The demand for natural aggregates is quite high in developing countries due to the rapid progress of building infrastructure, and this leads to shortages of resources; this is why the construction field in developing countries is trying to find alternative materials to replace the demand for natural aggregates. Aggregates occupy 60 to 80 % of concrete's volume and play a significant role in the evolution of its properties. Most natural occurring rocks can be used as concrete aggregates as long as they comply the national and international specification standards. Raw materials for the production of natural aggregates (NA) and for those of recycled aggregates (RA) contribute to differences and variations in their overall properties [1, 2]. In fact, igneous, metamorphic or sedimentary rocks used in the production of NA are relatively homogeneous, unlike concrete wastes, which often have a heterogeneous composition. Typically, NA that come from igneous, metamorphic or sedimentary rocks are relatively homogenous and quite robust [1]. On the contrary, RA are in large characterized by a high degree of heterogeneity [2]. Concerning the use of RA from concrete waste in the manufacture of new mixtures, it appears that the replacement of coarse NA with coarse RA has an effect on the durability of the new concrete. However, the effect of the use of fine RA is still a matter of debate. The primary criticism by some for the use of fine RA in concrete manufacture is their high water absorption, which can lead to concretes with poor performance. Nevertheless, published data suggest that, the use of fine RA can be reliable at certain substitution percentages, with a saturation point beyond which further replacement with fine RA leads to reduction in both durability and mechanical performance of concretes [3–5]. This reduction in performance is due to the following factors: (i) the lower mechanical strength of RA; (ii) the high-water absorption of RA; (iii) the compromise of the interfacial transition zone (ITZ) in concrete. Poon et al [6] have studied the microstructure

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of concretes made from recycled concrete and high performance concrete aggregates by the means of a scanning electron microscope (SEM). They found that the ITZ around RA was characterized by higher porosity. This can be problematic in terms of performance, as high porosity in the ITZ will lead in to two undesirable phenomena: the reduction in the ITZ strength (and hence of the composite in general) and in the increase of the permeability. The adhered cementitious matrix on the RA increases its overall apparent porosity, thereby increasing its specific surface area [7–9]. It is apparent that the properties of the cement paste that envelopes RA have a strong effect on the physic and mechanical properties of the RA [10, 11]. Nevertheless, early studies by Nagataki et al [12] showed that a critical aspect is the decontamination of RA from other construction waste and if this is done properly, the RA can be suitable alternative to coarse NA. Previous studies [13–16] have shown that the density of these RA is lower or that their absorption capacity is higher; this varies from 3 to 12 % whatever the size of the RA whereas the absorption of the natural aggregates is approximately 0.5 to 1 %. Moreover, their mechanical properties are known to be inferior to those of NA [10]. Barbudo et al [17] evaluated the influence of superplasticizers (SP) on the behavior of concrete utilizing fine RA. However, the authors found that SP had a greater influence on the behavior of NA-based concretes than on concretes based on fine RA. The loss of effectiveness of the admixtures was justified by the incorporation of the RA, which then caused an increase in the specific surface area of the aggregates. In addition, a parallel research on the influence of SP in concretes based on coarse RA was carried out by Pereira et al [18], which yielding similar observations.

In this context, the present work will study the effect of replacement of natural aggregates with recycled concrete aggregates on the durability of concrete. Three types of cement and chemical admixtures are used. The tests used to evaluate the durability are porosity and the diffusion of chloride ions in the concrete.

2. Experimental program

2.1. Materials and testing methods

2.1.1. Aggregates

RCA varies according to the origin of the concrete that is to say according to the basic formulation of the concrete called previous concrete in the literature [16]. Table 1 shows the water absorption coefficients of natural and recycled sand (NS, RS), natural and recycled gravel (NG, RG) measured according to NF EN-1097-6 [19]. The absorption coefficient of the RA are significantly higher than that of the NA. This is the most important parameter that differentiates RA from NA.

Table 1. Water absorption and density of aggregates used.

Type of aggregate	Water absorption (%)	Density (%)
NS (0/4 mm)	0.9	2.59
RS (0/4 mm)	10.0	2.71
NG (4/10 mm)	0.5	2.71
RG (4/10 mm)	5.1	2.17
NG (10/20 mm)	0.4	2.31
RG (10/20 mm)	5.7	2.29

