

INCREASING PROPERTIES OF CONCRETE WITH RECYCLED CONSTRUCTION AND DEMOLITION WASTES

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Abstract

Construction waste management is a quite important economic and environmental deal for our societies. More than 2 million tons demolition and construction wastes are annually produced only in Wallonia, Southern Region of Belgium; recycling has clearly to be promoted.

Concrete block wastes were crushed in the laboratory by a jaw crusher and the different fractions of laboratory produced RCA were characterized by measuring the hardened cement paste content, the density, the porosity and the water absorption. Results clearly show that, the recycled sands possessed significantly higher cement paste content and higher water absorption than coarse RCA. Then, concrete blocks with different substitutions (0%, 30%, 100%) of natural aggregate by the same volume fraction of RCA were manufactured. The fresh properties (slump, density, air content), and mechanical properties (compressive strength) were studied. The compressive strength of concrete decreased as the substitution of RCA increased. Results show that the compressive strength of concrete made with 100% RCA could reach 8 MPa after 28 days. Therefore, the use of RCA obtained from old block wastes in the production of new blocks can be envisaged depending on their class of exposure and the grade requirement.

Moreover, the influence of the fine recycled concrete aggregates (FRCA) on the mechanical and durability properties of concrete was studied. The industrial FRCA produced from recycling center was used into concrete. The concretes with different substitutions (0%, 30%, 100%) of natural sand by the FRCA were manufactured. Mechanical properties (compressive strength) and durability properties (capillary absorption, carbonation depth, and freeze/thaw resistance) were investigated. The results show that the compressive strength of concrete decreased as the substitution of FRCA increased. Durability of concrete could be strongly influenced by the high porosity and water absorption of fine recycled concrete aggregates.

Keywords: concrete, recycling, coarse aggregates, fine particles, durability

1 INTRODUCTION

Large quantities of construction and demolition wastes (CDW) are produced each year (Delvoie et al., 2018). So far, only a small fraction of these concrete wastes are reused as aggregate for concrete production (Topcu and Sengel, 2004). Recycled concrete aggregates are composed of a mix of natural aggregates and hardened adherent cement paste. The latter is usually much more porous than

natural aggregates (Zhao et al., 2013) and leads to a large water demand which makes RCA harder to recycle into concrete (Courard et al., 2010). Properties of RCA such as water absorption, porosity can deeply influence the properties of fresh concrete as well as mechanical properties and durability of concrete made with RCA (Poon et al., 2004; Khatib, 2005).

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The VALDEM research project focuses on the relationship between the properties of original industrial produced concrete to the different physical properties of RCA. In this study, RCA from industrial produced blocks (RCA_Blocks) and slabs (RCA_Slabs) were crushed by laboratory jaw crusher and then separated into four granular fractions (0/2, 2/6.3, 6.3/14, 14/20 mm). Each granular fraction of RCA was characterized in order to study the influence of granular fraction and the origin of recycled concrete aggregates on their properties. Real RCA from recycling plant were also used to compare with these two laboratory produced RCA from industrial concretes (Zhao et al., 2018). Moreover, the influence of the fine (Colman et al., 2018) recycled concrete aggregates (FRCA) on the mechanical and durability properties of concrete is investigated.

2 USE OF COARSE RECYCLED AGGREGATES FOR CONSTRUCTION BLOCKS PRODUCTION

2.1 Materials and testing

Concrete block wastes (C8/10) were collected from Prefer Company (Belgium) and then crushed in a laboratory jaw crusher retaining the same jaw opening for all products. After crushing, RCA_Blocks were separated into four granular fractions (0/2, 2/6.3, 6.3/14, 14/20 mm). RCA were characterized by measuring the hardened cement paste content, the density, the porosity and the water absorption. Only the fraction 2/6.3 mm was used for the manufacture of new concrete blocks.

