

EFFET DE LA FUMÉE DE SILICE SUR LA DURABILITÉ DES BÉTONS À BASE DE GRANULATS MULTI-RECYCLÉS

EFFECT OF SILICA FUME ON THE DURABILITY OF MULTI-RECYCLED COARSE AGGREGATE CONCRETE

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BELABBAS Oualid¹, BOUZIADI Farid¹, BOULEKBACHE Bensaid¹¹Laboratory of Materials Sciences and Environment, Hassiba Benbouali University of Chlef, Algeria.o.belabbas96@univ-chlef.dzf.bouziadi@univ-chlef.dzb.boulekbache@univ-chlef.dz

Résumé - Ce travail de recherche vise à étudier la durabilité des bétons fabriqués avec des granulats grossiers multi-recyclés. Quatre générations de béton ont été préparées : un béton témoin (NAC) contenant 100 % de granulats grossiers naturels (NCA) et trois générations de bétons recyclés (RAC1, RAC2 et RAC3). Dans chaque génération, le NAC est totalement remplacé par des granulats recyclés (RCA). Au cours de l'étude, il a été constaté que le multi-recyclage du béton entraîne une diminution significative de ses propriétés. Par conséquent, l'utilisation de 10 % de fumée de silice a été proposée pour améliorer ses performances. Les RCA sont pré-saturés avant leur utilisation afin d'obtenir la même ouvrabilité pour tous les bétons étudiés. La durabilité des bétons a été évaluée par des essais de perméabilité à l'eau, d'absorption d'eau et de diffusion des ions chlorures. Les résultats montrent que la perméabilité à l'eau et l'absorption d'eau du béton augmentent avec le nombre de cycles de recyclage, en raison de la structure plus poreuse, de la haute capacité d'absorption des RCA et de porosité de la matrice RAC. En outre, les bétons recyclés présentent une pénétration élevée des ions chlorure par rapport au béton témoin, cette pénétration augmentant avec le nombre de cycles de recyclage. Enfin, il a été observé que l'ajout de fumée de silice améliore la durabilité des bétons à base de granulats multi-recyclés.

Mots - clés : Granulat recyclé, Multi-recyclage, Perméabilité, Absorption d'eau, diffusion des ions chlorures

Abstract- This research work aims to study the durability of concretes made with multi-recycled coarse aggregate. Four generations of concrete were prepared in this study: a control concrete (NAC) with 100% natural coarse aggregate (NCA), and three different generations of recycled concrete (RAC1, RAC2 and RAC3). NAC is completely substituted by RCA in each generation. During the course of the work, it was observed that the multi-recycling of concrete involves a significant decrease in its properties. Therefore, the use of 10% silica fume was suggested to correct its performance. The RCA are pre-saturated before their use to achieve the same workability for all the studied concretes. The durability of the concrete was evaluated by conducting tests for water permeability, water absorption, as well as chloride ion diffusion tests. The results show that the water permeability and the water absorption of concrete increases with the increase in the number of recycling cycles due to the more porous structure and the high absorption capacity of RCA and the permeability of RAC matrix. Moreover, recycled concretes have high chlorine ion penetration compared to control concrete; the latter increases with the increase in recycling cycles. Finally, it was observed that the addition of silica fume leads to an improvement in the durability of the concretes made with multi-recycled aggregates.

Keywords: Recycled aggregate, Multi-recycling, Permeability, Water absorption, Chloride ions diffusion.