a. Sand

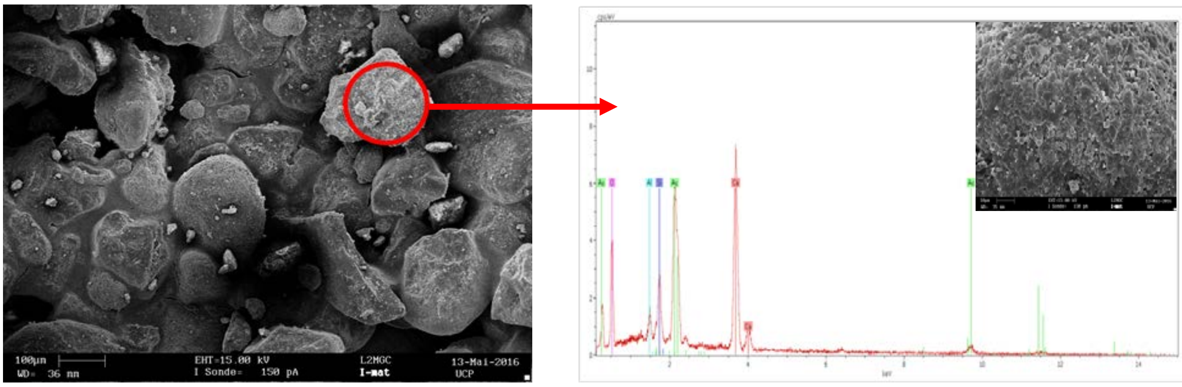
The results of the morphological and chemical analysis of sand are shown in Fig. 1. Fig. 1a shows that NS has an angular shape. Fig. 1b shows the morphology of RS as an accumulation of grains of NS of angular shape, which are interconnected by cement paste and contains many pores.

The chemical analysis of NS reveals that the main peaks of its composition are calcium and silicon. It is then a silico-calcareous sand. The chemical analysis of RS reveals that the main peaks are calcium, silicon, iron, magnesium and aluminum; these latter compounds can be considered as originating from the cement paste attached to the sand grains.

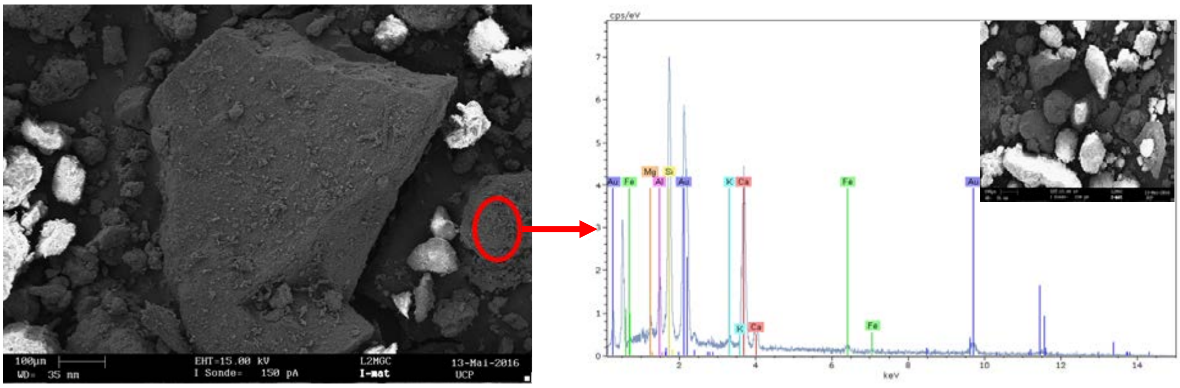
b. Gravel

The results of morphological and chemical analysis of gravel are presented in Fig. 2. The NG has an angular shape (Fig. 2a). RG is the accumulation of NG grains of angular shape connected to each other by a small amount of cement paste with the presence of pores in this paste (Fig. 2b).

The elemental analysis spectrum obtained for NG shows that the main peaks represent its composition are calcium and silicon; it is a siliceous gravel. The spectrum obtained for RG reveals that the main peaks are of calcium, magnesium and aluminum. These latter compounds can be considered as being derived from the cement paste attached to the gravel grains.

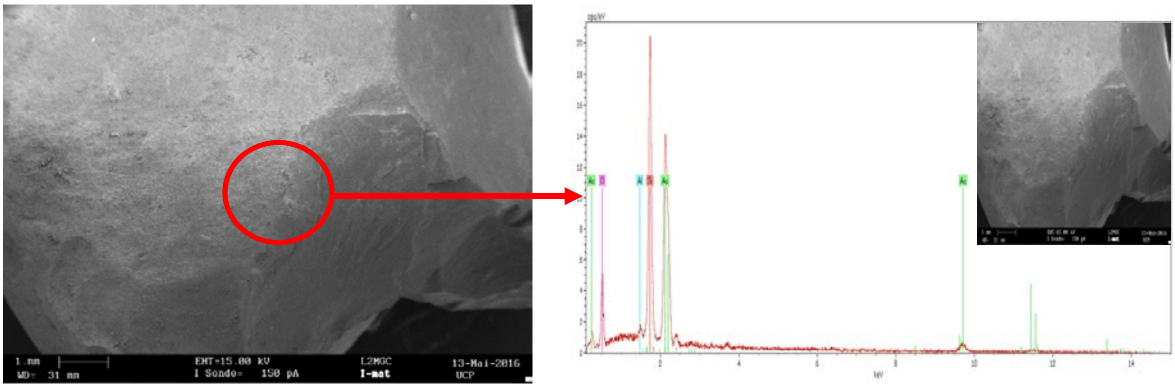


(a)