New concrete blocks with different substitution rates (0%, 30%, 100%) of natural aggregate by the same fraction of RCA (only fraction 2/6.3 mm) were manufactured. Table 1 shows the composition of new concrete blocks. CEM III/A 42.5 and water to cement ratio of 0.7 were used for the new concrete blocks. Natural calcareous aggregate (noted as NA 2/7) and natural river sand (noted as NS 0/2) were used for the manufacture of concretes. The water absorption of RCA 2/6.3 was 5.0% and its apparent particle density was 2.52 g/cm³ according to the standard EN 1097-6 (while it was 0.68% and 2.7 g/cm³ for natural aggregate). Natural aggregate and recycled aggregate were used in air dried condition. The absorbed water was adjusted according to the water content of the aggregates and their water absorption. A half of the total water was added to pre-saturate the aggregate in the mixer for 5 minutes before the addition of cement. The other half of the water was added after introduction of the cement.

Cement paste content of RCA was measured by the salicylic acid dissolution (Zhao et al., 2013). Salicylic acid allows the dissolution of most phases contained in OPC cement paste (C₂S, C₃S, ettringite, portlandite and C-S-H for example) but not of the main phases contained in natural aggregates and especially limestone. The water absorption coefficient of three coarse fractions of RCA was determined according to EN 1097-6. The water absorption coefficient of the fraction 0/2 mm

of RCA was determined on the basis of the relationship between water absorption and cement paste content (Zhao et al., 2017). The specimens were cast with the vibration table and stored in laboratory conditions. After 24h, they were demoulded and stored in climatic room ($20\pm 2^\circ\text{C}$ and a relative humidity $95\pm 5\%$). The compressive strength of concrete was measured according to EN 12390-3 on cubic samples ($150\text{mm} \times 150\text{mm} \times 150\text{mm}$), performed after 1 day, 7 days and 28 days of curing in climatic room.

Table 1. Compositions of concrete blocks (1 m^3)

	B_RCA0	B_RCA30	B_RCA100
NA 2/7 (kg)	1080	754	0
RCA 2/6.3 (kg)	0	302	1008
NS 0/2 (kg)	825	825	825
Cement (kg)	150	150	150
Efficient water (kg)	105	105	105
Absorbed water (kg)	13.12	26.00	56.20
W_{eff}/C	0.70	0.70	0.70

2.2 Concrete performances

Figure 1 shows the cement paste content (CPC) and water absorption of RCA as a function of granular fraction. As can be seen, CPC of fraction 0/2 mm was larger compared with the three coarse fractions of RCA, while the values obtained for the three coarser fractions were similar. The fraction 0/2 mm of RCA revealed a larger value of water absorption in comparison with the three coarse fractions of RCA, while the values obtained were similar for the three coarser fractions. Recycled sands thus possessed higher cement paste contents than the coarse recycled aggregates, which may heavily penalize their use properties (such as water absorption, porosity) comparing with coarse recycled aggregates.

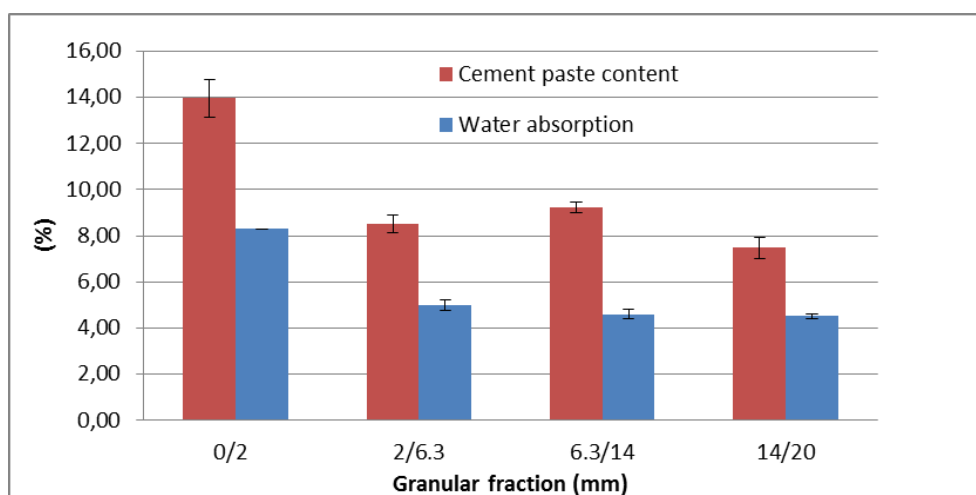


Figure 1. Cement paste content and water absorption of RCA as a function of granular fraction