1-Introduction

In the future, when all concrete is recycled concrete, it will be necessary to recycle the recycled concrete [1]. According to studies on the replacement of natural aggregates with recycled coarse aggregates to produce concrete, both the durability and mechanical properties of concrete are affected. However, it is generally accepted that the use of recycled aggregates has a greater impact on the durability performance. The use of a more porous aggregate results in a more porous concrete matrix, thus increasing its fluid penetration capacity [2 & 3]. This same porosity is the main cause of the decrease in resistance to corrosion processes, such as carbonation and chloride penetration. Furthermore, the incorporation of recycled aggregates results in a lower performance of concrete in terms of carbonation resistance [4 & 5]. Similar behaviour has been observed for resistance to chloride penetration [6]. It can be concluded that the main reason for the lower durability of RAC is its higher porosity, which is directly related to the attached mortar constituting the RCA. Therefore, since the multiple recycling process is expected to produce RCA with an increasing amount of attached mortar, it is likely that the studied mixtures will show decreasing durability, depending on the number of recycling cycles that have produced the RCA that compose them.

The attached mortar is commonly acknowledged as the major vulnerability of RCA. Therefore, some studies have focused on the treatment of RCA, either by improving their properties using mineral addition [7 & 8], or by separating the attached mortar by mechanical, chemical or physical methods [9]. These various techniques are based on the difference in properties between NCA and cement paste, which has a weaker interfacial transition zone (ITZ) [10].

The innovation of this research lies in determining the durability properties of multi-recycled concrete, produced from the crushing of an original concrete with the same composition and properties as the reference concrete, thus eliminating the entropy due to this parameter. Each new concrete with recycled aggregates was made with RCA from a previous recycling cycle of concrete having exactly the same composition

and constituents as the previous cycle, changing only the origin of the RCA.

2-Materials and method

2.1- Materials used

CEM II/A-L 42.5 N; Silica Fume with SSB = 22.5 m²/g; Sand of a fineness module 2.79; Natural limestone gravel 3.15/15; Three generations of recycled gravel 3.15/15.

2.2- Method

Four generations of concrete were prepared in this study: NAC with 100% NCA and three different generations of multi-recycled concrete. NCA is substituted by RCA with volume percentages 100% in each generation. The RCAs are pre-saturated before their use in order to achieve the same workability of all the concretes studied, while the NCA is used in the dry state. All concretes were manufactured with the same water/binder ratio (W/B = 0.57) and slump ratio (18 ± 1 cm). The proportions of different mixtures of concrete are reported in Tab 1.

Tableau 1 : formulation des différents mélanges

Table 1 : Composition of different mixtures (kg/m³)

Concrete	Cement	SF	Sand	NCA	RCA1	RCA2	RCA3
NAC	400		745	968			
RAC1	400		745		888		
RAC2	400		745			855	
RAC3	400		745				837
RAC1-SF	360	40	745		888		
RAC2-SF	360	40	745			855	
RAC3-SF	360	40	745				837

The aim of this work is to characterize the durability of concrete made with recycled coarse aggregate. The durability tests conducted are:

2.2.1 Water absorption by immersion

Water absorption by immersion measures its mass absorption capacity, expressed as the amount of water absorbed by a concrete sample. According to ASTM C642-06, the test involves placing 70x70x280 mm prismatic concrete samples, aged 90 days, in an oven at 105 °C and weighing them until a constant weight is achieved. The samples are then fully submerged in a water bath at 20 °C for 24 hours until the material is saturated.

2.2.2 Water permeability

Water permeability measures the migration of water through concrete under water pressure. Permeable concrete allows various external aggressive agents to penetrate. The water permeability test was conducted according to the NF EN 12390-8 standard. This test measures the depth of water penetration in a cylindrical sample with a diameter of 150 mm. Three samples were tested at 90 days of age. The samples were placed in the test device under a water pressure of 500 kPa (5 bars) for 72 hours. The surface of the sample exposed to the water pressure must be roughened with a wire brush. After 72 hours of applying the pressure, the samples were removed from the device, and each sample was then split into two halves using a splitting test. The depth of water penetration is measured with a calliper to the nearest millimetre.

