Development of self-consolidating concretes based on recycled aggregates: Effect of parent concrete strength

Dorbani Kamar [1*], *Melais Fatma Zohra*[1], Kirane Sacia[1], Draghmia Dallel[1], Arabi Noureddine[1]

[1]Badji Mokhtar-Annaba University 23000 Annaba, Algeria[1]

Abstract. Self-consolidating concrete is a recent type of highly fluid concrete. The high paste concentration ensures excellent rheological behavior. Concrete includes can be selected with durability aims in mind, considering the severe conditions to which the concrete will be exposed. However, the irregularity of recycled aggregates (initial properties unknown from the old concrete) leads to a need for more knowledge of durability indicators. This research is an experimental evaluation of the characteristics of SCC made with recycled aggregates and sand whose initial parent concrete strength was specified. Three ranges of parent concrete strength were chosen (20 to 30 MPa, 35 to 45 MPa, and above 50 MPa). The main objective is to study the effect of introducing recycled concrete aggregates on the mechanical behavior and durability of SCC (total immersion in water and capillary absorption). The test specimens were analyzed after 28 days of curing. The findings demonstrate increased durability and mechanical behavior were achieved using recycled aggregates with high strength in the parent concrete. However, the mechanical strength and durability of SCCs are reduced when recycled concrete aggregates with low parent concrete strength (20 to 30 MPa) are used in the mix.

1 Introduction

Use Self-consolidating concretes (SCC), developed over the last twenty years, are still qualified among «new concretes» because their use remains modest due to their high cost. This increase in cost is mainly due to the amount of mineral additions (fillers, silica fume, etc...) added to the composition of these concretes, aimed at increasing the volume of paste to guarantee the properties of a fresh SCC. The substitution of these additions by recycled waste such, as recycled sand filler, in the manufacture of SCC, aims to produce economic SCC. Moreover, in recent years, research has focused much more on the incorporation of recycled gravel (RG) into concrete [1], [2]. However, despite the different results obtained with the waste, the behavior in the hardened state and the durability of these SCC still needs to be better understood. It should also be noted that the compressive strength of recycled aggregate concrete (RAC) is closely related to the strength of the parent concrete from which the recycled concrete aggregates (RCA) are derived. Consequently, lower-grade parent concrete will tend to decrease the characteristics of RCA. [3], [4], [5]. In parallel, the size of the aggregates, the capillary absorption and the saturation state of the RCA are influential parameters on the criteria of durability of the concretes, even if the authors do not always agree on the meaning of this correlation. [6], [7]. The present work aims to study the impact of the introduction of recycled concrete aggregates of different known parent concrete strengths on the mechanical behavior and durability of SCC.

2 Materials and methods

The cement used is a CEMI 42.5.5R compliant with the Algerian standard NA 442. Two types of sand were used: rolled sand (0/1 mm) and quarry sand (0/3mm). Two natural gravels (NAC) of fractions 3/8 and 8/16 mm for control concrete are used for gravels. Three varieties of RCA were chosen with 3/8 and 8/16 mm fractions but with parent concrete resistors: 20 to 30MPa, 35 to 45 MPa and greater than 50 MPa. The additions used are the limestone filler (ENG El Khroub) for the control concrete, and the recycled sand filler for the RAC- SCC. The physical properties of the materials used are shown in Table 1.

Table 1. Physical characteristics of materials.

Fraction Gravels/Parent concrete strength of RCA (PCS-RCA)	Absolute volumetric mass (t/m³)	Absorption (%)
3-8 mm (PCS-RCA20-30MPa)	2.50	5.84
8-16 mm (PCS-RCA20-30MPa)	2.50	5.88
3-8 mm (PCS-RCA35-45MPa)	2.63	4.77
8-16 mm (PCS-RCA35-45MPa)	2.21	4.79
3-8 mm (PCS-RCA>50MPa)	2.59	3.53
8-16 mm (PCS-RCA>50MPa)	2.43	3.58
3-8 mm (NAC)	2.80	1.50
8-16 mm (NAC)	2.70	1.55
Rolled Sand (0/1mm)	2.50	1.81
Quarry Sand (0/3)	3.10	1.15
Recycled sand filler	2.43	12.97

* kamardorbani3@gmail.com

2.1 Experimental Methodology

Four (04) SCC compositions were studied for this work, with a cement dosage of 350 Kg.
SCC (01): natural aggregate control concrete + limestone filler;
SCC (02): 100% RCA (PCS-RCA20 to 30 MPa) + Recycled sand filler;
SCC (03):100% RCA (PCS-RCA35 to 45 MPa) + Recycled sand filler;
SCC (04):100% RCA (PCS-RCA greater than 50 MPa) + Recycled sand filler.

