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Research Article

Performance of Eco-Friendly Self-Compacting Concrete Incorporating Recycled Concrete Aggregates of Different Sizes and Contents

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ABSTRACT

In recent years, the rapid increase in population and building demand across the world leads to significant deterioration or reduction of natural resources. Meanwhile the huge amounts of waste from the demolition of buildings and concrete structures in the landfill space become a serious ecological and environmental problem. The recovery of aggregates from recycled concrete for the formulation of new concrete would contribute to reducing the depletion of natural resources and therefore integrate into the context of sustainable development, because there are several socio-economic advantages. The objective of this possibility of using aggregates from recycled concrete mixes. We have established a comparison between the physical and mechanical behavior of SCC based on RCA (Recycled Sand: SR 0/3 and Recycled Gravel RG: 3/8 and 8/15) and that of SCC based on natural aggregates (NA) on fresh support and hardened state. Additionally, Non-Destructive Testing (NDT) methods were conducted in this research to obtain more information about the properties of the studied SCC. The results of the tests on fresh SCC meet the recommendations of the French Association of Civil Engineering (AFGC). The physical and mechanical behavior of SCC-RS is relatively weak compared to SCC-NA/RG. This is due to the high absorption capacity of the aggregates (depending on the size of the aggregates) and the poor quality of the mortar attached to the aggregates, which can create areas of weakness in the concrete structure.

Keywords: recycled concrete aggregates size, eco-Self-compacting concrete, physical-mechanical behavior, nondestructive test .a

INTRODUCTION

The enormous consumption of natural aggregates during the production of concrete presents a serious threat to the environment due to the depletion of natural resources and the emission of carbon monoxide Co2 [1].On the other hand, the increase in demolition waste and its landfill areas has a negative impact on the environment [2].

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The valorization of aggregates from recycled concrete for the formulation of a new concrete would contribute to the reduction of the depletion of natural resources and would thus be integrated in the context of sustainable development, because there are several advantages of a socio-economic [3-4]. Indeed, the costs of transport of natural aggregates on the one hand, and the storage of demolition waste on the other hand, are very important.

The SCC are very fluid concretes which are characterized by a large volume of paste and an optimized granular distribution and have sufficient viscosity to ensure good stability, these concretes can be placed without vibration and have several environmental, technological and economic advantages [5].

In recent years, some studies on the use of RCA have started to be published with self-compacting concrete (SCC), although they are still rare. Most of these studies compare the different fresh and hardened properties of SCC with coarse recycled aggregate (CRA) and natural aggregates (NA).

The non-destructive testing (NDT) has been developed to assess and characterize the properties of concrete on site without modifying either its performance or its appearance in rapid and simple way [6]. This method is based on the measurement of the rebound hammer and the ultrasonic pulse velocity. Many studies have highlighted the reliability of non-destructive testing in terms of evaluating the mechanical properties of building materials and structures [7]. These tests are combined to develop a correlation between rebound hammer, ultrasonic pulse velocity and concrete compressive strength [8].

The present research work therefore consists in carrying out a comparison in terms of physical-mechanical performance between SCC based on two types of aggregates from recycled concrete (sand and gravel) and SCC based on natural aggregates (NA) in the fresh and hardened state. For that, we substituted 100% of the quantity of natural sand (NS 0/3) introduced in the formulation of the SCC by the sand resulting from the recycled concretes (RS 0/3) that is to say (SCC-RS), and 100% of the quantity of the natural gravel (NA 3/8-8/15) by the gravel resulting from the recycled concretes (RG 3/8-8/15) that is to say SCC-RG).

MATERIALS AND SPECIMENS PREPARATION

Cement

The cement used is Portland Cement CEMI 42.5 N-SR3, where its properties are presented in Table 1 and 2 respectively.

Table 1. Chemical composition of used cement and mineral additions (%)

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P.F
Content %	18.77	3.94	6.49	63.02	2.55	2.06	0.02	0.36	1.5

Source: Authors.

Table 2. Physical and mineralogical compositions of cement used.