2.2.3 Penetration of chloride ions

The penetration of chloride ions into concrete is determined using the permeability method according to ASTM C1202-12. The test is conducted on cylindrical samples with a diameter of 100 mm and a height of 50 mm at 90 days of age. The perimeter of the sample is coated with a waterproof paint (flintkote) to direct the diffusion of chloride ions in a single direction. Before each test, the samples are pre-saturated in water at 20 °C.

3-Results and discussion

3.1- Properties of aggregates

Fig. 1 represents the particle size analysis of the different types of aggregates and Tab 2 shows the properties of the different generations of coarse aggregates.

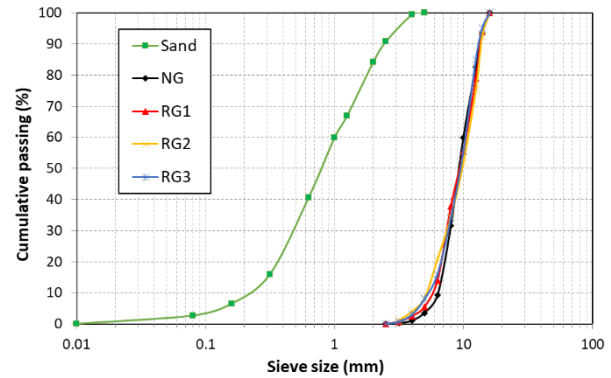


Figure 1 : Distribution granulométrique
Figure 1 : Particle size distribution

Tableau 1 : formulation des différents mélanges (kg/m³)

Table 1 : Composition of different mixtures (kg/m³)

	NCA	RCA1	RCA2	RCA3
Specific weight (g/cm ³)	2.65	2.43	2.34	2.29
Attached mortar (%)		35	54	79
Water absorption (%)	0.63	6.5	10.1	13.7
Los-Angeles coefficient (%)	29	36	44	57
Fragmentation coefficient (%)	21	29	34	39

The mechanical properties of the RCAs deteriorate after each recycling cycle; this is due to the fragility of the mortar attached to the NCA [11]. In addition, these high values of the coefficients are characterized by a high sensitivity to wear and therefore the RCA are less resistant than the NCA.

3.2- Water absorption by immersion

3.2.1- Influence of multi-recycling on water absorption by immersion

Fig. 2 shows the influence of multiple recycling on the water absorption by immersion of the tested concretes at 90 days. According to the curves, an increase in the water absorption coefficient is observed as the number of recycling cycles increases. Following this trend, RAC3 had the highest water absorption (12%), while NAC had the lowest (4%). These results align with those reported by De Brito et al.[12] and Ozbakkaloglu et al. [13], who observed a progressive increase in the water absorption capacity of concrete as the substitution of natural aggregates with recycled aggregates increased. The adhered mortar on the aggregates is responsible for the increased water absorption capacity of recycled concrete aggregates due to its relatively higher porosity compared to natural aggregates.

3.2.2- Influence of silica fume on water absorption by immersion

According to Fig. 2, after the addition of silica fume, reductions of 26%, 19%, and 9% are observed for the first, second, and third recycling cycles, respectively. This decrease is attributed to the finer structure of silica fume compared to cement, which coats the surface of the recycled aggregates and reduces water absorption [14]. Silica fume can also help fill voids, leading to increased compactness and cohesion of the mix [15].

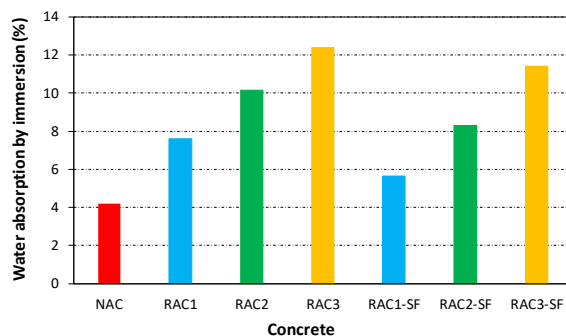


Figure 1 : Absorption d'eau par immersion des bétons

Figure 1 : Water absorption by immersion of concretes.