3 Results and discussions

3.1 Compressive strength test

The results obtained with the compressive strength test made it possible to trace the evolution of the hardening kinetics of the SCC as a function of time (Figure 1). We note that for all ages, there is an increase in compressive strength for SCC 01 compared to other SCCs of RCA. This increase is justified by the more porous structure of recycled gravel, which leads to an overall increase in open pores in concrete.

For SCC based on RCA and after 7 days of hardening, the quality of the parent concrete is noticeable. The trend is the same for maturities with 28 and 90 days of hardening. The best resistance is obtained by SCC04 (RCA having a parent concrete strength superior to 50MPa). Thus, the resistance of the previously known RCA is highlighted because whenever the strength of the parent concrete is better, the capillary pores of the concretes decrease. As a result, the SCC will be more efficient and resistant, with much lower permeability and the phenomena of transport of aggressive ions.
For SCC based on RCA and after 7 days of hardening, the quality of the parent concrete is noticeable. The trend is the same for maturities with 28 and 90 days of hardening. The best resistance is obtained by SCC04 (RCA having a parent concrete strength superior to 50MPa). Thus, the resistance of the previously known RCA is highlighted because whenever the strength of the parent concrete is better, the capillary pores of the concretes decrease. As a result, the SCC will be more efficient and resistant, with much lower permeability and the phenomena of transport of aggressive ions.

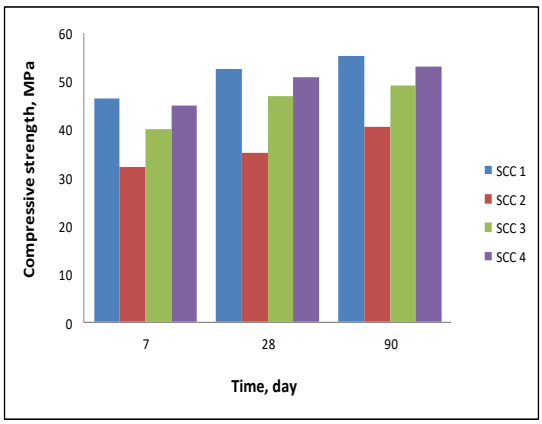

Fig. 1. Compression strength test

3.2 Total immersion water absorption

According to ASTM C642 [8], the 28-day old concrete test pieces were immersed entirely in a 20 °C water tank after being placed in an oven at a temperature of 105°C and measured the weight of these test pieces after 24 hours of immersion. Water absorption by immersion measures the ratio of water absorbed during the process using [9]:

$$W\% = \frac{Mwd - Ms}{Mwd} \quad (1)$$

M_s: the mass of the dry specimen;
M_{wd}: the mass of the test piece after 24 hours of immersion in water.

Water absorption by immersion was measured at 28 days. It increases linearly with the decrease in the strength of the RG parent concrete.

There is an absorption coefficient of up to 4.36% increase for a range of resistance of the original concrete (20 to 30 MPa), as shown in Figure 2. This increase is justified by the more porous structure of RCA, which leads to an overall increase in open pores in concrete.

SCC 04, the absorption coefficient decreases up to 1.50% for a resistance of RCA that exceeds 50 MPa. In addition, the control concrete with natural aggregates has reached an absorption of 1.13% due to the compactness of natural aggregates.

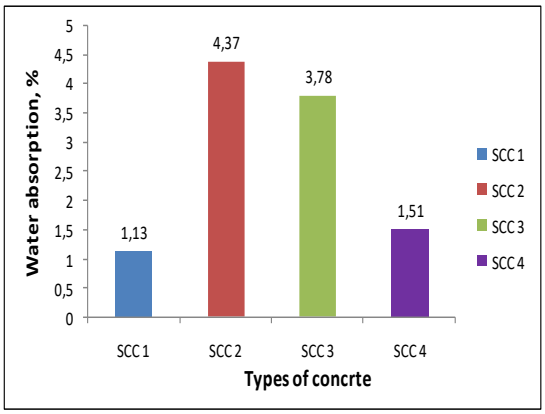

Fig. 2. Water absorption of concretes

3.3 Capillary water absorption

The test was carried out according to the procedure recommended by [10] shown in Fig. 3. The specimens used are cylindrical in shape and have dimensions 11×5 cm². After curing for 28 days under water at a temperature of 20 ± 2 °C, the specimens are dried at a temperature of 80°C until constant mass. The side surfaces of the specimens are coated with resin to prevent evaporation of water absorbed during the test, then immersed in the water of the container to a maximum height of 3 mm. At each deadline, the specimens are taken out of the container, wiped with a damp sponge, weighed and then placed back in the container. The capillary water absorption coefficient is determined by relation (2) at the following times: 0.25, 0.5, 1, 2, 4, 8 and 24 hours.

$$Ca_t = \frac{M_t - M_0}{A} \text{ (kg/m}^2\text{)} \quad (2)$$

Ca_t : capillary absorption coefficient at (t) time, (kg/m²)
M_t : Mass of specimen at (t) time (kg).
M_0: Initial mass of specimen (kg).
A : Specimen section (m²).

