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Improving the physical and mechanical properties new concrete containing crushed dune sand and demolition waste as coarse aggregate.

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Abstract

Using concrete waste as aggregates in new concrete compositions brings numerous advantages. It helps in reducing the costs associated with managing demolition waste and contributes to the preservation of natural deposits and mountains by minimizing the demand for new quarries. However, when completely substituting natural aggregates (NA) with recycled concrete aggregates (RCA) in concrete, it directly affects the fundamental properties of the material, particularly its physical and mechanical characteristics. This is primarily due to the inferior qualities exhibited by RCAs in comparison to natural coarse aggregates, primarily stemming from their increased porosity and water absorption. In the experimental study conducted, the focus was on investigating the influence of substituting cement with crushed dune sand (CDS) at different replacement levels (5%, 10%, and 15%) on the mechanical and physical properties of self-compacting concrete (SCC) incorporating 100% RCA. The findings from this study indicated that the substitution of cement with CS resulted in improved mechanical and physical behavior of the self-compacting concrete containing 100% RCA, particularly when CS was present at 5% and 10% levels. Overall, the study suggests that incorporating CS as a partial substitute for cement in SCC containing 100% RCA can positively affect the properties of the concrete mixture, enhancing its mechanical and physical performance.

Keywords: Self-compacting concrete. Recycled concrete aggregates. Crushed dune sand. Mechanical and physical properties.

1. Introduction

The aggregates represent 65 and 75% of concrete in term of volume, especially self-compacting concrete (SCC), and play an important role in the improvement of its properties (Tahar *et al*., 2022). The high consumption of natural aggregates in the manufacturing of concrete poses serious problems environmental due to the exhaustion of natural resources and the emission of carbon monoxide C02 (Nili *et al*., 2019; Sandanayake *et al*., 2019; Rabehi *et al*., 2023) The increasing accumulation of demolition waste and the expanding footprint of landfill areas pose significant environmental challenges and negative impacts. (Tuyan *et al*., 2014).

The valorization of recycled concrete aggregates (RCA) in new concrete not only reduces the amount of natural aggregates but also helps in reducing the accumulation of demolition waste (Kebaili *et al*., 2022). However, the increased porosity and water absorption of recycled concrete aggregates (RCAs), stemming from the presence of attached mortar on their surface, contribute to their inferior qualities when compared to natural coarse aggregates. (Galishnikova *et al*.,2020; Zheng *et al*., 2021; Rabehi *et al*., 2023).

Several studies have demonstrated that the adding of pozzolanic minerals to concrete microstructure improves mechanical and physical characteristics (Silica fume, fly ash, crushed granulated blast furnace slag) (Kisku *et al*., 2017; Yin *et al*., 2018; Herath *et al*., 2020). Yergol and Shastri (2021) found that adding 10% FS increase the strength of concrete containing 45% RCA by filling voids by micro filling. Çakır and Sofyanlı (2015) showed that the use of 5% and 10% SF as a cement substitute increased the compressive strength of the recycled concrete mixture by 7% and 11%, respectively. Indeed, SF can bring a better pozzolanic effect than cement by producing hydrated calcium silicate (CSH) in the concrete and providing a micro-filling effect, which fills the pores on the surface of the RCA with improved adhesion to ITZ mortar-aggregate. Previous studies have also demonstrated the benefits of incorporating other mineral additives. For example, the incorporation of fly ash was found to increase the compressive strength of 100% RCA-based recycled concrete (Kou and Poon., 2012), attributed to the micro-filling effect and additional pozzolanic reaction provided by fly ash. Ransinchung and Jindal (2016) found that the recycled concrete (RC) with granulated ground blast furnace slag (GGBS) a lower water absorption than recycled concrete without GGBS. Djelloul *et al*. (2018) investigated the incorporation of GGBS at different levels in self-compacting concrete made from fine and coarse recycled aggregates and observed a decrease in water absorption and water permeability depth.