The workability of three concretes is low (the slumps were zero), which is conventionally observed in the industrial environment for the manufacture of blocks (using mechanical vibration for putting on a caisson). Figure 2 shows the compressive strength of the various mixes at different ages. The compressive strengths of concretes with RCA were lower than those of concrete with natural aggregate. The compressive strength of concrete made with 100% RCA at 28 days decreased 14.4% comparing with the reference concrete, while the concrete made with 30% RCA at 28 days decreased 7.2%. These lower mechanical strengths are certainly caused by the poorer properties of RCA in comparison to natural aggregate used; the presence of adherent cement paste leading to higher porosity comparing with the natural aggregate. The compressive strength of concrete made with 100% RCA could reach 8 MPa after 28 days.

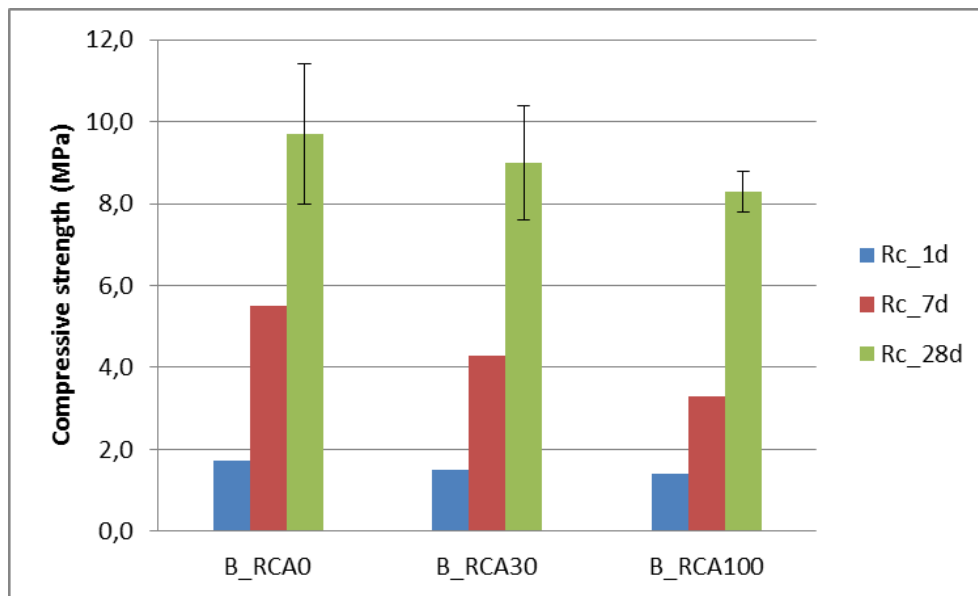


Figure 2. Compressive strength of new concrete blocks at different ages

3 DURABILITY PROPERTIES OF CONCRETE MADE WITH FINE RECYCLED CONCRETE AGGREGATES

3.1 Introduction

The fine fraction of RCA, essentially composed of mortar and hardened cement paste, possesses a large water demand which makes it harder to recycle into concrete compared to coarser RCA. The influence of the fine recycled concrete aggregates (FRCA) on the mechanical and durability properties of concrete was studied (Zhao et al., 2017). The industrial FRCA produced from recycling center was used into concrete. The concretes with different substitutions (0%, 30%, 100%) of natural sand by the FRCA were manufactured, and fresh properties (slump), mechanical properties (compressive strength), and durability properties (capillary absorption, carbonation depth, and freeze/thaw resistance) of these concretes were studied. The results showed that the compressive strength of concrete decreased as the substitution of FRCA increased. Durability of concrete could be strongly influenced by the high porosity and water absorption of fine recycled concrete aggregates.

3.2 Materials and testing

The cement used in concrete was an Ordinary Portland Cement (CEM I 52.5 N). Two calcareous natural aggregates (noted as NA2/7, NA6/14) were used for the manufacture of concretes. The water absorption of these two aggregates was 0.68 and 0.32% respectively for NA2/7 and NA6/14 and their apparent particle density was 2.70 g/cm³ according to the standard EN 1097-6. A natural river sand (noted as NS0/2) was used for the manufacture of concretes with a water absorption of 0.70%.

