



Mechanical Properties of Self-compacting Concrete Containing Fine Aggregates from Cement Kiln Dust and Hardened Cement Waste

Leila Kherraf^{1*}, Karim Younes¹, Assia Abdelouahed¹, Mouloud Belachia¹, Houria Hebhou¹

¹ University of 20 August 1955, Skikda, Algeria,
Department of Civil Engineering
*e-mail: kherrafleila@yahoo.com

Abstract

The aim of this research is to assess the mechanical performance of self-compacting concrete containing different percentages of fine aggregates, produced from the wastes generated by the cement plant industry and construction sites. Eight mixes, incorporating cement kiln dust (CKD) and hardened cement waste with partial fine aggregate replacement of 5%, 10%, 15%, and 20%, were produced and compared with a control mix made with 100% of crushed sand. The workability properties (e.g., flowability, passing ability, and resistance to segregation) and mechanical properties (e.g., compressive, flexural, and splitting tensile strengths) of all mixes were evaluated. The results showed that concretes containing recycled fine aggregates proved to have the best mechanical properties, compared to one made with crushed calcareous sand. However, self-compacting concrete with high mechanical strength could be produced with up to 15% wt. CKD replacement and with 10% wt. hardened cement waste replacement.

Keywords: fine CKD aggregate, fine hardened cement aggregate, self-compacting concrete, mechanical performance

1 Introduction

Self-compacting concretes (SCCs) are very fluid, high-performance concretes, which are placed in the form and compacted under the sole effect of gravity [1]. These concretes are characterised by a formulation containing a high dosage of cement, a large number of fine minerals, a reduced volume of small gravel, rolled or crushed sand, a large dose of superplasticiser, and (sometimes) a viscosity agent. The exact dosages of the constituents depend on the method of formulation chosen [2]. The volume of sand is, generally, 40% of the mortar volume of the concrete [3], which allows it to improve the compactness of the granular skeleton, consequently reducing granular friction and playing a very important role in determining the properties of fresh and hardened SCCs. Crushed or rolled sands have been successfully used in the production of SCCs, crushed sand generally contains a very high content of fine particles, which is considered to be a second source of filler [4]. The angular

shape, the roughness, and the water absorption capacity of the grains promote good adhesion of the grains [5] since they make it possible to increase the paste-sand bonds and densify the layer of these bonds because of the chemical reaction between calcite crystals and cement, to form monocaboaluminate [6]. This reaction is limited to the surface of the aggregates due to the low mobility of the carbonate ions [7]. As a result, the mechanical characteristics of concrete are improved, namely the compressive and tensile strength [8]. The dune sand is fine siliceous sand, characterised by its fineness and a high water absorption capacity. The grain shapes are rounded and spherical, with a smooth surface and almost uniform grain size. Dune sand decreases the fluidity but improves the viscosity of the SCC. Beyond a content of 30%, additional quantities of water and superplasticiser are necessary to satisfy the self-compacting properties [9].

Although it brings many advantages to the world of construction, such as saved time and labour, reduction of noise pollution during its installation, and, of course, very good results in terms of the aesthetic quality of facings, the use of this type of concrete is rapidly becoming popular in developed countries. However, its use is still limited in Algeria, mainly due to its high cost. To this end, we have considered the recovery of waste from the construction sector because it is available and less expensive as an aggregate, in the composition of this type of concrete. This could minimise manufacturing costs and provide interesting properties, perpetuating, and preserving natural resources within the framework of environmental sanitation and the living environment.

In this research, we examine the influence of two types of recycled sand on the rheological and mechanical properties of SCCs, namely: cement kiln dust (CKD) waste sand and hardened cement waste sand.

Cement kiln dust is an industrial by-product formed during the manufacture of cement and is a waste material that is traditionally destined for landfill [10]. This dust, whose composition varies from one clinker production line to another and even from one period to another (within the same line), includes clinker particles and particles resulting from the wearing of the refractory and/or monolithic brick lining of the furnace and associated equipment [11]. CKD has a chemical composition similar to that of conventional Portland cement [12]. Free lime can be found in CKD and its concentration is typically highest in the coarser particles collected closest to the kiln. Finer particles tend to exhibit higher concentrations of sulphates and alkalis [13]. Some of the generated CKD could be reused in a cement kiln as raw feed. However, this is limited by the alkali concentrations in CKD, which may cause the alkali content in cement to exceed the allowable limit [14]. The portion of CKD that is not returned to the cement industry is disposed of, which could pose significant problems. The main environmental problems of CKDs reside in the congestion caused by the increased number of heaps of CKD in the vicinity of cement plants and the pollution of groundwater and water runoff, caused by the leaching of toxic compounds and contamination by soluble substances, such as sulphates, carbonates, chlorides, alkalis, and metals. In addition, CKD affects human health by causing serious health hazards including asthma, skin irritation, and eye problems [15,16].