Elément	Finesse Blaine (cm^2/g)	Absolute density (g/cm^3)	Normal consistency (%)	C_3A (%)
Content	3200 at 3800	3.05	25 at 28	< 3.0

Aggregates

The used Aggregates play an important role in the behaviour of concrete. Their influence is very strong in terms of mechanical performance [9]. Rolled sand (NS0/3) comes from Oued lakhdar (Bechar) quarry (Bechar) and gravel (NG3/8), (NG8/15) comes from Benchickh quarry (Bechar).The recycled aggregates are formed of the original aggregate and mortar attached to it.

The aggregates from recycled concrete (RS0/3) (RG3/8), (RG8/15) resulting from crushing of old concrete specimens (Figure 1)

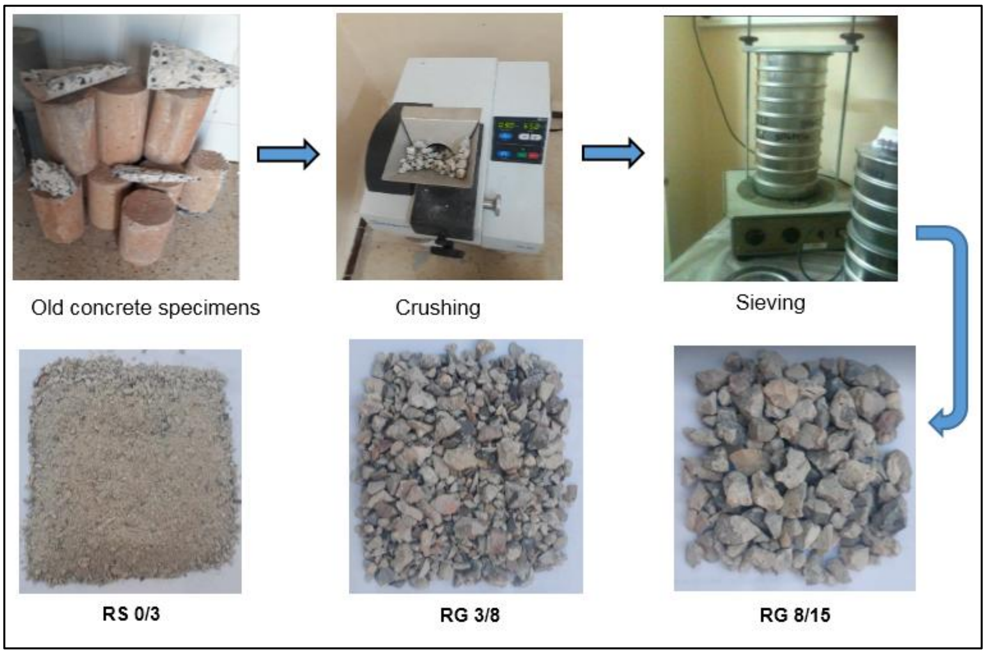

Figure 1. Production of recycled concrete aggregate

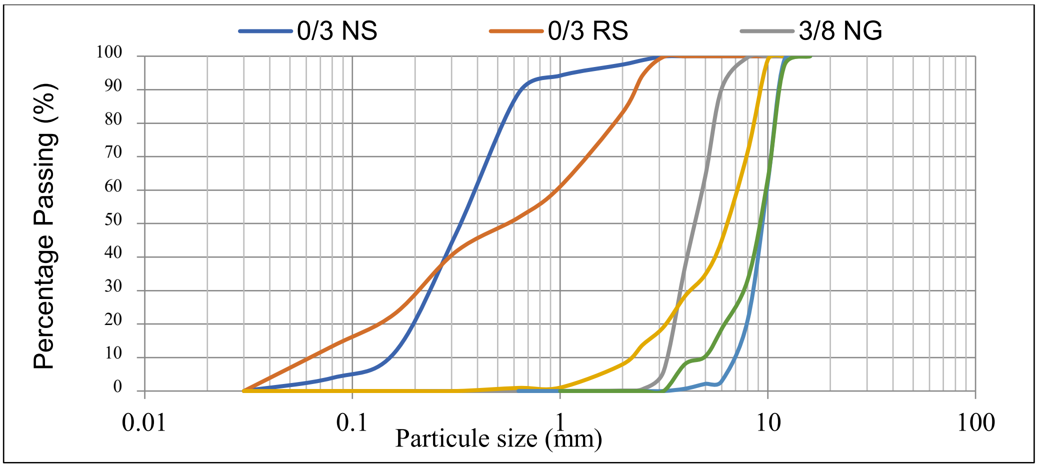

Figure 2. Particle size distributions of aggregate used.