Recycled concrete aggregates (RCA) (0/31.5mm) were provided by crushing concrete wastes in the recycling center and only the fine fraction 0/2mm (noted as FRCA0/2). The water absorption of FRCA0/2 was 8.8% and its apparent particle density was 2.47 g/cm³. The sieve analysis showed that the grain size distribution of NS and used FRCA was comparable.

The concretes with different substitutions (0%, 30%, 100%) of natural sand by the same volume of FRCA were manufactured (Table 2). Natural aggregates and recycled aggregates were used in air dried condition. The absorbed water was adjusted according to the water content of the aggregates and their water absorption. A half of the total water was added to pre-saturate the aggregate in the mixer for 5 minutes before the addition of cement. The other half of the water was added after introduction of the cement.

Table 2: Compositions of concretes (1 m³)

	B_FRCA0	B_FRCA30	B_FRCA100
NA 6/14 (kg)	550.0	550.0	550.0
NA 2/7 (kg)	775.0	775.0	775.0
NS 0/2 (kg)	600.0	420.0	0.0
FRCA 0/2 (kg)	0.0	168.0	559.2
Cement (kg)	320.0	320.0	320.0
Efficient water (kg)	160.0	160.0	160.0
Absorbed water (kg)	11.2	24.7	56.2
Superplasticizer (kg)	3.4	3.4	3.4
W_{eff}/C	0.5	0.5	0.5

After the mixing, the slump of fresh concrete was measured with the Abrams cone according to EN 12350-2. The air content of fresh concrete was measured according to EN 12350-7. The specimens were cast with the vibration table and stored in laboratory conditions and covered with plastic film in order to avoid evaporation of water. After 24h, they were demoulded and stored in climatic room (20±2°C and a relative humidity 95±5%).

The compressive strength of concrete was measured according to EN 12390-3 on cubic samples (150mm x 150mm x 150mm), performed after 7 days and 28 days of curing in climatic room. The capillary water absorption of concrete was measured on cubic samples (100mm x 100mm x 100mm) according to NBN 15-217. The lower side of the specimen was placed into water and removed and weighed at various time intervals. The porosity of concrete was evaluated by the total immersion test in water.

The carbonation of concrete was evaluated on prismatic specimens (100mm x 100mm x 400mm). After curing for 28 days in the climatic room, the specimen was stored in a room at 20±2°C and a relative humidity of 60±5% until constant mass. Then it was stored in the carbonation room with a CO₂ concentration of 3% by volume for 4 weeks. After each week, specimens were taken out the carbonation chamber and split. The fresh split surface was sprayed with a phenolphthalein pH indicator. In the carbonated part of the specimens, where the alkalinity was reduced, no coloration occurred. Thus, the average depth of the colorless phenolphthalein region was measured from three points in each side.

In order to evaluate the resistance to freezing, the specimens (100mm x 100mm x 100mm) were subjected to 14 freeze-thaw cycles (24h cycle from -15°C to +10°C) according to NBN B 05-203. The freezing was carried out at -15°C in air and thawing was undertaken in the water at 10°C. The mass of all the specimens were recorded to show the weight loss trend.

3.3 Fresh properties of concretes

Figure 3 shows the variation of slump for the three concretes after 0 and 30 minutes. It can be seen that the initial slump slightly decreased for concretes with recycled sand. After 30 minutes, the slump of all types of concrete decreased whatever the different substitutions. It is also shown that the rate of slump loss was larger as the substitution increased, which could be due to the higher water quantity absorbed by the higher percentage of recycled sand after the mix.