Current CKD recovery channels are raw feedstock, base stabiliser for pavements, a solidifier and stabiliser for contaminated wastes, and agricultural soil enhancement. It has been in the study phase in the field of construction for several years. The use of CKD as an addition to

Portland cement has been evaluated by a number of researchers. As an indication, Alnahhal et al. [17] investigated the effects of using nano-sized CKD as a partial replacement for Ordinary Portland Cement (OPC) on the strength of cement mortars. A total of 28 concrete mortar mixtures were prepared with four different replacement percentages of nano-CKD (5, 10, 15, and 20%), and seven different milling times. The compressive strengths of all cement mortar mixtures were evaluated after curing periods of 7, 28, and 56 days. The experimental results showed that the partial replacement of OPC with up to 20% nano-CKD resulted in an increase in the compressive strength of cement mortar by about 15 to 30%, compared with normal mortar without CKD. Saleh et al. (2020) [18] concluded that the use of CKD as waste material in concrete makes it economical and it is assumed that the reuse of this waste is the best ecological option to handle the waste disposal problem. At the same time, better performance of light concrete can be achieved in building material applications. Ibrahim Saad Agwa, 2019 [19] studied the potential of using CKD as a cement replacement in self-compacting concrete (SCC). Eight mixes incorporating CKD with a partial cement replacement of 0%, 5%, 10%, 20%, 30%, 40%, 50%, and 75%, in addition to a control mix, were investigated. It was found that the SCC mixture incorporating 5 to 10% CKD was almost similar to that of the control mixture. The workability of SCC concrete decreased as CKD replacement increased. This established the benefits of substituting cement with CKD to make SCC. Khalid B. Najim (2016) [20] investigated the use of CKD as a cement replacement material in producing high-performance/self-compacting concrete. Different percentages of replacement by cement weight were tried, including 10%, 20%, and 30%, whilst keeping other constituent contents constant. The results showed that there was a progressive decrease in flowability and mechanical strength properties with increasing CKD replacement. However, high-strength, self-compacting concrete could be produced with up to 20% wt. CKD replacement, while high-performance/self-compacting concrete was obtained with 30% wt. CKD replacement.

Hardened cement is cementitious waste produced accidentally or through negligence, following the crystallisation of the powder in the event that a bag of cement is in contact with water or a humid environment and becomes unusable on site. Its recovery must be immediate, in order to avoid any kind of possible environmental pollution. The literature review showed that there are no studies concerned with the recovery of this category of waste.

The main objective of this study is to find a substitute for natural aggregate through the incorporation of waste from the cement industry, such as recycled sand, in self-compacting concrete (SCC), illustrating its potential in order to promote the popularisation of its use as a building material in the civil engineering sector.

2 Experimental Program

2.1 Used Materials

- A Portland cement composed of the CEM II/B-L 42.5N type was used, with an absolute density of 3.06 g/cm^3 and the specific surface area of $3190 \text{ cm}^2/\text{g}$.
- The limestone filler (LF) used was prepared by sieving powder recovered from the Ben Azzouz crushing quarry (Skikda-East of Algeria) with an $80 \mu\text{m}$ sieve; the absolute

density was 2.7 g/cm³ and specific surface area was 3200 cm²/gr. The chemical properties of the cement and limestone filler are shown in Table 1.

- Two classes of gravel (G 4/8 and G 8/16) were used during this study, comprising crushed limestone from the ENOF – LAGHEDIR quarry (Skikda-East of Algeria).
- Three types of sand were used as fine aggregates: class 0/4 quarry sand (Q-S) from the ENOF – Laghedir quarry (Skikda-East of Algeria); fine sand from cement kiln dust waste (CKD-S) of class 0/1, from industrial residues recovered by electrostatic filters during the manufacture of clinker at the Hadjar-Soud cement plant in Azzaba (located in Skikda); and fine hardened cement waste sand (HC-S) of class 0/1, recovered from construction sites and obtained after crushing and sieving the rejected hardened cement blocks. The chemical and physical properties of various types of sand and gravel are grouped in Tables 1 and 2, respectively, and their particle size distributions are shown later, in Figure 2.
- A high water-reducing Sikaviscocrete tempo 12 superplasticiser (SP) was used. Its density was 1.06±0.01, its pH was 4.5 and its solid particle concentration was 29%±1.5.
- Tap water (T = 28°C) for mixing.

2.2 Characterization of Materials

2.2.1 Chemical Characteristics

The chemical composition of the cement and the sands were determined by X-ray fluorescence spectroscopy (XRF), according to NF EN ISO 12677:2004. The analysis technique is made from a sample in powder form. The material sample is dried at 105°C at a constant weight and finely ground mechanically. The resulting powder is put in a specific pellet, well compressed, and the surface upper is well smoothed.