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Table 3. Physical and mechanical properties of aggregate used.

Type of aggregate	Density (g/cm3)	Fineness modulus	Water absorption (%)	Los Angeles (%)
SN 0/3 (mm)	2.57	2.28	1.50	/
GN3/8 (mm)	2.62	/	0.50	22.50
GN 8/15 (mm	2.63	/	0.45	21.60
SR 0/3 (mm)	2.34	2.61	10.07	/
GR 3/8 (mm)	2.47	/	5.04	26.12
GR 8/15 (mm)	2.45	/	3.70	26.82

Superplasticizer

The superplasticizer used during this study is Master Glenium SKY3080 high water reducer, which is suitable for ready-mixed and self-placing concretes according to the standard [NF 934 -2].

Mixing water

The water abstraction in done on the conduct of drinking water supply for the town of Bechar. This water is treated for drinking.

EPERIMENTAL PROGRAMMER

Contrary to the formulation of ordinary concrete, the determination of the composition of the SCC does not follow a classical formulation. To this end, we have respected the criteria recommended by the French Association of Civil Engineering (AFGC) [10]

- gravel/sand ratio (G/S) close to 1;
- water/cement ratio (W/C) = 0.5;
- minimum cement dosage Cmin=300 kg/m3 ;
- determined percentage in superplasticizer additions to ensure the fluidity of the mix;
- 300 l/m3≤ paste volume ≤400 l/m3.

Three concretes are obtained; one is the reference concrete based on natural aggregates and without the incorporation of recycled aggregates called SCC-NG and the other two concretes based on recycled concrete aggregates RCA, one with 100% recycled sand called SCC-RS, and the other with 100% recycled gravel called SCC-RG. (Table 4).

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Table 4. Compositions of SCC studied

Mixture	Cement	NS 0/3	NG 3/8	NG 8/15	RS 0/3	RG 3/8	RG 8/15	Water	Sp
	(Kg/m3)								
SCC-NA	520	900	150	580	0	0	0	256	4.44
SCC-RS	520	0	150	580	150	0	0	256	4.44
SCC-RG	520	900	0	0	0	150	580	256	4.44

Tests performed

In order to characterize the effect of the size of the aggregates from recycled concrete (RCA) on the properties of the concrete, different types of tests were carried out on SCC in the fresh state and in the hardened state. Additionally, non-destructive TND testing methods were used in this studie to obtain more information on the mechanical properties of the studied SCCs (Table 5).

Table 5. Tests performed .

Tests		Standard
Workability	Slump-flow	AFGC (2008)
	L– box	AFGC (2008)
	Stability in sieve	AFGC (2008)
Mechanical strength	Flexural tensile strength	NF P18-407
	Compressive strength	NF P18-406
Physical tests	Porosity	[AFREM, 1997]
	Water absorption by capillary	[AFREM, 1997]
Non-destructive test	Ultrasonic pulse velocity (UPV)	NFP 18-418
	Rebound hammer	NFP18-417