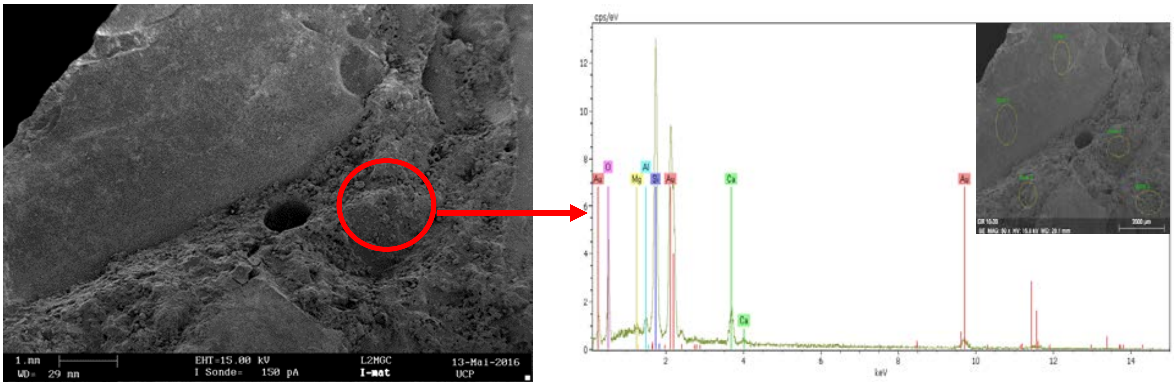


(b)

Figure 1. SEM of sand used: (a) NS, (b) RS.



(a)



(b)

Figure 2. SEM of gravel used: (a) NG, (b) RG.

2.1.2. Cement

Three types of cement are used in this investigation. The chemical analysis and physical properties of cements used are presented in Table 2.

Table 2. Chemical analysis and physical properties of cements used.

Cement	C1	C2	C3
Physical properties			
Finesse Blaine (cm^2/g)	4520	3250	4110
Median diameter (µm)	9.7	16.5	12.3
Water demand (%)	27.2	26.0	26.5
Initial setting time (min)	120	165	140
Hydration heat at 41h (j/g)	328	300	320
Chemical analysis (%)			
S_iO_2	19.54	20.19	20.1
Al_2O_3	5.70	3.81	5.5
Fe_2O_3	3.06	2.99	4.8
CaO	60.10	61.50	59.70
SO_3	3.71	3.31	2.31
MgO	1.85	1.96	3.26
K_2O	0.86	0.81	1.81
Na_2O	0.19	0.17	0.22
Cl^-	0.07	0.02	0.06
Loss on ignition	0.33	0.68	0.78

2.1.3. Chemical admixtures

Three admixtures are used in this study; the properties of these admixtures are given in Table 3.

Table 1. Properties of chemical admixtures used.

Admixtures	A1	A2	A3
Chemical Type	Polycarboxylate	Ether polycarboxylique	Polycarboxylate
Type	High water reducing	Water reducing	Water reducing
Solids content (%)	22.5	22.5	20
Form	liquid	liquid	liquid
Color	light yellow	light brown	light yellow
pH	4 – 6	6 – 8	4.5 ± 1.0
Recommended Dosage (%)	0.1 – 3.0	0.2 – 1.9	0.1 – 3.0
Content Na2O (%)	≤ 1	≤ 1	≤ 0.5
Content ions Cl- (%)	≤ 0.1%	≤ 0.1	≤ 0.1

2.2. Testing methods

The mix proportions of different concrete mixtures made with NA and RA are given in Table 4.

The apparent density (ρ_d) and the porosity accessible to water (ε) were determined at the age of 28 days according the standard NF-EN 1097-6 [19].

The diffusion of chloride ions test was determined at the age of 28 days according to the standard (ASTM C 1202-97) [20].

Table 2. Mix proportion of different concretes made with NA and RA.

Group/C	Mixture	C (kg/m³)	NS (kg/m³)	RS (kg/m³)	NG (4/10) (kg/m³)	NG (10/20) (kg/m³)	RG (4/10) (kg/m³)	RG (10/20) (kg/m³)	SP (%)	Water (kg/m³)	W/C
A/C1	0RS0RG	320	852	0	325	696	0	0	0.40	188	0.59
	15RS0RG		724	105					0.40	196	0.61
	30RS0RG		596	211					0.40	206	0.64
	50RS0RG		426	350					0.40	218	0.68
	70RS0RG		256	492					0.40	231	0.72
	100RS0RG		0	702					0.30	250	0.78
	0RS0RG		852	0	325	696	0	0	0.40	188	0.59
	0RS15RG				276	592	42	87	0.40	193	0.60
	0RS30RG				228	487	84	173	0.58	200	0.63
	0RS50RG				163	348	140	288	0.65	205	0.64
	0RS70RG				98	209	195	404	0.78	217	0.68
	0RS100RG				0	0	279	578	0.78	200	0.63
B/C2	0RS0RG	320	852	0	325	696	0	0	0.20	176	0.55
	15RS0RG		724	105					0.40	185	0.58
	30RS0RG		596	211					0.40	195	0.61
	50RS0RG		426	350					0.40	205	0.64
	70RS0RG		256	492					0.40	220	0.69
	100RS0RG		0	702					0.40	238	0.74
	0RS0RG		852	0	325	696	0	0	0.20	176	0.55
	0RS15RG				276	592	42	87	0.67	182	0.57
	0RS30RG				228	487	84	173	0.51	189	0.59
	0RS50RG				163	348	140	288	0.50	200	0.63
	0RS70RG				98	209	195	404	0.48	206	0.64
	0RS100RG				0	0	279	578	0.42	218	0.68
C/C3	0RS0RG	320	852	0	325	696	0	0	0.30	180	0.56
	15RS0RG		724	105					0.40	195	0.61
	30RS0RG		596	211					0.40	203	0.63
	50RS0RG		426	350					0.40	215	0.67
	70RS0RG		256	492					0.40	230	0.72
	100RS0RG		0	702					0.40	245	0.77
	0RS0RG		852	0	325	696	0	0	0.30	180	0.56
	0RS15RG				276	592	42	87	0.50	188	0.59
	0RS30RG				228	487	84	173	0.50	190	0.59
	0RS50RG				163	348	140	288	0.45	200	0.63
	0RS70RG				98	209	195	404	0.45	220	0.69
	0RS100RG				0	0	279	578	0.42	228	0.71