Table 1: Chemical composition of cement, limestone filler and sands used

Oxides (%)	CEM II	LF	HC-S	CKD-S	Q-S
CaO	64.02	55.7	63.97	65.04	51.56
Al ₂ O ₃	5.12	0.3	5.43	6.44	0.59
Fe ₂ O ₃	3.3	0.16	3.95	4.24	0.75
SiO ₂	22.05	0.57	21.88	22.43	2.62
MgO	1.25	0.37	1.66	1.2	1.52
Na ₂ O	0.12	0.07	0.08	0.28	0.04
K ₂ O	0.52	0.03	0.53	0.99	0.13
Cl ⁻	0.005	0	0.013	0.016	0
SO ₃	1.84	0.01	2.15	0.27	0.3

According to the results illustrated in Table 1, it can be seen that the nature of the sands used is essentially calcareous.

2.2.2 Physical Characteristics

The physical characteristics were determined in accordance with the standards and test results and are presented in Table 2.

Table 2: Physical characteristics of sands and aggregates

Characteristic	HC-S	CKD-S	Q-S	G 3/8	G 8/16	Standards
Bulk density (g/cm ³)	1.50	1.58	1.456	1.53	1.44	NF EN 1097-3
Particle density (g/cm ³)	2.70	2.72	2.683	2.71	2.75	NF EN 1097-6
Sand equivalent (%)	73	83	88	--	--	NF EN 933-8
Water absorption (%)	1.73	1.44	0.783	1.18	0.61	NF EN 1097-6
Fineness modulus	1.70	1.76	2.78	--	--	NF EN 933-1
Fines content (%)	2	1	10.68	--	--	NF EN 933-1
Los Angeles testing (%)	--	--	--	--	24	NF P 18 - 573

It should be noted that:

- The two types of sand HC-S and CKD-S have a similar bulk density. The small difference (about 5%) is attributed to the shape of the sand grains. In addition, Q-S has a value that deviates by 3%, compared to HC-S sand, and 8.5%, compared to CKD-S sand. The angular shape of Q-S sand increases the space between its grains and, therefore, the value of the apparent density decreases.
- The HC-S sand had adequate cleanliness, between 70% and 80%. This indicates that the sand is clean, with a low percentage of clay fines, and perfectly suitable for high-quality concrete. Furthermore, the other two types of sand have cleanliness values greater than 80%, which means that the CKD-S and Q-S sands are very clean.
- CKD-S and HC-S sands are fine sands while Q-S sand is medium and well-spread sand.
- The water absorption capacity A_b (%) of HC-S sand is the highest and is followed by that of CKD-S sand.
- Unlike CKD-S and HC-S sands, Q-S sand contains a large volume of fines <63 μm .

2.2.3 Particle Size Analyses

Granulometric analysis of the sands and aggregates used was carried out according to the Standard NF EN 933-1:2012, as shown in Figure 1.

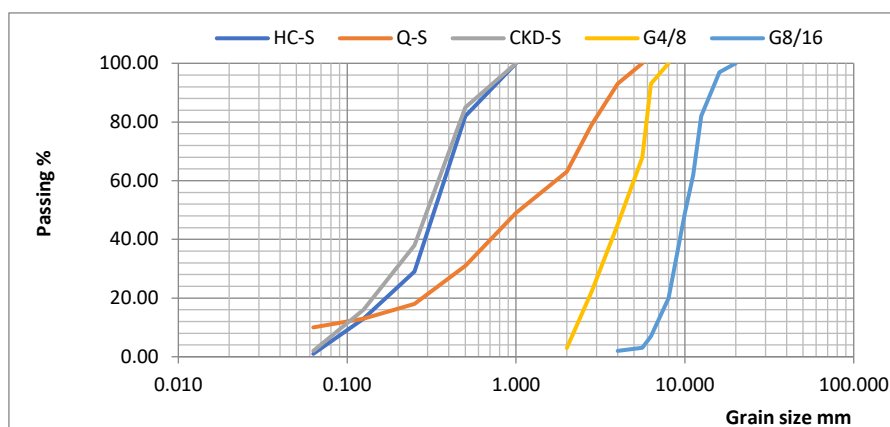


Figure 1: Particle size distribution curves for the sands used

It is noted that the grain size curves of all sands are continuous and relatively comparable for both HC-S and CKD-S sands.