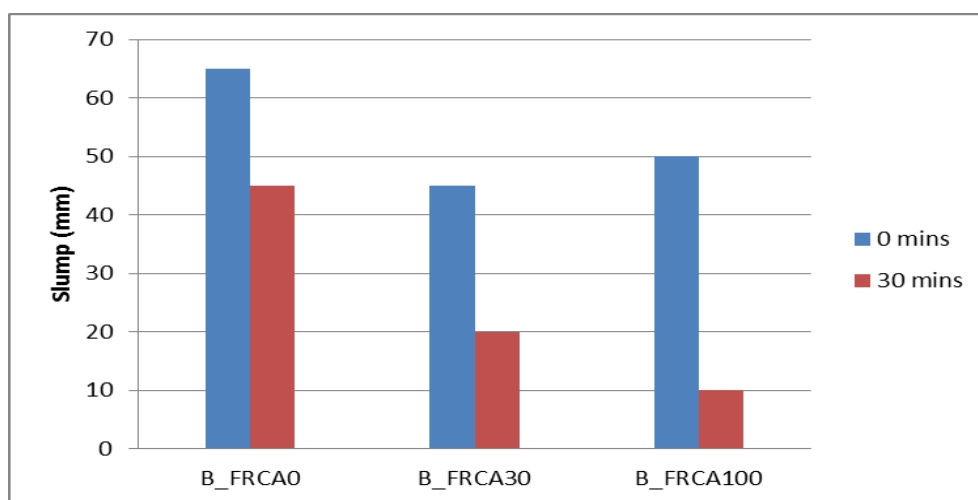


Figure 3: Change of slump as a function of three concretes

The air content of concrete increased (2.2% for concrete B_FRCA0, 3.3% for concrete B_FRCA30, and 5.5% for concrete B_FRCA100) when the substitution of recycled sand increased. Increased air content is also known to occur in lightweight aggregate concrete, which shows some similarities with concrete made with recycled aggregate (Amnon, 2003).

3.4 Mechanical and durability performances

Figure 4 shows the compressive strength of the various mixes at different ages. The compressive strengths of concretes with FRCA were lower than those of concrete with natural sand. The compressive strength of concrete made with 100% FRCA at 28 days decreased 48.2% comparing with the reference concrete, while the concrete made with 30% FRCA at 28 days decreased 15.9% comparing with the reference concrete. These lower mechanical strengths are certainly caused by the poorer properties of FRCA in comparison to natural sand used; the presence of adherent cement paste leading to higher porosity comparing with the natural sand (Zhao et al., 2015).

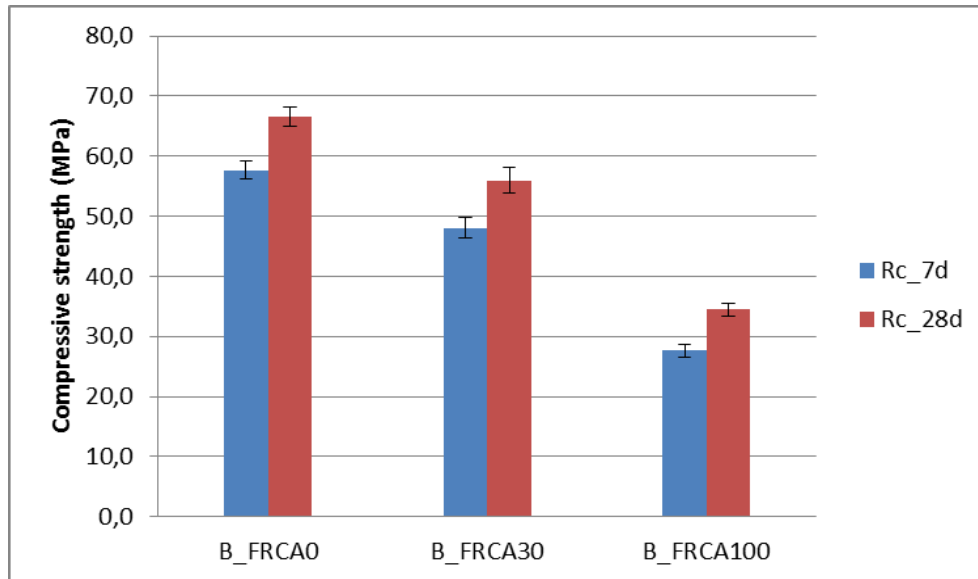


Figure 4: Compressive strength of concretes at different ages

Figure 5 presents the rate of capillary absorption as a function of types of concretes. As can be seen in this figure, the rates of absorption of the recycled concrete were much larger than the reference concrete. The coefficient of capillary absorption of concrete B_FRCA100 was $0.38 \text{ kg/m}^2/\text{h}^{0.5}$, while it was 0.11 and $0.14 \text{ g/m}^2/\text{h}^{0.5}$ for the reference concrete and B_FRCA30 respectively. The higher capillary absorptions of recycled concrete were certainly caused by the incorporation of FRCA, which had higher porosity comparing with the natural sand, leading to the higher porosity of concrete. It appeared that the capillary absorption of concrete was little affected by the presence of FRCA up to 30%. This was confirmed by the results of porosity of concrete measured by immersion (the total porosity estimated by water absorption for the concrete B_FRCA100 was 9.5%, while it was estimated as 4.2% and 5.3% for the reference concrete and B_FRCA30 respectively). The rate of absorption, rather than the total absorption is mainly affected by the structure and size distribution of the pores in the concrete.