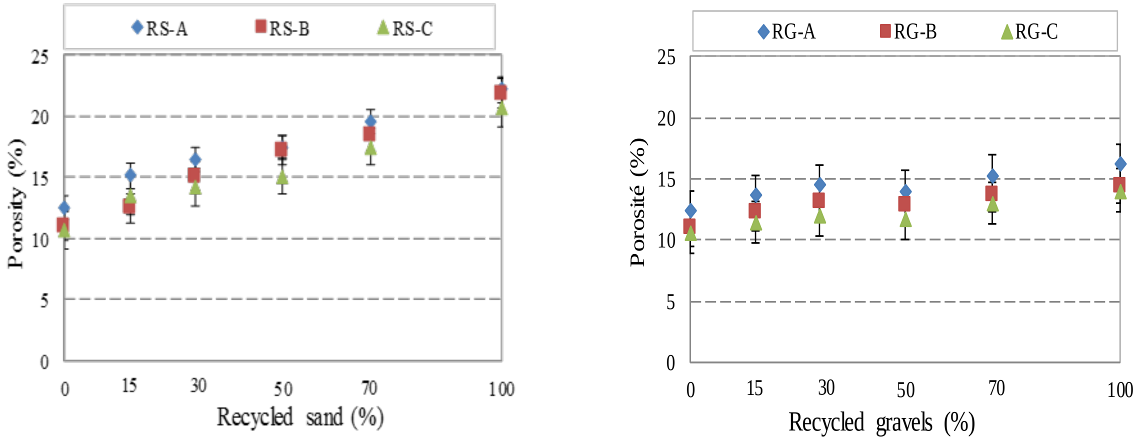
C: cement; NS: natural sand; RS: recycled sand; NG: natural gravel; RG: recycled gravel; SP: superplasticizer

3. Results and Discussion

3.1. Evolution of density and porosity accessible to water

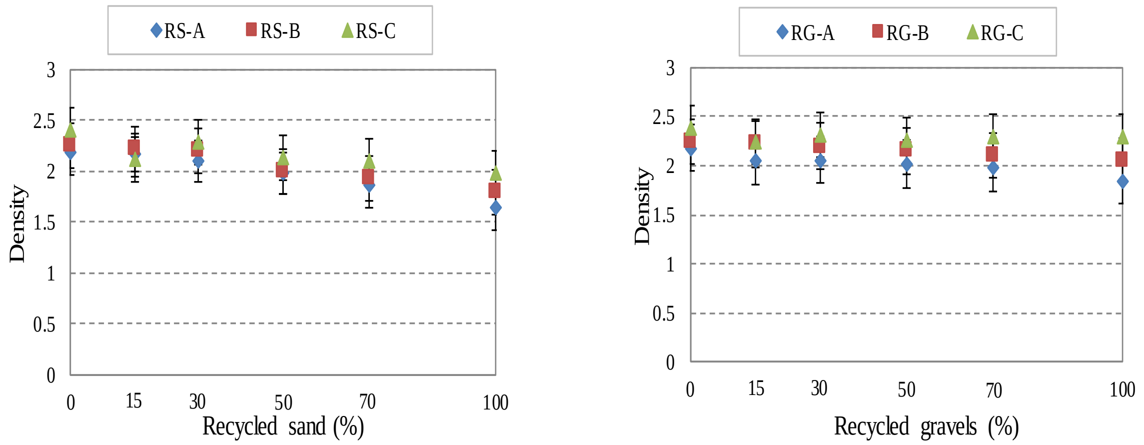
The evolution of the porosity (ε) and the density (ρ_d) measured at 28 days are presented in Fig. 3 and 4 respectively. Fig. 3a shows that the 28-day porosity of concrete made with RS increases remarkably, when the substitution percentage of RS increases, regardless of the type of cement and chemical admixtures that are being tested. It reaches a 50 % increase for a 100 % substitution percentage of RS compared to NS. Fig. 3b shows a less marked increase when the substitution concerns NG by RG, regardless of the type of cement and admixtures tested. Indeed, the more the percentage of RG increases and the more the porosity of the concrete increases; this tendency to increase remains nevertheless reasonable (it is about + 20 % whatever the couple). Moreover, for the two series of concrete (RS and RG), the distinction of the results as a function of the type of cement and admixtures is not obvious.