Figure 3. Different types of tests

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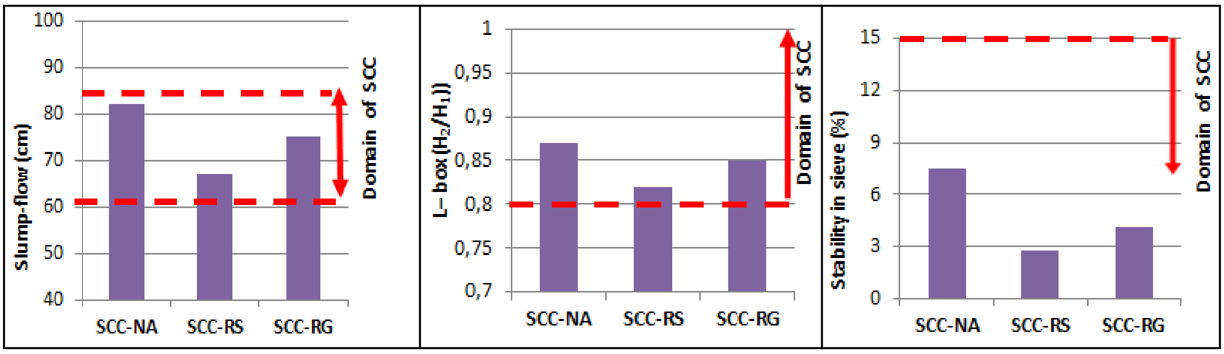
RESULTS AND DISCUSSION

Properties of the fresh scc

The values of different tests (Slump flow, L-box flow and sieve stability of different SCC) were measured. From the results presented in (figure 4), it is observed that all the SCC meet the criteria of self-workability recommended by AFGC [10]. In particular, all the values of the percentage of laitance are lower than 15% which indicates a satisfactory and approvable stability of the concrete.



(a) Slump-flow (b) L-box (c) Stability in sieve

Figure 4. Effect of aggregate size from RCA on the fresh properties of SCC.

The results obtained (Figure 5) show that the flexural tensile strength of SCC-RG decreases slightly compared to SCC-NA. However, the incorporation of RS causes a loss of flexural tensile strength in the order of 23.3% and 15.89% at 7 days and 28 days respectively compared to the reference mix SCC-NA. This reduction evolved to around 21.77% at the age of 90 days and remained almost stable for maturities of 180 and 365 days, this is due to the insufficient bond between the mortar attached to the aggregates from the recycled RCA concrete and the new cement paste. This is in agreement with the results of literature works [3]. [11-12].

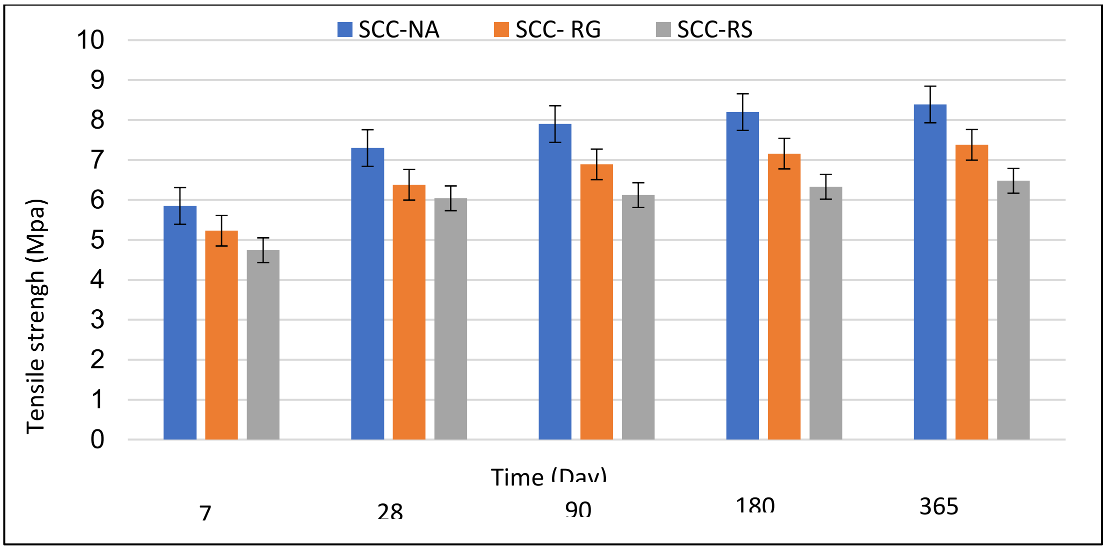


Figure 5. Effect of aggregate size from RCA on tensile strength.