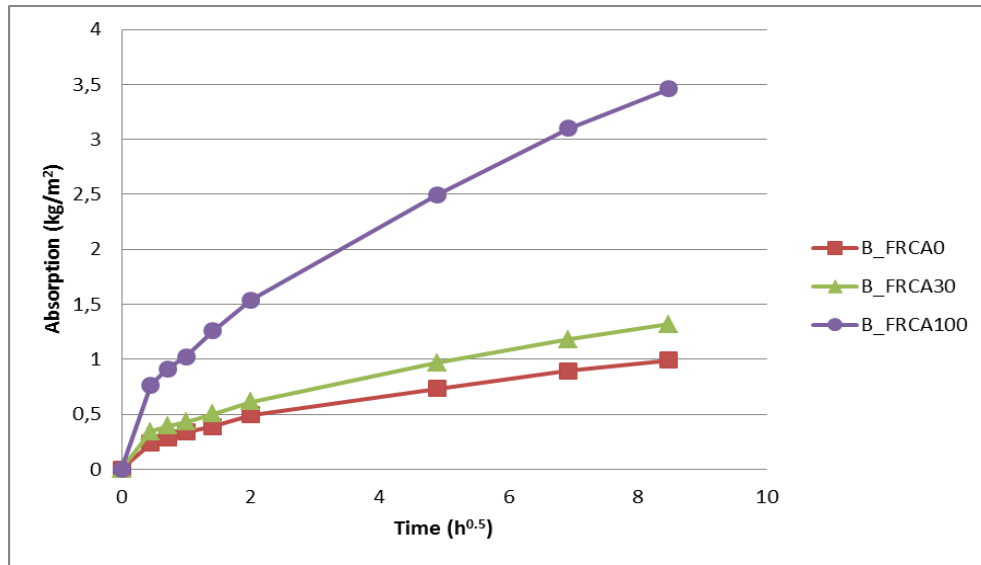


Figure 5: Capillary absorption as a function of types of concretes

Figure 6 shows the depth of carbonation as a function of time in the carbonation room for all types of concretes. For the first 14 days, the carbonation depths of B_FRCA0 and B_FRCA30 were zero, while it was 5 mm for the concrete made with 100% recycled sand. After 28 days, the carbonation depth of B_FRCA100 was 9mm, while it was lower than 2mm for the B_FRCA30, and zero for the reference concrete. The higher depth of carbonation of the recycled concrete could be due to the higher porosity in concrete, inducing a faster diffusion of CO₂ into the concrete.