2.2.4 Mixtures and Methods

To achieve the objectives of this study and the required composition of the self-compacting concrete, the quarry sand was successively substituted by a mass fraction of sand from hardened cement waste and CKD sand at rates of 0%, 5%, 10%, 15%, and 20%. The behaviour of the concretes produced in the fresh state, as well as in the hardened state, were evaluated and compared with those of a control concrete, initially composed of 100% crushed sand. The formulation method adopted in the case of this study is an empirical method based on the experience acquired in recent years [21,22]. The proportions of the constituents were determined by trial and error around certain orders of magnitude.

For a rather high cement dosage (the mass of the cement is greater than or equal to the minimum required by the ready-mixed concrete standard (P18 305), i.e., generally 300 to 350 kg/m³), the percentage of additional materials was determined experimentally (superplasticiser, limestone filler). The volume of occluded air was around 2%, and the volume of paste for one cubic meter of concrete was equal to the sum of the volume of cement, superplasticiser, limestone filler, entrained air, and sand, i.e., between 330 and 400 l/m³, and a volume ratio of gravel/sand close to 1.

In fact, the constant parameters for all SCC are cement C = 420 kg/m³, water/binder ratio W/B = 0.37, fillers FC = 74.11 kg/m³, water E = 182.82 l, the superplasticiser SP = 1% (i.e., 4.20 kg/m³), the volume of paste = 370 L/m³, and the gravel/sand volume ratio G/S = 0.9. The only variant was the nature of the sand. The prepared compositions are shown in Table 3 and the notations used are as displayed in Table 4.

Table 3: Compositions of concretes formulated with recycled sand

Concrete	C (kg/m ³)	FC (kg/m ³)	E (l)	S 0/4 (kg/m ³)	HC-S 0/1(kg/m ³)	CKD -S 0/1(kg/m ³)	G4/8 (kg/m ³)	G8/16 (kg/m ³)	Adj (kg/m ³)
SCC1	420	74.11	182.82	878.68	--	--	404.35	410.32	4.20
SCC2	420	74.11	182.82	834.75	43.93	--	404.35	410.32	4.20
SCC3	420	74.11	182.82	790.81	87.87	--	404.35	410.32	4.20
SCC4	420	74.11	182.82	746.88	131.8	--	404.35	410.32	4.20

SCC5	420	74.11	182.82	702.94	175.73	--	404.35	410.32	4.20
SCC6	420	74.11	182.82	834.75	--	43.93	404.35	410.32	4.20
SCC 7	420	74.11	182.82	790.81	--	87.87	404.35	410.32	4.20
SCC 8	420	74.11	182.82	746.88	--	131.8	404.35	410.32	4.20
SCC 9	420	74.11	182.82	702.94	--	175.73	404.35	410.32	4.20

Table 4: Compositions

SCC1: Concrete made with 100% quarry sand							
SCC2	Concrete made with 5% HC-S and 95% Q-S			SCC6	Concrete made with 5% CKD-S and 95% Q-S		
SCC3	Concrete made with 10% HC-S and 90% Q-S			SCC7	Concrete made with 10% CKD-S and 90% Q-S		
SCC4	Concrete made with 15% HC-S and 85% Q-S			SCC8	Concrete made with 15% CKD-S and 85% Q-S		
SCC5	Concrete made with 20% HC-S and 80% Q-S			SCC9	Concrete made with 20% CKD-S and 80% Q-S		

An electric cement mixer, with an inclined axis and a capacity of 60 l, was used to make the concretes for the study. All of the materials were mixed, in order to homogenise them, and the total mixing time was 5 minutes, including 2 minutes of dry mixing. At the end of mixing, the concrete was emptied from the mixer into a tank, in order to examine the characteristics of the SCCs in the fresh state, it was then poured into the cubic moulds $15 \times 15 \times 15$ cm, and the $7 \times 7 \times 28$ cm moulds. Unmoulding took place after 24 hours. The test specimens were then kept in water, at an average temperature of $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$ until the end of the test, in accordance with standard NF EN 12390-2: 2012.

3 Results and Discussion

3.1 Characterization Tests of Self-compacting Concrete in the Fresh State

Before defining a composition as being that of self-compacting concrete, it must be ensured that the properties of the concrete in the fresh state comply with certain criteria established by the recommendations of the AFGC (French Association of Civil Engineering).

3.1.1 Slump-Flow Test

The slump flow test was operated according to EN 12350: Part 8-2010 and used to measure the flowability of fresh SCC. Figure 2 shows the results obtained.