Cement, being the second most consumed material globally after water, poses a significant environmental threat due to CO_2 emissions. The Algerian desert contains vast reserves of dune sand, which is rich in silica quartz and has not been utilized in construction applications (Tafraoui *et al*., 2006). The valorization of finely ground dune sand as a mineral additive in concrete formulations offers both economic and environmental advantages and can help reduce CO_2 emissions. The objective of this investigation is to examine the influence of incorporating crushed dune sand (CS) as a mineral addition at various levels of cement replacement on the physical and mechanical properties of self-compacting concrete (SCC) containing 100% recycled aggregate concrete (RAC). Five concrete mixes were prepared: one using 100% natural coarse aggregates, referred to as SCC-NA; and four using 100% recycled coarse concrete aggregate. Among the latter, one mix did not include crushed dune sand and served as the control, named SCC-RA 0%CS. The remaining three mixes incorporated 5%, 10%, and 15% of crushed dune sand, denoted as SCC-RA5% CS, SCC-RA10% CS, and SCC-RA15% CS, respectively. Multiple tests were carried out on the concrete samples, encompassing assessments of compressive and tensile strength, open porosity, water absorption, and microstructural analysis. The test results indicate that the addition of crushed dune sand positively impacts the physical properties of SCC containing 100% recycled coarse aggregate. This finding demonstrates the feasibility of producing new concrete compositions that incorporate concrete waste as a coarse aggregate.

2. Materials and methods

2.1. Raw materials

The cement used is of the CEMI 42.5 N–SR3 type from the Algeria Lafarge (Figure 1) under the name Mokaouem Plus .The dune sand that has been pulverized and is at the region of Taghit, Algeria.

Figure 1– Cement and CDS.

The results of elemental analysis by XRD on the dune sand (Figure 2) show a peak of approximately 100% silica, which reflects the dominance of SiO2 in the analyzed sand. The other elements revealed being CaCO3 and Fe2O3 present at low percentages. To detect the fraction of sands richest in silica (Tafraoui and Lebaili, 2006).

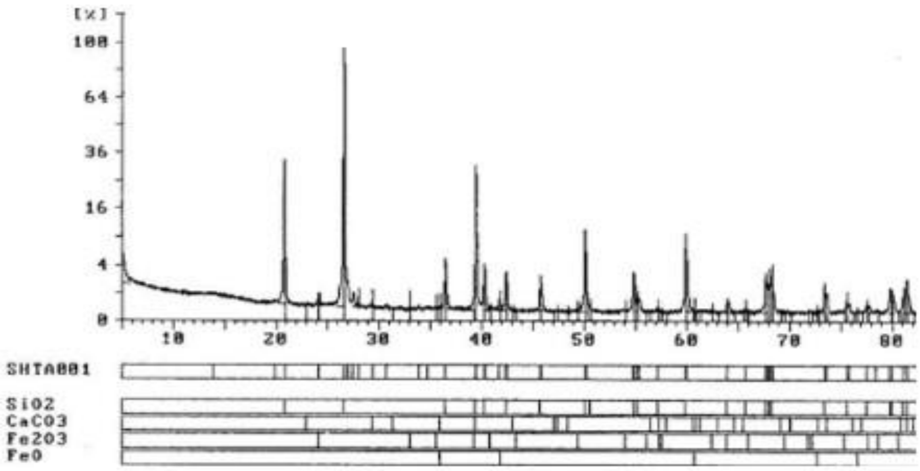


Figure 2– XRD analysis of dune sand (Tafraoui and Lebaili, 2006).

Table 1 and Table 2 present the chemical and physical of properties of the cement and CDS respectively.

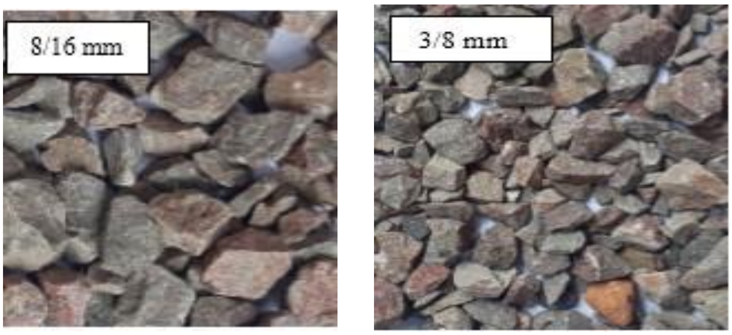
Table 1 - Chemical characteristics of cement and CDS.