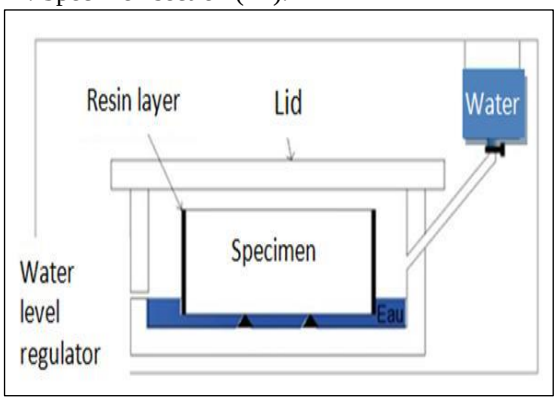

Fig. 3. Capillary water absorption test [11]

Figure 4 shows the results of measuring capillary absorption coefficients as a function of the square root time of the SCC after a 28-day wet cure. A linear increase in water absorption by capillarity is observed with the decrease of the resistance of the original concrete. The finer the porous lattice, the lower the absorption kinetics and, therefore, the absorption coefficient.

It is known that compressive strength is closely related to the porosity of concrete. The high compressive strength of concrete corresponds to a low porosity concrete; therefore, low permeability and vice versa, a low strength, high porosity, guarantees a more permeable concrete. Results shown in (Figure 2) confirm that.

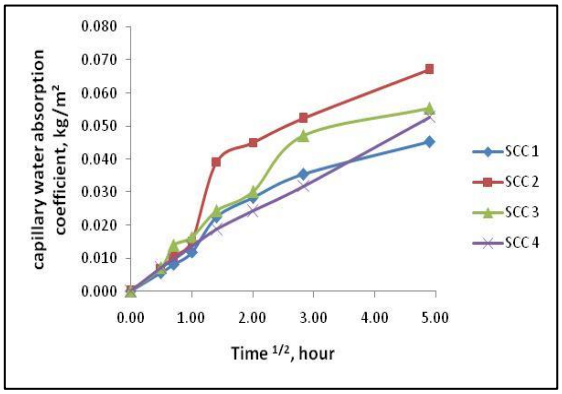

Fig. 4. Capillary water absorption of concretes

4 Conclusion

From the results presented, several assessments can be drawn:

- The incorporation of RCA in concrete, especially RCA having high strength as parent concrete, causes an increase in mechanical strength and decreases in water absorption capacity.
- The mechanical strengths obtained for concretes-based RCA are comparable to those of conventional concretes, provided that the RCA have good initial properties.
- Finally, SCC 04, incorporating RCA from parent concretes with a strength exceeding 50 MPa, is the optimal choice to minimize the impact on water absorption by immersion.

References

1. KOU S.C., and POON C.S, «Effect of the quality of parent concrete on the properties of high performance recycled aggregate concrete», Construction and Building Materials, vol. 77, 2015, p. 501-508.
2. SILVA R.V., NEVES R., DE BRITO J. and DHIR R.K., «Carbonation behavior of recycled aggregate concrete», Cement and Concrete Composites, vol. 62, 2015, p. 22-32
3. Andrzej A., Alina K., «Influence of recycled aggregates on mechanical properties of HS/HPC», Cement & Concrete Composites 24 269–279, 2002
4. Tsung Y.T., Yuen-Yuen C., Chao-Lung H., « Properties of HPC with recycled aggregates », Cement and concrete research, vol 36, p 943-950, 2006.
5. Akash R, Kumar N. J., Sudhir M., « Use of aggregate from recycled construction and

demolition waste in concrete », Resources conservation and concrete, vol. 50, n°1, p. 71-81, 2007.

6. Etxeberria M., Vázquez E., Marí A., Barra M., « Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete», Cement and concrete research, vol 37, p 735-742, 2007.
7. Hanifi B., Tahir S., Orhan A., Hasan K., «Durability of concrete made with granite and marble as recycle aggregates», Journal of Materials Processing Technology, Vol 208, Issues 1-3, 21 pp 299-308, November 2008.
8. ASTM-C642, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete1.
9. Evangelista L., De Brito J., Durability performance of concrete made with fine recycled concrete aggregates, Cement and Concrete Composites 32(1) (2010) 9-14.
10. Arliguie, G., Hugues, H. (2007). GranDuBé, Grandeurs Associées à la Durabilité des Bétons.
11. Jonoobi, M., Shafie, M., Shirmohammadli, Y., Ashori, A., Hosseinabadi, H.Z., Mekonnen, T. (2019). A review on date palm tree: Properties, characterization and its potential applications, J. Renew. Mater., 7(11), pp. 1055–1075.