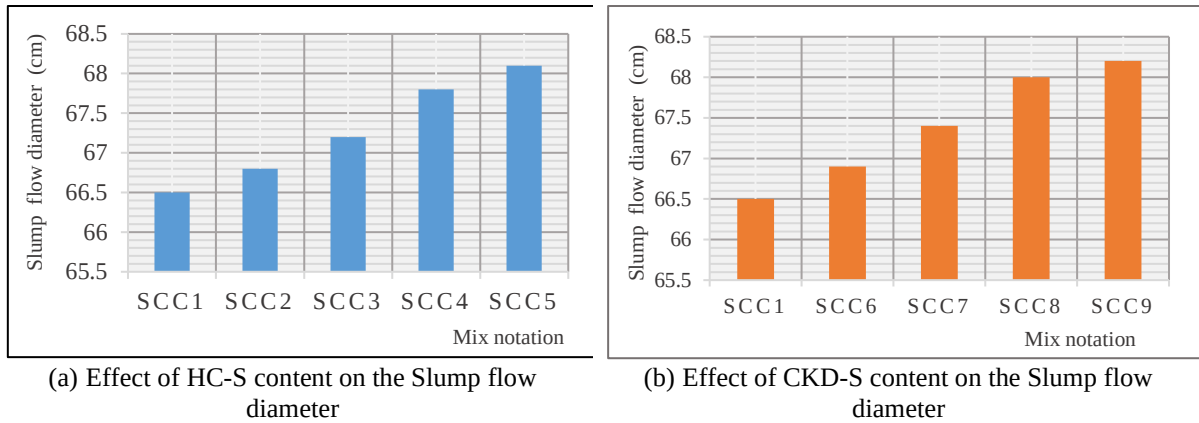


Figure 2: Slump flow diameter of the SCC mixes

Figure 2 shows that the flowability of SCCs, based on hardened cement waste sand or CKD, falls within the range of the SF2 class (660 to 750 mm) defined by the AFGC recommendations [22]. In fact, by increasing the substitution rate of ordinary sand with hardened cement waste sand or CKD sand in the mixtures, the flowability improves remarkably and continuously. However, the values exhibited by CKD-based SCCs are relatively higher than those shown by cement waste sand-based concretes. The maximum slump flow diameter is given by SCC9. It exceeds that of the control by 2.55% and that of SCC5 by 0.14%. All these flowability variations are related to:

- * The use of hardened cement waste sand and CKD sand increased the volume of the paste due to the introduction of a significant number of fine grains which fill the voids available between the aggregates and, as a consequence, the amount of water that occupied the voids is released into the interstitial solution, resulting in better fluidity.

- * The dispersion effect exerted by the superplasticiser used where the molecules of the latter are adsorbed on the surface of the grains of cement, limestone filler, CKD sand and hardened cement sand, causing a kind of coating while preventing water from attaching itself directly to the walls of the grains [23], thus the lubrication of the mixture is all the more noticeable in the case of concrete containing CKD sand.

The difference in behaviour between SCCs with CKD and hardened cement sand depends on the fineness, the absorption ratio, and the compatibility of the superplasticiser with the ternary mixture of cement, limestone filler and fine particles of each of these recycled sands.

3.1.2 L-box Test

The passing ability (PA) of SCCs is characterised by the L-box test, according to EN 12350: Part 10-2010. The results of the variation of the H_2/H_1 ratio are shown in Figure 3. These results clearly show that all the formulations have PA higher than 0.80, which complies with the requirements of the AFGC recommendations.

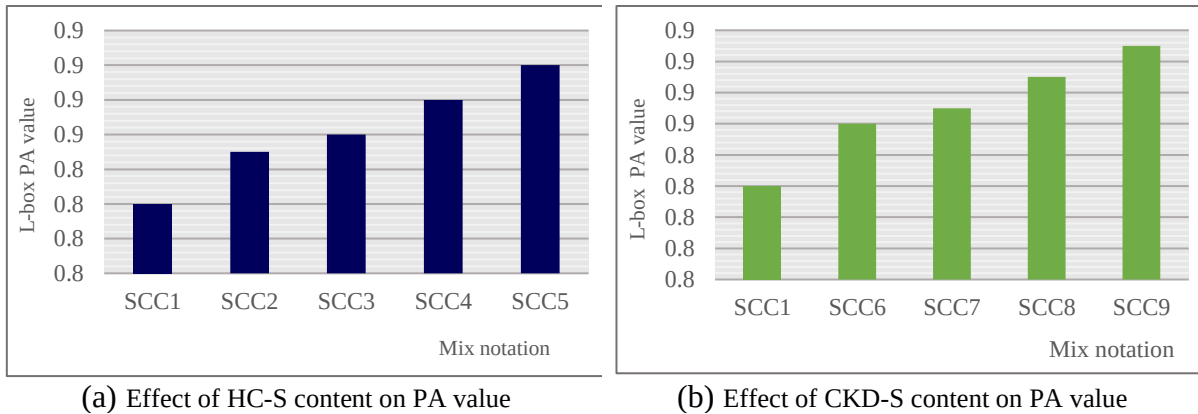


Figure 3: L-box PA values of the SCC mixes

Indeed, the incorporation of increasing rates of hardened cement waste sand and CKD sand in the reference formulation generates a progressive increase in the capacity of the concrete to flow in a confined space. However, compositions based on CKD-S are still the best. This can be attributed to the rounded shape and smooth surface of the grains of CKD sand or hardened cement as well as the presence of several grain sizes and the use of a superplasticiser, which improves the total arrangement of the components in the matrix; the flow of self-compacting concrete is improved by reducing friction between the aggregates.