Elements	SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	Na2O	K2O	P.F.
CDS	97.15	0.79	0.21	0.11	0.05	0.14	0.18	0.02	0.58
Cement	18.77	3. 94	6.49	63.02	2.55	2.06	0.02	0.36	1.5

Table 2 - Physical properties of cement and CDS.

Parameters	Cement	CDS
Absolute density (g/cm^3)	3.05	2.8
Specific surface cm^2/g)	3200	3110
Masse volumique apparente (g/cm^3)	1120	1300

The naturel sand (NS0/3) and naturel coarse aggregate (NA3/8), (NA8/16) comes from the Oued lakhdar quarry located in Béchar (Algeria) Figure 3(a). The recycled concrete aggregates are formed from the original aggregate and mortar attached to it. These must therefore be considered as a system composed of two distinct phases, the mortar and the original aggregate .The recycled aggregates concrete (RA3/8), (RA8/16) resulting from crushing of waste concrete Figure 3(b).



a) Naturel aggregate (NCA)

b) Recycled aggregate (RCA)

Figure 3– Naturel aggregate and recycled aggregate.

Figure 4 show the particle size distributions of aggregate used.

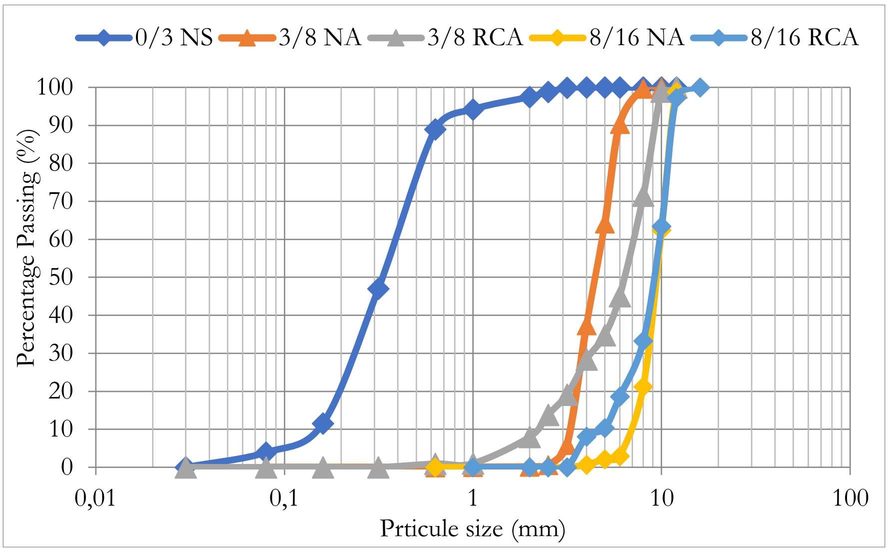


Figure 4– Particle size distributions of aggregate used.

Table 3 - Physical and mechanical characteristics of aggregate.

	0/3 NS	**3/8 NA**	**8/16 NA**	**3/8 RCA**	**8/16 RCA**
Apparent density (g/cm3)	1.6	1.39	1.40	1.32	1.36
Absolute density (g/cm3)	2.57	2.62	2.63	2.47	2.45
Fineness modulus	2.61	/	/	/	/
Sand equivalent (%)	82.57	/	/	/	/
Water absorption (%)	1.50	0.50	0.45	5.04	3.70
Los Angeles coefficient (%)	/	22.50	21.60	26.12	26.82

The incorporation of the superplasticizer in the SCC formulation is necessary to improve fluidity. The superplasticizer used during this study is Master Glenium SKY 3080 high water reducer according to (NF 934-2, 2012).

The water is withdrawn from the potable water source of the city of Béchar (Algeria).

2.2. Mix design of SCC

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 French Association of Civil Engineering recommendations (AFGC, 2008) Table 4.

Table 4 - Compositions of SCC studied.