Fig. 4 shows that increasing the percentage substitution of RA results in a decrease in density; however, this decrease is more pronounced in the case of substitution with RS (Fig. 4a) than for RG (Fig. 4b). This result also confirms the evolution of the porosity of the concretes, namely that the more the concrete is porous, the more the density decreases.



(a) **(b)**

Figure 3. Evolution of porosity of RCA: (a) RS; (b) RG.



(a) **(b)**

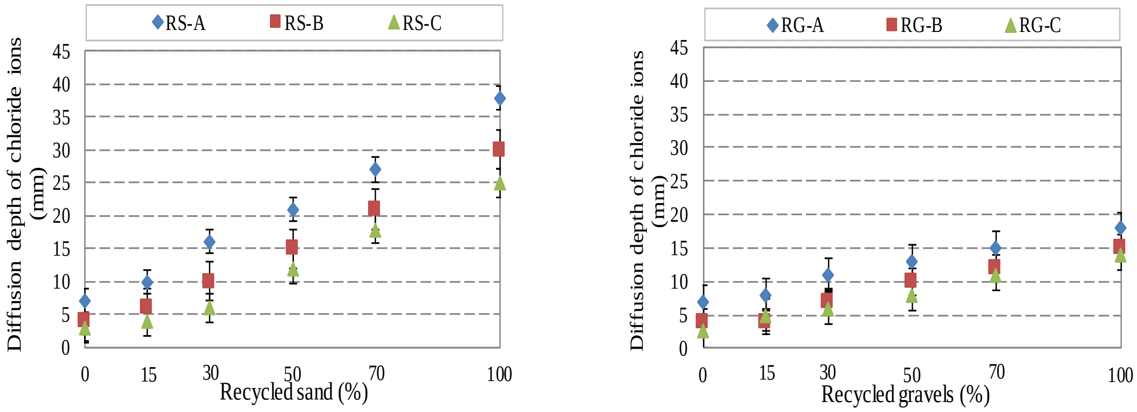
Figure 4. Evolution of density of RCA: (a) RS; (b) RG.

3.2. Evolution of the diffusion of chloride ions

Fig. 5 shows the evolution of the diffusion depth of chloride ions as a function of the percentage of substitution of RS and RG for the three types of cement and admixtures at 28 days. Fig. 5a shows that in the case of RS concrete the depth of diffusion of the chloride ions increases dramatically and linearly with the increase in the percentage of substitution, irrespective of the couples cement / admixture. It can reach up to 40 mm deep in the case of the RS-A couple with 100 % substitution, an 85 % increase compared to concrete based on NS. It also increases linearly but less markedly in the case of concrete based on RG (Fig. 5b); the increase is 60 % for the RG-A couple. Indeed, the diffusion of chloride ions is influenced by the presence of pores in the concrete structure since these ions penetrate by capillary absorption. Therefore, more the concrete is porous the diffusion is greater, which is the case of concrete made with RS which thus present a deeper chloride ion penetration. It should also be noted that, the type of cement and admixtures affect the chloride ion diffusion depth results for both types of RA. The couple RS-A and RG-A have higher diffusion depths compared to the couple RS-B and RG-B and increased with the percentage of substitution. The couple RS-C as well as RG-C has average diffusion depths according to their percentages of substitution. This phenomenon can be explained by the fact that the amount of C_3A is greater in the couple of RS-A as well as RG-A compared to the couple RS-B and RS-C, as well as RG-B and RG-C. The couple RS-C as well as RG-C has average amount of C_3A.

The diffusion of chloride ions in concrete is closely related to the porous structure of the material [21]. Indeed, several researchers have demonstrated the tendency of chloride ions to react with the constituents of the cement to give a complex solid phase based on chloride known as *Friedel salt* ($C_3A.CaCl_2.10H_2O$)

[22]. The interactions between the chlorides and the cement constituents were firstly attributed to the C_3A phase in the cement. Subsequently, other studies have shown that the fixing capacity of the cement paste depends on the total aluminate content (composed of C_3A and C_4AF) [23–25]. In fact, the amount of fixed chloride ions increases with the C_3A content of the cement; nevertheless, starting from a certain content of C_3A, this quantity does not evolve any more, whatever the nature of the cement or the considered deadline. Experimental observations show that the factor limiting the diffusion of chloride ions is C_3A. The latter decreases during hydration [26]. It should also be noted that C_3A is less reactive than C_4AF and that hydration is very slow [27, 28].



(a) **(b)**

Figure 5. Evolution of the diffusion depth of chloride ions of RCA: (a) RS; (b) RG.

3.3. Relationship between the durability parameters

3.3.1. Relationship between the density and porosity

Fig. 6 shows the existing relationship between density and porosity. According to the figure, the density decreases as porosity increases for RS and RG concrete. On the other hand, this decrease is more marked in the case of the RS concrete than for the RG concrete. This is explained by the small variation in the porosity of RG compared to RS.