3.1.3 Seive Segregative Test

Segregation can be defined as the separation of the constituents of a heterogeneous material so that their distribution is no longer uniform. The sieve stability results are presented in histograms in Figure 4. It should be noted that the segregation index is between 10.30% and 13.45%, which is synonymous with satisfactory stability, according to EN 12350-11:2010.

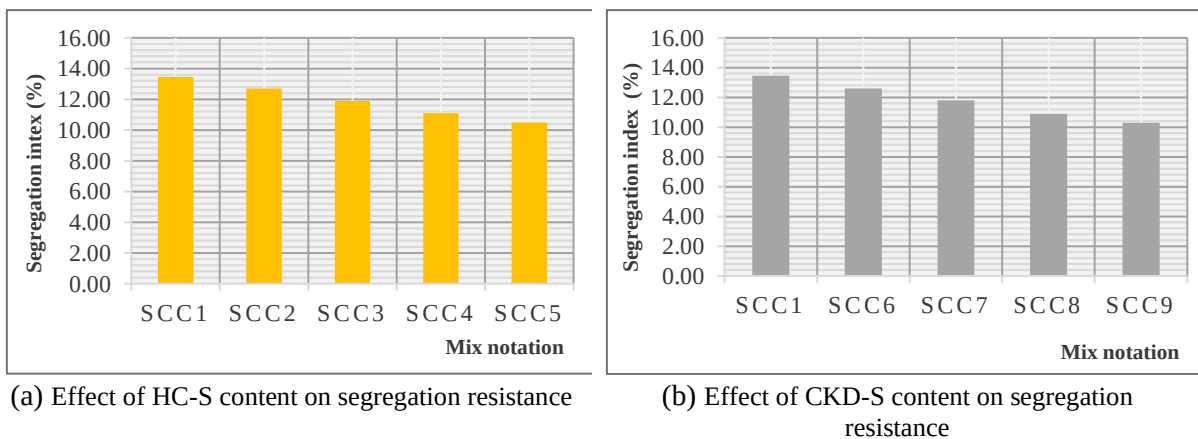


Figure 4: Segregation resistance of self-compacting concrete

The partial incorporation of recycled sand (whether hardened cement or CKD) improves resistance to static segregation and bleeding and there is a proportionality between the increase in the replacement percentage and the improvement of stability. This means that the stability

increases as a result of the increase in the concentration of the solid by volume because the two types of recycled sand are finer than the quarry sand and well deflocculated by the superplasticiser. The absence of bleeding in concretes based on recycled sands is justified by the presence of alkalis in the composition of CKD and hardened cement is higher than that present in quarry sand because, according to [24], there is less bleeding when the cement contains a high dose of alkali. The reference mixture has the highest amount of laitance (IS=13.45%) compared to the others, which indicates that this composition is of poor homogeneity due to the size of the quarry sand grains, which create more voids between the aggregates. Therefore, at different recycled sand contents, the rheological characteristics are satisfied and below the acceptable performance criteria for SCC.

3.2 Characterization Tests of Self-compacting Concrete in the Hardened State

3.2.1 Compressive Strength

To understand the influence of the fine aggregate replacement ratio on the compressive strength of concrete at 7, 28, and 90 days, the test results are shown in Figure 5. This strength represents the average of the resistances of a series of three cubic specimens of dimensions (15 x 15 x 15) cm³ subjected to crushing according to NF EN 12390-3: 2012.

It can be seen that the compressive strength of all the mixtures is developed at different testing durations. However, the values obtained by the mixtures containing the waste sand are clearly higher than the strength developed by the reference mixture. In fact, the variation in compressive strengths for each series of SCCs is a decreasing function of the replacement percentage of quarry sand by waste sand. As an indication, after seven days, the concrete containing 5% hardened cement waste sand (SSC2) achieves a strength value higher than that of the control concrete by 52%, whereas the composition containing 5% CKD waste (SSC6) illustrates a value superior to the reference value by 57.6%. Moreover, the values displayed by the SCCs containing 20% of HC-S (SSC5) or CKD-S (SSC9) are better than those of the control one by 41.82% and 46.44%, respectively.