Mix (kg/m3)	**SCC-NA**	**SCC-RA 0%CS**	**SCC-RA 5%CS**	**SCC-RA 10%CS**	**SCC-RA 15%CS**
Cement	520	520	494	468	442
CS	0	0	26	52	78
NS 0/3	900	900	900	900	900
NCA 3/8	150	0	0	0	0

NCA 8/16	580	0	0	0	0
RCA 3/8	0	150	150	150	150
RCA 8/16	0	580	580	580	580
Water	256	256	256	256	256
Superplasticizer	4.44	4.44	4.44	4.44	4.44

The various preliminary formulations were tested and characterized experimentally, until the final formulation meeting the aforementioned criteria was obtained. The composition of the SCC is shown in the table below Table 4. Five concretes are obtained, one is the concrete based on 100% natural aggregates called SCC-NA. The other four concretes containing 100% recycled concrete aggregate, one mix without the incorporation of CS called SCC-RA 0%CS (Reference mix), and the other three concretes with 5%, 10% and 15% of CS called SCC-RA5% CS, SCC-RA10% CS and SCC-RA15% CS respectively.

2.3. Test methods

Workability: The SCC must satisfy many tests; for this study, we selected three tests recommended by AFGC (AFGC, 2008) to assess the key properties of SCC in its fresh state (figure 5). These tests include measuring fluidity, static and dynamic stability, and assessing the behavior of SCC in both free and confined environments. The fluidity of SCC is evaluated using the Abrams cone flow box test, while stability is determined through a sieve analysis. The details of these tests and their results can be found in Table 5.

a) Slump-flow test b) L-box test c) Sieve stability test

Figure 6– Workability tests.

Table 5 - Limit values of tests recommended by (AFGC, 2008).

Test	**Slump-flow (cm)**	**L– box (H2/H1)**	**Sieve stability (%)**
Values limits	55 à 85	≥ 0.80	≤ 15

Hardened state : At the specified curing ages (7, 28 days), three-point bending test according to the standard (NF P18-407, 1981) was first performed for each group of prismatic specimens (7x7x28) cm, using an Amsler universal testing machine. Next, compressive strength was measured, using the fractured pieces after the bending test (Figure 6). The flexural and compressive loads were applied on the sides of the prismatic specimens' perpendicular to the casting direction. The flexural strength was an average of three test specimens, but the compressive strength was an average of six fractured pieces (F P18-406, 1981).

a) Tensile strength test b) Compressive strength test

Figure 7– Mechanical strength tests.

Physical proprieties: The aim of the accessible porosity test is to quantify the amount of surface-connected voids within the concrete according to the AFREM recommendation (AFREM, 1997).

$$P = \frac{M_{air} - M_{dry}}{M_{air} - M_{water}} x100 \quad (1)$$

Equation 1 show how to measuring the porosity; where P represents the porosity accessible to water, M_{water} is the mass of weighed under water, Mair is the mass of the specimen saturated and M_{dry} is the mass in air of the dry test piece.

The capillarity water absorption is a physical phenomenon by which the water penetrates from the outside to the inside of a porous medium thanks to a capillary rise phenomenon. The quantity of water absorbed by a prepackaged sample of concrete is measured according to the recommendations of (AFREM, 1997). After demolding, the specimens are kept until 28 days of age in water at (20 ± 2) °C. The time frames are as follows: 0.25, 0.5, 1, 2, 4, 8, 24 hours. Equation 2.

$$C_a = \frac{M_x - M_0}{A} \quad (2)$$

Where Ca represents absorption coefficient, Mx is the mass of the specimen after absorption to constant mass, M_0 is the mass of the specimen after drying to constant mass at 105±5 and A represents the surface area.