3.3- Water permeability

3.3.1- Influence of multi-recycling on water permeability

The water penetration depths under pressure, depending on the recycling cycle, are illustrated in Fig. 3. The results show that the water penetration depth is greater in concrete made with recycled aggregates from the third cycle. RAC1 exhibited a water penetration depth of 48 mm, while NAC showed a depth of 28 mm. RAC2 and RAC3 displayed average values of around 60 mm and 72 mm, respectively. It is evident that the increase in the number of recycling cycles leads to significantly higher water permeability. This increase is explained by the high absorption capacity of the recycled aggregates and the permeability of the concrete matrix.

3.3.2- Influence of silica fume on water permeability

The water permeability of the tested concretes is illustrated in Fig. 3. In general, permeability decreases after the addition of silica fume across all cycles. According to the observations from the diagram, water permeability decreases by 27% in the first cycle, and by 14% and 11% in the second and third cycles, respectively. This reduction in depth is due to the presence of silica fume, which fills the voids and pores with C-S-H, thereby blocking water penetration [16].

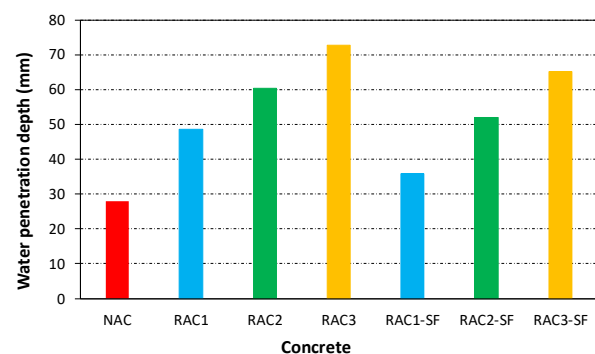


Figure 1 : Profondeur de pénétration de l'eau dans les bétons

Figure 1 : Water penetration depth of concretes

3.4- Water permeability

3.4.1- Influence of multi-recycling on chloride ions penetration

The results of the chloride ion penetration test at 90 days are presented in Fig. 4. The results indicate that the chloride ion migration coefficient increases with the number of recycling cycles. This increase is approximately 32% for RAC1, 61% for RAC2, and 96% for RAC3 compared to conventional concrete. This rise is directly linked to the concrete's porosity and grows linearly with each cycle due to the increasing amount of adhered mortar.

The total charge is significantly higher in recycled concretes and increases proportionally with the recycling cycle. This can be explained by the greater permeability of recycled concretes compared to conventional concrete [17].

3.4.2- Influence of silica fume on chloride ions penetration

Fig. 4 shows the influence of silica fume on the chloride ion permeability of the tested concretes at 90 days. Based on these results, a reduction in total charge is observed with the increase in the number of recycling cycles after the addition of silica fume. This reduction reaches 20%, 13%, and 8% for the first, second, and third cycles, respectively. This decrease in charge is due to the formation of C-S-H and the filling of cement paste pores by silica fume.

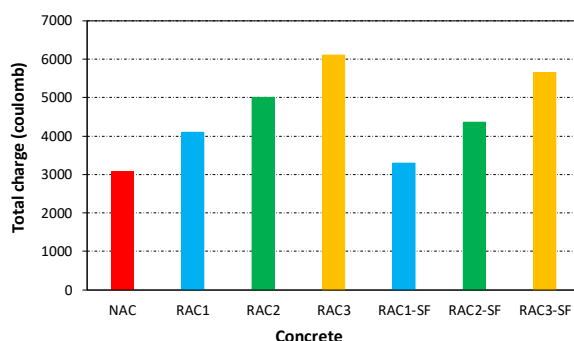


Figure 1 : Charge totale de pénétration des ions chlorure

Figure 1: Total charge of chloride ion penetration

4- Conclusion

According to this experimental study, the main conclusions we reached are:

1. RCA of each generation is characterized by higher absorption, lower density and reduced abrasion resistance compared to those of NCA.
2. The immersion water absorption and water permeability of concretes increases with increasing number of recycling cycles due to the more porous structure and high absorption capacity of RCA.
3. Recycled concretes exhibit higher chloride ion penetration compared to the control concrete, and this penetration increases with the number of recycling cycles.
4. The addition of silica fume enhances the durability stability of concretes made with multi-recycled aggregates.