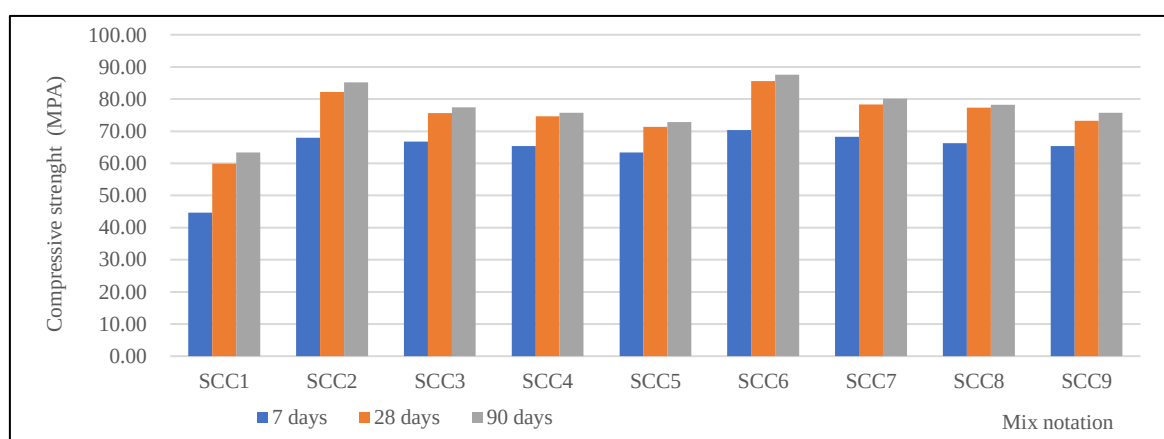


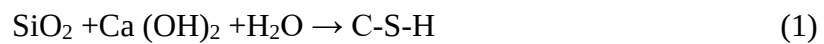
Figure 5: Compressive strength of SCC mixes with different sand content

After 28 days, the trends were almost similar to those on the seventh day. SCCs based on 5% waste sand are the most efficient and the increases in compressive strengths are about: 37.19%

(SSC2) and 42.85% (SSC6) compared to the control mix. Moreover, the concretes incorporating 20% recycled sands exhibit strength which increases by 19.04% (SSC5) and 22.16% (SSC9). In the long term, it should be noted that the improvement in the compressive strengths of the SCCs at 7 and 28 days is reproduced once again. The percentages of variation increase by 34% and 38% of the strength of the reference concrete in the (SSC2), (SSC5), and 14.85 and 19.4% in concretes (SSC6), (SSC9), respectively. The improvement in compressive strength in the case of concretes based on recycled sand is due to the effect of the following parameters:

- * Reduction of the W/C ratio, because the absorption capacity of CKD-S and HC-S is greater than that of quarry sand.

- * The presence of the superplasticiser promotes the hydration of the fine particles of CKD and, as a consequence, the formation of hydrates, which can be qualified as a hydraulic power at a young age [2]. After 90 days, a pozzolanic effect appeared according to the formula (1) [25]:



- * Nucleation sites formed by existing fines in hardened cement sand. The latter contains calcium silicate hydrates (CSH), calcium hydroxide (CH), and hydrated aluminates (CAH), which will accelerate the hydration reaction [26] and densify the microstructure of the long-term cementitious matrix [27].

- * Activation of fine hardened cement particles by the grinding process and by the superplasticifier.

- * The presence of fine particles not yet hydrated (anhydrous phases C_3S , C_2S , C_4AF) in the hardened cement sand contributes to increasing the strength, which results in a long-term pozzolanic effect [28].

- * A filling effect due to the fact that recycled sand is finer than crushed sand, which improves the compactness of the mixtures.

Indeed, the compressive strength of self-compacting concretes prepared with recycled sand depends on the origin of the recycled sand used, the replacement rate, its compatibility with the admixture, and its intrinsic characteristics.

3.2.2 Flexural Strength

The variation in flexural tensile strength of self-compacting concretes at curing times of 7, 28, and 90 days (depending on the type of sand) is shown in Figure 6. The result shown is the average of three measurements, taken from seven prismatic specimens (of dimensions $7 \times 7 \times 28$ cm) for each concrete. The test was performed according to NF EN 12390-6: 2012.

Figure 6 shows that the partial incorporation of hardened cement waste sand or CKD sand into the control concrete leads to an improvement in the flexural strength (after seven days) of the mixtures: SSC2; (SSC3), and SSC6, with a gain of 35.44%, 16.4%, and 10% successively. On the other hand, at 28 days, the mixtures containing up to 15% of waste sand, display an increase in strength in comparison with the control. For example, these improvements have a value of 43.00%, 8.11%, 38.00%, and 1.26% in the four self-compacting concretes SSC2, SSC4; SSC6, and SSC8, respectively.