3. Results and discussion

3.1. Fresh state- workability

The experimental results obtained and presented in Table 6 confirmed the autoplacability of all the concretes studied according to the recommendations of the (AFGC, 2008). The addition of crushed dune sand as an addition of up to 15% improves the rheological workability parameters of the SCC based on the recycled concrete aggregate SCC-RA, this is mainly due to the spherical form of the CDS particles and which fill the voids available between the SCC particles. The spreading values are between 74 cm and 78 cm, which are located within the range of SCC, recommended by the (AFGC, 2008). All of the SCC-RA mixtures incorporated into the CDS having a good filling capacity with a rate that is H2 /H1 > 0.80. The results of the resistance to static segregation carried out by sieve stability tests show that all the concretes have satisfactory stability (0% <p <15%) and that there is no risk of segregation.

Table 6 - Effect of CS on fresh SCC properties.

Mix	Slump-flow (cm)	L– box (H2/H1)	Sieve Stability (%)
SCC-NA	82	0,87	4,1
SCC-RA 0%CS	74	0,84	4,1
SCC-RA 5%CS	75	0,85	5,7
SCC-RA 10%CS	77	0,87	5,4
SCC-RA 15%CS	78	0,91	5,2

3.2. Hardened state- mechanical proprieties

From Figure 7, the addition of 5% of CS increases the tensile strength by bending for SCC-RA5%CS about 16.3% and 7.31 after 7 and 28 days compared to SCC-RA0%. This is due to the improvement of the compactness by the densification effect and the partial pozzalanic reaction of the CS, [(Zaouai *et al*., 2020; Rennani *et al*., 2021). One can also observe a domination of the tensile strength by bending for the SCC at replacement rates of 10 and 15%.

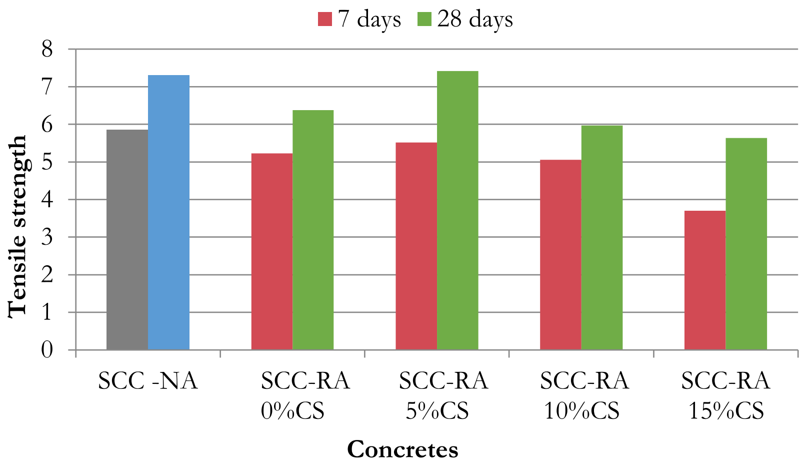


Figure 7– Effect of CS on tensile strength of SCC.

Several researchers have concluded that an insignificant decrease of compressive strength of up to 50% from substitution of NA by RCA in a mixture of SCC (Oliveira *et al*., 2014). According to Figure 8, SCC-RA has slightly lower compressive strength than SCC-NA. in the order of 4.21% and 7.31% after 7 and 28 days respectively. This due to the low quality of the cement paste to RCA and that created the weak zones in the concrete (Panda and Bal., 2013; Modani and Mohitkar., 2014). The addition of 5% crushed dune sand CS increased the compressive strength of SCC-RA5%CS to the order of 7.3% and 13.28% compared to SCC-RA0%CS after 7 and 28 days of hardening and even exceed that of concrete based on natural coarse aggregate SCC-NA. The replacement of 10% of the cement by the CS gives a compressive strength almost comparable to that of the control concrete SCC-RA0%CS and this due to the physical effect of crushed dune sand by the best filling of the inter granular voids by reinforcing the cement matrix and gives better adhesion in the interfacial transition zone (ITZ), that is in accordance with (Benmerioul *et al.*, 2017; Zaouai *et al.*, 2020).