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Several researchers have concluded that insignificant reductions in compressive strength up to 50% of replacement of NA with RCA in a SCC mix, [13-14]. From (Figure 7), it can be seen that the compressive strength is slightly decreased to the order of 4.74% and 12.35% for SCC-RS after 7 and 28 days of curing respectively compared to the reference mix SCC-NA. This reduction evolved to around 18.28% at the age of 365 days. This is due to the poor quality of the mortar attached to the aggregates from the recycled concrete, which created the weak areas in the concrete [1]. [3].

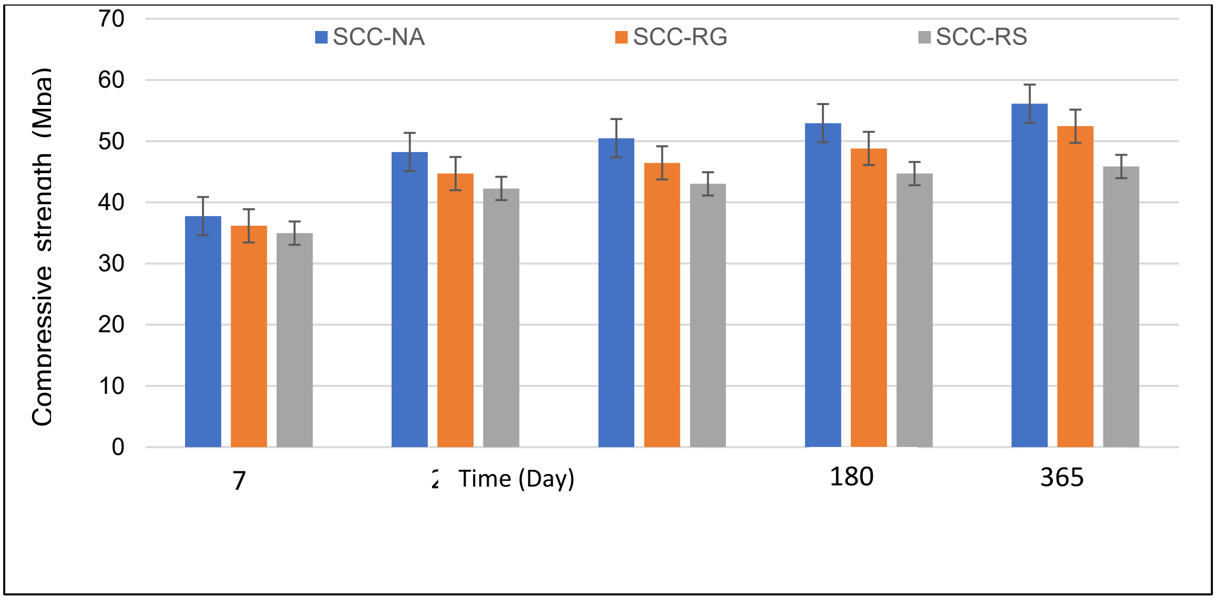

Figure 6. Effect of aggregate size from RCA on compressive strength

Porosity accessible to water

From (Figure 7), it can be seen that the porosity of SCC -GR and SCC - RS is higher in the order of 16% and 2,88% respectively compared to the reference concrete SCC -NA. This is directly related to the high water absorption of the aggregates (depending on the size of the aggregates) and the poor bond quality between the aggregates from the recycled concrete and the cement paste [15]. [16].

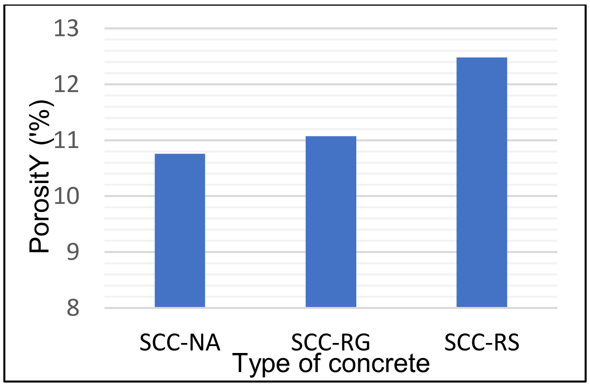

Figure 7. Effect of RCA size on porosity of different SCC

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The relationship between the open porosity and the compressive strength at 28 days of the different types of concrete produced is shown in (Figure 8). It can be seen that a good correlation between compressive strength and porosity was obtained as indicated by the higher values of R-squared (R2=0.803), the compressive strength of recycled concrete decreases with increasing porosity, which confirms the trend evoked by [17].