Bibliographic references

- [1] Thomas, C. De Brito, J. Cimentada, A. Sainz-Aja, J. Macro-and micro-properties of multi-recycled aggregate concrete. *Journal of Cleaner Production*. 2020;245:118843.
- [2] Katz, A. Properties of concrete made with recycled aggregate from partially hydrated old concrete. *Cement and concrete research*. 2003;33(5):703-11.
- [3] Kwan, WH. Ramli, M. Kam, KJ. Sulieman, MZ. Influence of the amount of recycled coarse aggregate in concrete design and durability properties. *Construction and Building Materials*. 2012;26(1):565-73.
- [4] Kou, S. Poon, CS. Enhancing the durability properties of concrete prepared with coarse recycled aggregate. *Construction and Building Materials*. 2012;35:69-76.
- [5] Xiao, J. Lei, B. Zhang, C. On carbonation behavior of recycled aggregate concrete. *Science China Technological Sciences*. 2012;55:2609-16.

- [6] Chakradhara Rao, M. Bhattacharyya, S. Barai, S. Influence of field recycled coarse aggregate on properties of concrete. *Materials and structures*. 2011;44:205-20.
- [7] Khodabakhshian, A. Ghalehnovi, M. De Brito, J. Shamsabadi, EA. Durability performance of structural concrete containing silica fume and marble industry waste powder. *Journal of Cleaner Production*. 2018;170:42-60.
- [8] Omrane, M. Rabehi, M. Effect of natural pozzolan and recycled concrete aggregates on thermal and physico-mechanical characteristics of self-compacting concrete. *Construction and Building Materials*. 2020;247:118576.
- [9] Kou, S-c. Poon, C-s. Agrela, F. Comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures. *Cement and Concrete Composites*. 2011;33(8):788-95.
- [10] Aldred, JM. Holland, TC. Morgan, DR. Roy, DM. Bury, MA. Hooton, RD. et al. Guide for the use of silica fume in concrete. ACI–American Concrete Institute–Committee: Farmington Hills, MI, USA. 2006;234.
- [11] Duan, ZH. Poon, CS. Properties of recycled aggregate concrete made with recycled aggregates with different amounts of old adhered mortars. *Materials & Design*. 2014;58:19-29.
- [12] De Brito, J. Saikia, N. Recycled aggregate in concrete: use of industrial, construction and demolition waste: Springer Science & Business Media; 2012.
- [13] Ozbakkaloglu, T. Gholampour, A. Xie, T. Mechanical and durability properties of recycled aggregate concrete: effect of recycled aggregate properties and content. *Journal of Materials in Civil Engineering*. 2018;30(2):04017275.
- [14] Sasanipour, H. Aslani, F. Taherinezhad, J. Effect of silica fume on durability of self-compacting concrete made with waste recycled concrete aggregates. *Construction and Building Materials*. 2019;227:116598.
- [15] Isaia, GC. GASTALDINI, ALG. Moraes, R. Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. *Cement and Concrete Composites*. 2003;25(1):69-76.
- [16] Rostami, M. Behfarnia, K. The effect of silica fume on durability of alkali activated slag concrete. *Construction and Building Materials*. 2017;134:262-8.
- [17] Rahmani, AA. Chemrouk, M. Ammar-Boudjelal, A. Rheological, physico-mechanical and durability properties of multi-recycled concrete. *Advances in concrete construction*. 2020;9(1):9-22.