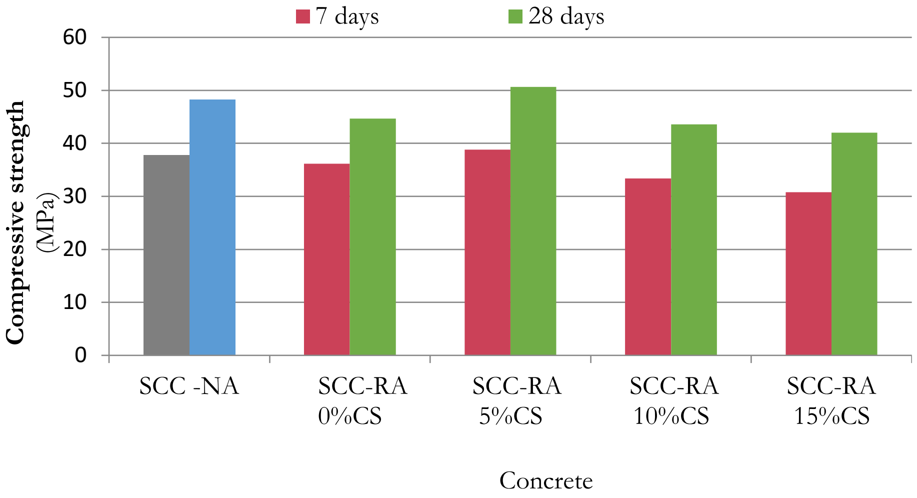


Figure 8– Effect of CS on compressive strength of SCC.

The increase of compressive strength is could be explained by the partial pozzolanic reaction between CH and ground silica in crush dune sand CS in the form of CSH, which make the cement paste denser and more compact and contribute to the increase compressive strength. These results are in agreement with those found previous studies (Gettable and Mezghiche., 2011; Mechti *et al.*, 2013).

3.3 Porosity

The total replacement of natural aggregates by RCA increased the water porosity of SCC – RA by around 4.41% compared to SCC –NA. This is directly linked to the high porosity of recycled gravel and the poor adhesion between aggregates from recycled concrete and cement paste. Figure 9 demonstrates that incorporating of crushed dune sand with substitution rates of 5% improved the porosity at 28 days of SCC-RA (control SCC) on the order of 5.23%, and the replacement of 10% of the cement by the CS gives the water porosity almost similar to that of the control concrete SCC-RA0%CS, this is explained by the densification filling effect of the CS.

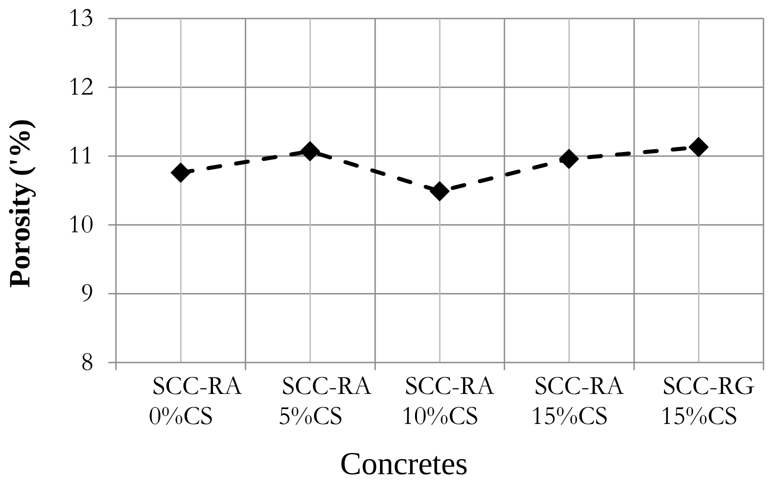


Figure 9– Effect of CS on porosity of SCC.

3.4 Water absorption by capillarity

The initial absorption at a young age for 2 hours is significantly higher than that of the kinetics for the period (2-24 hours) for all SCC, SCC-RA has a capillary absorption and a slightly higher absorption kinetics than the others in the period of (0-2h), this can be attributed to the RCA's high porosity and weak adherence quality (ITZ) between RCA and cement paste. The results obtained show that the capillary absorption coefficient for SCC with 5% crushed dune sand are reduced compared with the SCC without CS Figure 10.