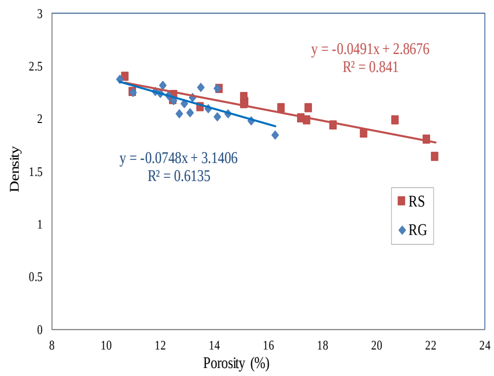


Figure 6. Relationship between the porosity and the hardened density of RCA.

3.3.2. Relationship between the diffusion depth of chloride ions and density

Fig. 7 shows that regardless of the type of RA and regardless of the couple cement/admixture, there is a linear relationship between chloride ions diffusion depth and density. Indeed, when the latter increases, the diffusion of chloride ions decreases. However, this relationship is more pronounced in the case of concretes made with RS since they experience a remarkable decrease as a function of the increase in density; this decrease is considerably diminished for the concrete made with RG. In addition, it should be noted that they experience a very low variation in density and depth of diffusion of chloride ions, regardless of their percentages of substitution. Concrete made with RS show a variation in density but above all the depth of diffusion of chloride ions higher; the slope showing the relationship for concrete made with RS is therefore much sharper than that of concretes made with RG. The relationship between the diffusion depth of the chloride ions and density for the concrete can be expressed as follows:

$$\text{For RS: } X_d = 19.44(\rho_d)^2 - 129.74\rho_d + 200 \text{ with } R^2 = 0.9, \tag{1}$$

$$\text{For RG: } X_d = 32.51(\rho_d)^2 - 162.15\rho_d + 207.4 \text{ with } R^2 = 0.5, \tag{2}$$

X_d is the depth of diffusion of chloride ions (mm);

ρ_d is the density in the cured state.

3.3.3. Relationship between the diffusion depth of chloride ions and porosity

Fig. 8 shows a reverse relationship to the one previously proposed. Indeed, an increase in the diffusion depth of chloride ions as a function of the increase in porosity is to be observed. This relationship is all the stronger as it concerns the concrete made with RS, although those of the concrete made with RG also experience an elevation of this depth according to the porosity. In addition, the variation of the values of the porosity and the diffusion depth of the chloride ions between the different percentages of RS is particularly high compared to that which exists for the same properties of the concrete made with RG. The equations reflecting the evolution of the porosity as a function of the diffusion depth of the chloride ions for the concrete made with RS and with RG are as follows:

$$\text{For RS: } X_d = 0.25\varepsilon^2 - 4.86\varepsilon + 27.01 \text{ with } R^2 = 0.9 \tag{3}$$

$$\text{For RG: } X_d = 0.23\varepsilon^2 - 3.05\varepsilon + 10.01 \text{ with } R^2 = 0.7 \tag{4}$$

X_d is the depth of diffusion of chloride ions (mm).

ε is the porosity accessible to water.

In addition, the variation of the values of the porosity and the diffusion depth of the chloride ions between the different percentages of RS is particularly high compared with that which exists for the same properties in the concrete made with RG. Two models of calculations of the chloride ions diffusion depth as a function of porosity were proposed from the values obtained by the experimental measurements as shown in Fig. 9.

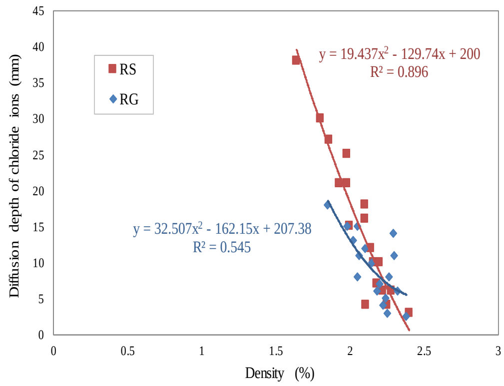


Figure 7. Relationship between the diffusion depth of chloride ions and the density of RCA.