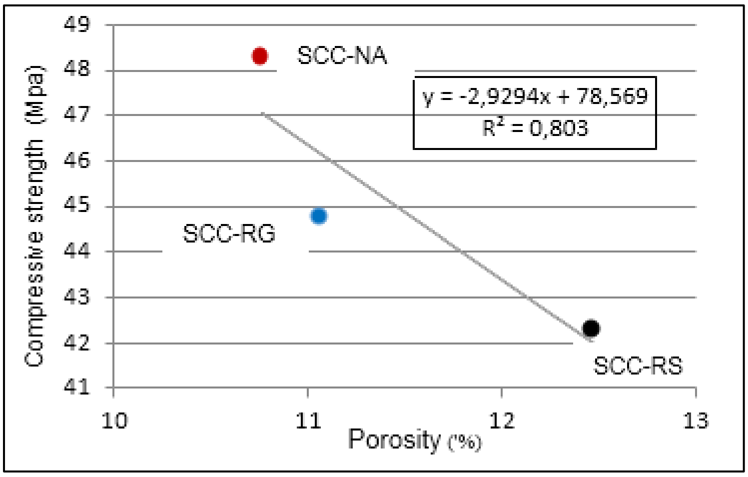

Figure 8. Correlation between porosity at 28 days and compressive strength

Water absorption by capillary

The capillary absorption results at 24 hours and the kinetics of this absorption have been reported in (Table 6) to facilitate the comparison between SCC. The evolution of water absorption by capillarity over time of the different concretes produced is shown in (Figure 9).

Table 6. Data for water absorption by capillarity of SCC

Characteristics		SCC-NA	SCC-RG	SCC-RS
Water absorption on 24 h (kg/m2)	2h	1.92	1.98	2.20
	24h	4.53	4.69	4.94
Water absorption kinetic (kg/m2.h1/2)	0- 2h	1.36	1.40	1.56
	2-24h	0.56	0.58	0.58

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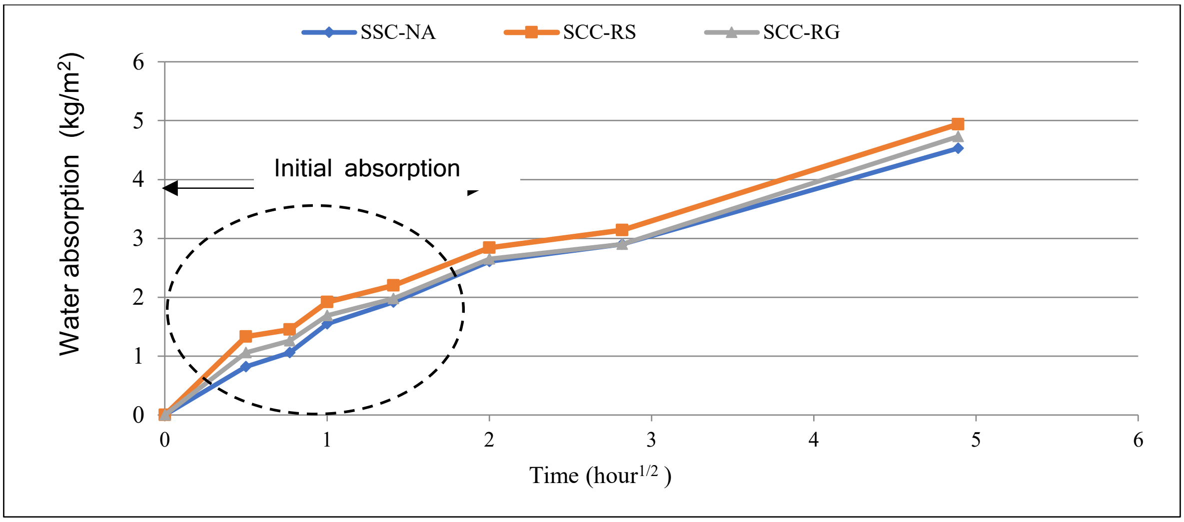