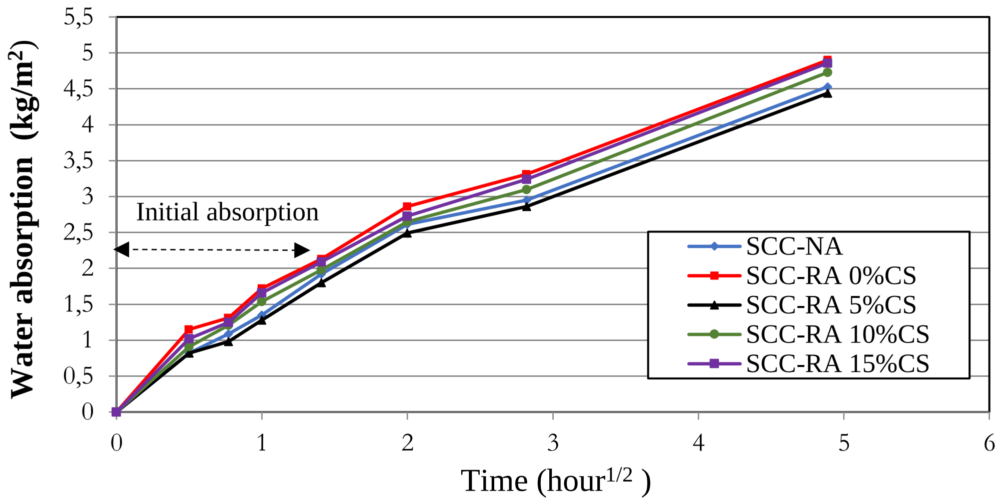


Figure 10– Evolution of SCC capillary absorption according to CS.

4 Correlation

4.1 Correlation between porosity and compressive strength

According Figure 11, the results demonstrated that the compressive strength have a strong relationship with the porosity. The compressive strength improved with improves of the porosity for the different types of SCC. The expression proposed for this correlation is a linear equation with a coefficient of correlation $R^2 = 0.914$.

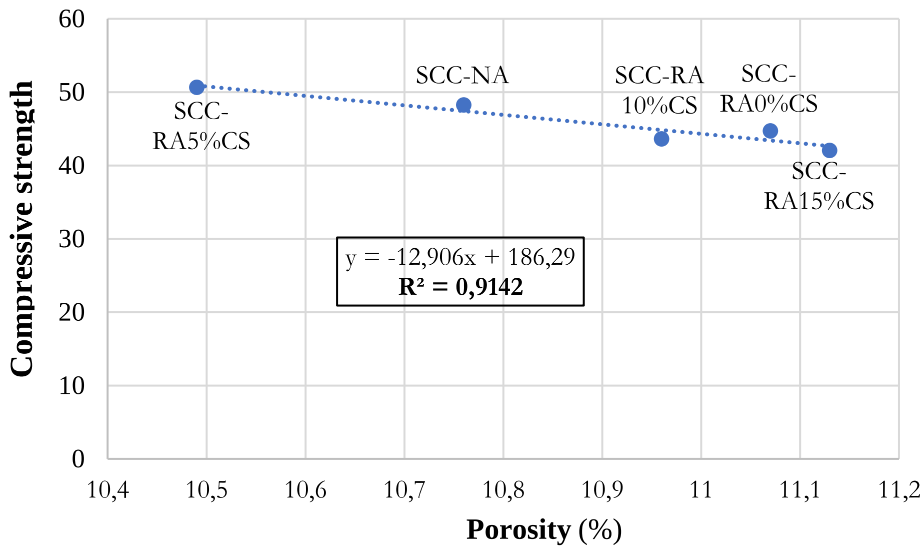


Figure 11– Relationship between the compressive strength and porosity.

4.2 Relationship between porosity and water absorption

Figure 12 shows a linear correlation between the porosity (%) and water absorption (kg/m^2) of the different concrete with a relatively high correlation coefficient R^2= 0.926. It shows that the porosity affects the water absorption.