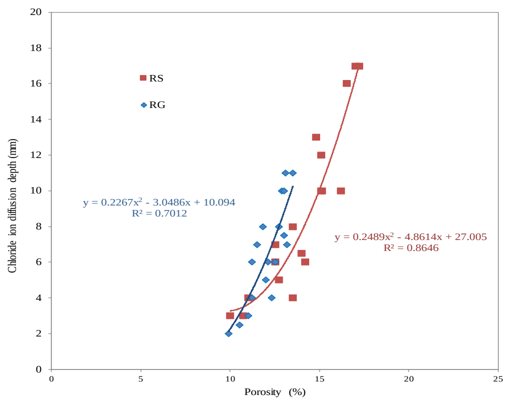
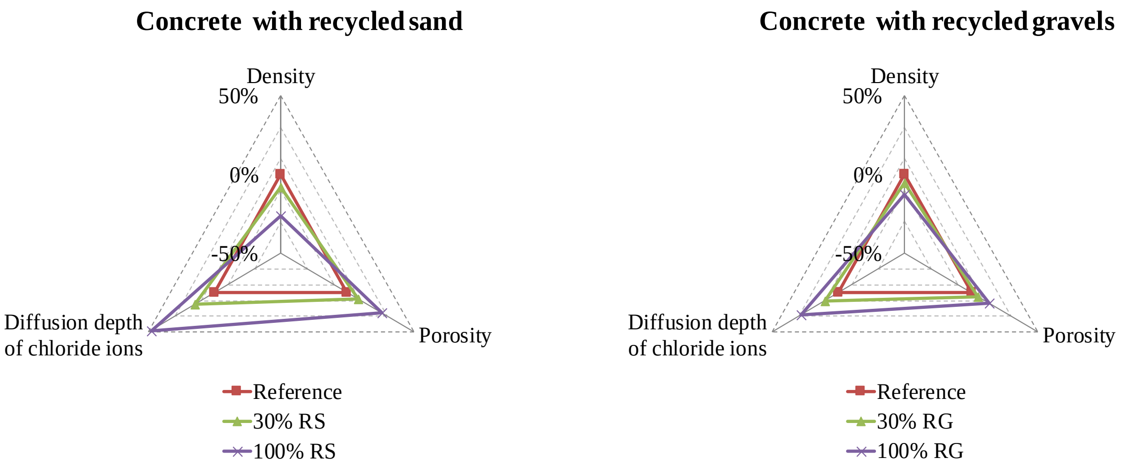


Figure 8. Relationship between the chloride ions diffusion depth and the porosity of RCA.



(a) **(b)**

Figure 9. Relationship between density, porosity and depth of chloride ions diffusion of RCA: (a) RS; (b) RG.

4. Conclusions

This study investigates the effect of replacement of NA with RCA on the durability performance of concrete. Based on the obtained results, the main conclusions may be drawn:

1. Regardless of the couple cement / admixture, there is a relationship between chloride ions diffusion depth and density. Indeed, when the latter increases, the chloride ions diffusion depth decreases considerably. However, this relationship remains qualitative.

2. A significant increase in the diffusion depth of the chloride ions as a function of the increase in porosity is observed. This increase is accompanied by a wide range of chloride ion diffusion depth values for the different percentages of RS. A model for calculating these two parameters has also been proposed based on the values obtained by the experimental measurements.

3. The diffusion depth of the chloride ions and the porosity increases significantly with the increase in the percentage of RG. Regardless of the couple of cement and admixtures. This rise is less pronounced than in the case of concrete made with RS.

4. The couple of cement and admixtures stand out because of their chloride ion diffusion depth results. This can be explained by the amount of C_3A that these couple contain. Indeed, the diffusion depth of the chloride ions is high when the C_3A content of the cement is important. The same observation concerning the concrete made with RS.

5. The relationship between chloride ions diffusion depth and density is linear regardless of the couple cement / admixture. Indeed, the variation of these two properties is very small. Furthermore, it has previously been found that the diffusion depth of the chloride ions of the concrete made with RS decreased significantly with increasing density. The slope showing the relationship for these concretes is therefore much sharper than that of concretes made with RG.

6. An increase in the diffusion depth of the chloride ions with the increase in porosity is observed. This relationship is all the stronger as it concerns the concrete made with RS, although those of the concrete made with RG also have an elevation of this depth according to the porosity.