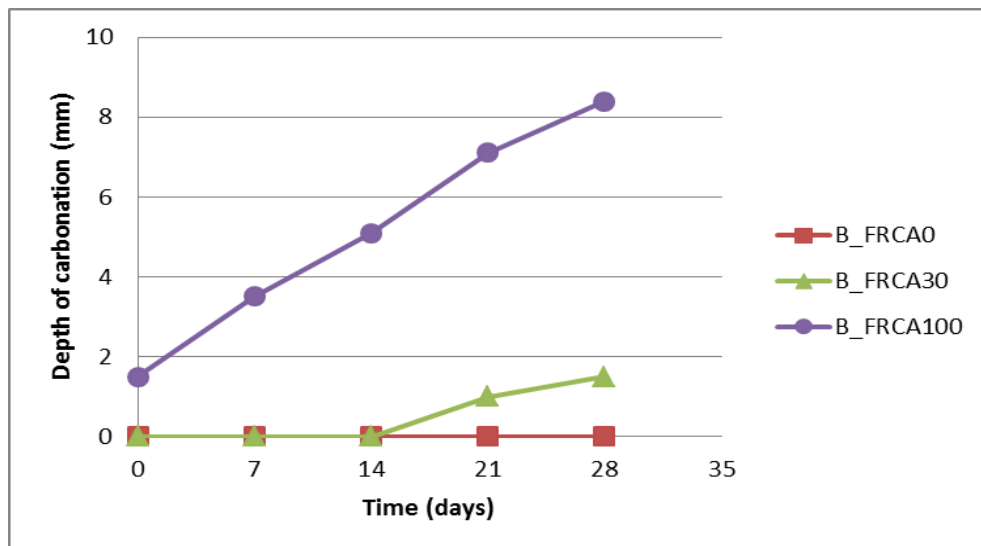


Figure 6: Depth of carbonation as a function of time in the carbonation room

After 14 cycles of freeze-thaw, the visual specimen's examination did not allow detecting any significant deterioration for all the concretes. The mass loss is presented in Figure 7. The recycled concretes had lower freeze-thaw resistance comparing with the reference concrete, which was due to higher porosity in the recycled concrete.

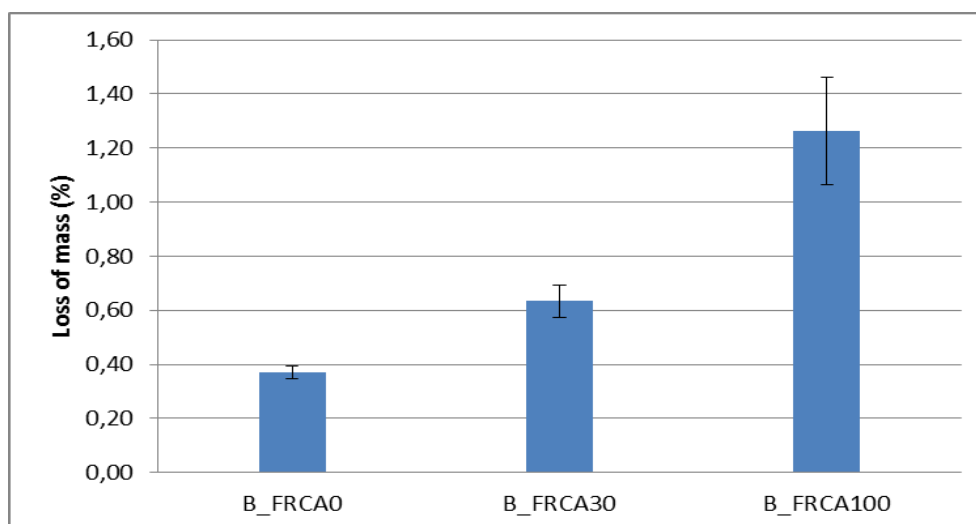


Figure 7: Mass loss due to the freeze-thaw cycles

4 CONCLUSIONS

The feasibility of using RCA obtained from old concrete block wastes in the production of new concrete blocks is studied. Results clearly show that, the recycled sands possessed significantly higher cement paste content and higher water absorption than coarse RCA. The compressive strength of concrete blocks decreased as the substitution of RCA increased. The compressive strength of concrete made with 100% RCA could reach 8 MPa after 28 days without increasing the cement content of the concrete mix. Therefore, the use of RCA obtained from old block wastes in the production of new blocks can be envisaged depending on their class of exposure and the grade requirement.

Concrete design with recycled materials shows that the compressive strength decreases as the substitution of FRCA increased. The compressive strength of concrete made with 100% FRCA decreased in the range of 48.2% comparing with the reference concrete, while the concrete made with 30% FRCA decreased up to 15.9% comparing with the reference concrete. However, the compressive strength of concrete made with 100% FRCA could reach 35MPa after 28 days. Durability of concrete could be strongly influenced by the high porosity and water absorption of recycled concrete aggregates. The durability properties of concrete made with 30% FRCA were comparable to the reference concrete, especially for capillary absorption and carbonation. Therefore, the use of FRCA in concrete structures can be envisaged depending on their class of exposure and the concrete grade requirement (for example the concrete C25/30 with no risk of corrosion or attack). Substitution rate of natural sand up to 30% is acceptable, while for the substitution rate higher than 30%, mechanical properties of concrete should be checked while the effects on durability should be also monitored for specific applications.

Investigations performed here above clearly show that an adapted design opens opportunities for recycling aggregates and fine from CDW.

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