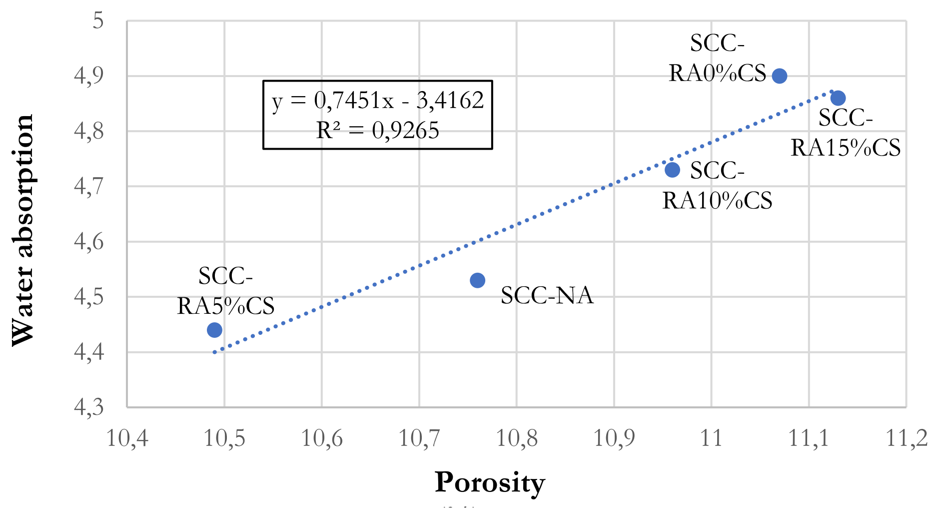


Figure 12– Relationship between the water absorption and porosity.

4.3 Evolution of physical and mechanical proprieties of different SCC

Figure 13 allows us more obviously to consider the evolution of the results on physical and mechanical behavior according to SCC-RA with different ratio of CS (0%, 5%, 10% and 15%), a relationship can be observed with these results. The compressive strength having an invertible with the porosity accessible to water and the capillary absorption. It can be deduced that concrete with high compressive strength has low porosity and capillary absorption.

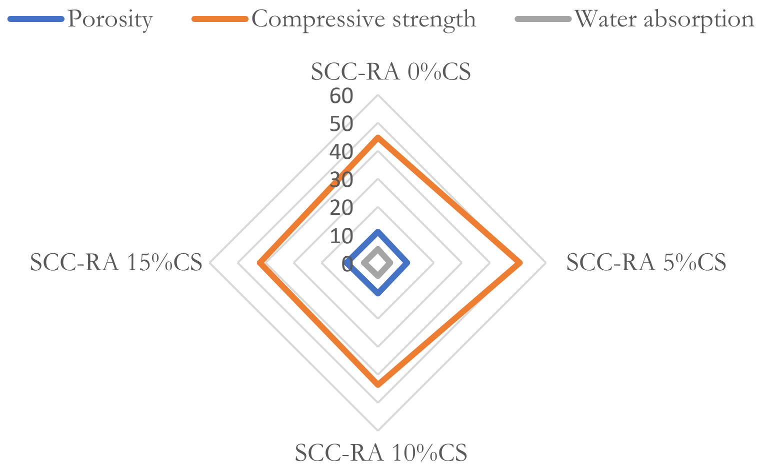


Figure 13– Effect of CS on physical and mechanical proprieties of SCC.

5 Conclusions

The experimental investigation produced the following conclusions:

- The addition of crushed dune sand up to a maximum of 15% enhances the rheological workability parameters of SCC containing 100% recycled coarse aggregate while remaining within the specified SCC range defined by AFGC.
- Substituting cement with crushed dune sand improves the compressive strength and flexural tensile strength of the self-compacting concrete containing 100% RCA. The optimum effect is observed at a 5% content of crushed dune sand, with a significant improvement up to a 10% content.
- The incorporation of crushed dune sand improves the physical properties of the concrete, specifically porosity and water absorption. The optimal effect is achieved at a 5% content of crushed dune sand, with improvements observed up to a 10% content.
- The improvement in porosity positively affects both compressive strength and water absorption properties of the concrete.

In conclusion, it is feasible to produce new concrete using 100% recycled coarse concrete aggregate, incorporating partial replacements of cement with crushed dune sand. This approach offers economic and environmental benefits.

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