Figure 9. Effect of aggregate size from recycled concrete on water absorption of SCC

From (Figure 9), it can be noted that the initial absorption at a young age for 2 hours is significantly greater than that of kinetics for the period (2-24 hours). For all the SCC, the SCC-RS has a capillary absorption and a slightly higher absorption kinetics than the others In the period of (0-2h) This is due to the high porosity of the recycled sand (RS) and the poor bond quality between the aggregates from the recycled concrete and the cement paste [16].[18].

Figure 10 shows the results of the capillary absorption kinetics per unit area as a function of the compressive strength. These results show that the capillary absorption kinetics is a decreasing function with the compressive strength for 2h and almost stable for 2-24h. We can say that for 2 hours concrete with high compressive strength has a low capillary absorption coefficient than concrete with less strength in the order of 12.82% [17].

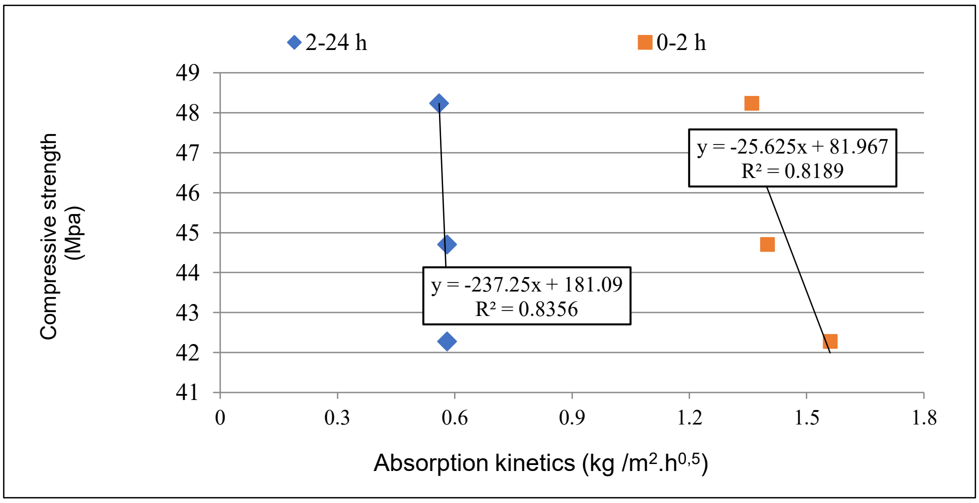

Figure 10. Correlation between absorption kinetics and compressive strength of SCC

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CONCLUSION

This study has shown that the substitution of natural aggregates (NA) by recycled concrete aggregates (RS / RG), in the composition of self-compacting concrete (SCC), contributes to a slight variation in workability parameters in the fresh state. While always remaining in the field of SCC required by the AFGC recommendations.

The results of physical behavior of SCC –RS / RG show a slight variation compared to the reference SCC (SCC –NA).

The physical and mechanical behaviors of SCC -RS are relatively weak compared to SCC-NA / RG. This is due to the high absorption capacity of sands from recycled concrete and the poor quality of the mortar attached to the aggregates which can create areas of weakness in the concrete structure.

The size and properties of recycled concrete aggregate (RCA) had an effect on non-destructive testing results, a decrease in (rebound hammer number and ultrasonic pulse velocity for SCC based on RCA (SSC-RS and SSC-RG) compared to SCC-NA.

The valorization of recycled aggregates is of major interest, because it offers a solution to the scarcity of natural aggregates, prolongs the operation of active quarries, minimizes waste dump areas and reduces carbon dioxide Co2 emissions.

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