References

1. Benabed, B. Effect of combined use of crushed sand and Algerian desert dune sand on fresh properties and strength of SCC. Epitoanyag- Journal of Silicate Based & Composite Materials. 2018. 70. Pp. 155–166. https://doi.org/10.14382/epitoanyag-jsbcm.2018.29
2. Abed, M., Nemes, R. Fresh properties of the self-compacting high performance concrete using recycled concrete aggregate. Epitoanyag-Journal of Silicate Based & Composite Materials. 2019. 71. Pp. 18–23. https://doi.org/10.14382/epitoanyag-jsbcm.2019.4
3. Evangelista, L., de Brito, J. Concrete with fine recycled aggregates: a review. Eur. J. Environ. Civ. Eng. 2014. 18. Pp. 129–172. https://doi.org/10.1080/19648189.2013.851038
4. Xuan, D., Zhan, B., Poon, C.S. Durability of recycled aggregate concrete prepared with carbonated recycled concrete aggregates. Cem. Concr. Compos. 2017. 84. Pp. 214–221. https://doi.org/10.1016/j.cemconcomp.2017.09.015
5. Evangelista, L., de Brito, J. Durability performance of concrete made with fine recycled concrete aggregates. Cem. Concr. Compos. 2010. 32. Pp. 9–14. https://doi.org/10.1016/j.cemconcomp.2009.09.005
6. Poon, C., Shui, Z., Lam, L. Effect of microstructure of ITZ on compressive strength of concrete prepared with recycled aggregates. Constr. Build. Mater. 2004. 18. Pp. 461–468. https://doi.org/10.1016/j.conbuildmat.2004.03.005
7. Buyle-Bodin, R.H.Z.F. Influence of industrially produced recycled aggregates on flow properties of concrete. Mater. Struct. 35 (2002) 504–509. https://doi.org/10.1007/BF02483138
8. Kosmatka, S.H., Kerkhoff, B., Panarese, W.C. Design and control of concrete mixtures, 14th Edition, Portland Cement Association. 2002.
9. Chakradhara Rao, M., Bhattacharyya, S.K., Barai, S.V. Influence of field recycled coarse aggregate on properties of concrete. Mater. Struct. 2010. 44. Pp. 205–220. https://doi.org/10.1617/s11527-010-9620-x
10. de Juan, M.S., Gutiérrez, P.A. Influence of attached mortar contento n the properties of recycled concrete aggregate. International RILEM Conference on the Use of Recycled Materials in Building and Structures, Editor(s): E. Vázquez, Ch.F. Hendriks and G.M.T. Janssen. 2004. Pp. 536–544. DOI: 10.1617/2912143756.059
11. Etxeberria, M., Vázquez, E., Marí, A., Barra, M. Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete. Cem. Concr. Res. 2007. 37. Pp. 735–742. DOI: 10.1016/j.cemconres.2007.02.002
12. Nagataki, S., Gokce, A., Saeki, T., Hisada, M. Assessment of recycling process induced damage sensitivity of recycled concrete aggregates, Cem. Concr. Res. 2004. 34. Pp. 965–971. https://doi.org/10.1016/j.cemconres.2003.11.008
13. Padmini, A.K., Ramamurthy, K., Mathews, M.S. Influence of parent concrete on the properties of recycled aggregate concrete. Constr. Build. Mater. 2009. 23. Pp. 829–836. https://doi.org/10.1016/j.conbuildmat.2008.03.006
14. Gómez-Soberón, J.M. Porosity of recycled concrete with substitution of recycled concrete aggregate: An experimental study. Cem. Concr. Res. 2002. 32. Pp. 1301–1311. https://doi.org/10.1016/S0008-8846(02)00795-0
15. Katz, A. Properties of concrete made with recycled aggregate from partially hydrated old concrete. Cem. Concr. Res. 2003. 33. Pp. 703–711. https://doi.org/10.1016/S0008-8846(02)01033-5
16. Rao, A., Jha, K.N., Misra, S. Use of aggregates from recycled construction and demolition waste in concrete. Resour. Conserv. Recycl. 2007. 50. Pp. 71–81. https://doi.org/10.1016/j.resconrec.2006.05.010

17. Barbudo, A., de Brito, J., Evangelista, L., Bravo, M., Agrela, F. Influence of water-reducing admixtures on the mechanical performance of recycled concrete. J. Clean. Prod. 2007. 59. Pp. 93–98. https://doi.org/10.1016/j.jclepro.2013.06.022
18. Pereira, P., Evangelista, L., de Brito, J. The effect of superplasticisers on the workability and compressive strength of concrete made with fine recycled concrete aggregates. Constr. Build. Mater. 2012. 28. Pp. 722–729. https://doi.org/10.1016/j.conbuildmat.2011.10.050
19. NF-EN 1097-6. Essais pour déterminer les caractéristiques mécaniques et physiques des granulats – Partie 6 : détermination de la masse volumique réelle et du coefficient d'absorption d'eau. 2014.
20. ASTM C 1202-97. Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration. 2003.
21. Bágel', L., Živica, V. Relationship between pore structure and permeability of hardened cement mortars: On the choice of effective pore structure parameter. Cem. Concr. Res. 1997. 27. Pp. 1225–1235. https://doi.org/10.1016/S00088846(97)-00111-7
22. Arya, C., Buenfeld, N.R., Newman, J.B. Factors influencing chloride-binding in concrete. Cem. Concr. Res. 1990. 20. Pp. 291–300. https://doi.org/10.1016/0008-8846(90)90083-A
23. Alonso, C., Andrade, C., Castellote, M., Castro, P. Chloride threshold values to depassivate reinforcing bars embedded in a standardized OPC mortar. Cem. Concr. Res. 2000. 30. Pp. 1047–1055. https://doi.org/10.1016/S0008-8846(00)00265-9
24. Deby, F., Carcassès, M., Sellier, A. Probabilistic approach for durability design of reinforced concrete in marine environment. Cem. Concr. Res. 2009. 39. Pp. 466–471. https://doi.org/10.1016/j.cemconres.2009.03.003
25. Theissing, E.M., de Larr, T.M., De Wind, G. . The combining of sodium chloride and calcium chloride by the hardened portland cement compounds C3S, C3A and C4AF, In 8th Int. Symposium on Chemistry of Cement. 1986. Pp. 823–828.
26. Suryavanshi, A., Scantlebury, J.D. Mechanism of friedel's salt formation in cements rich in tri-calcium aluminate. Cem. Concr. Res. 1996. 26. Pp. 717–727. https://doi.org/10.1016/S0008-8846(96)85009-5
27. Rasheeduzzafar, S., Ehtesham Hussain, S., Al-Saadoun, S.S. Effect of cement composition on chloride binding and corrosion of reinforcing steel in concrete. Cem. Concr. Res. 1991. 21. Pp. 777–794. https://doi.org/10.1016/0008-8846(91)90173-F
28. Luping, T., Nilsson, L.O. Chloride binding capacity and binding isotherms of OPC pastes and mortars. Cem. Concr. Res. 1993. 23. Pp. 247–253. https://doi.org/10.1016/0008-8846(93)90089-R

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