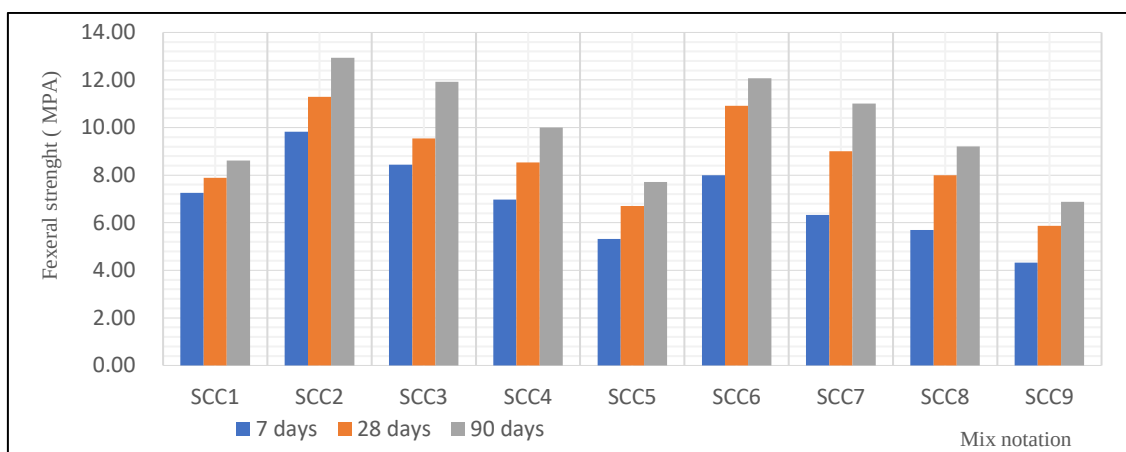


Figure 6: Flexural tensile strength of SCC mixes with different sand content

After 90 days, the best flexural strength is achieved by the self-compacting concrete SCC2, exceeding the reference concrete value by 50%. Furthermore, the SCC5 illustrates a flexural strength gain higher by 40% than the value of the control concrete. In addition, it is clear that the incorporation of up to 15% of recycled sands seems beneficial for the improvement of flexural strength. The cause of this result is that the interfacial transition zone between the grain of hardened cement or CKD-paste is more compact and less porous than that of ordinary sand-paste, due to the existence of more or less reactive fines in the composition of the recycled sand [29].

3.2.3 Split Tensile Strength

The tensile strength is estimated by splitting the $15 \times 15 \times 15$ cm cubic specimens according to NF EN12390-6: 2014. The results obtained are shown in the Figure 7 below.

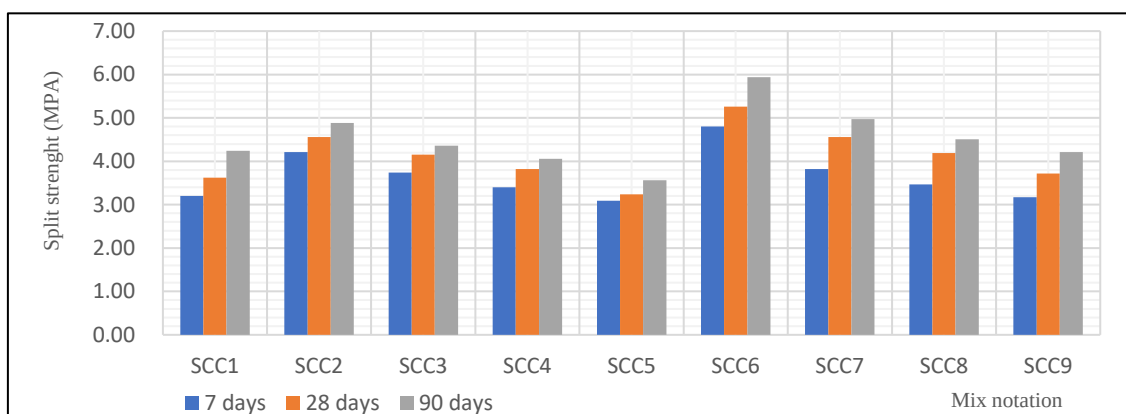


Figure 7: Split tensile strength of SCC mixes with different sand content

By analysing the results illustrated in Figure 7, it can be seen that after seven days, the increase in the amount of CKD sand in the control self-compacting concrete leads to an improvement in the splitting strength of the mixtures incorporating up to 15% waste sand. The rates of increase are around 50.0% (SCC6), 22.5% (SCC7), and 8.4% (SCC8). On the other hand, the incorporation of hardened cement waste sand generates a less significant improvement. The

percentage gains are about 31.56%, 16.87%, and 6.25% for the mixtures SCC1, SCC2, and SCC3, compared to the control concrete.

At 28 days of age, mixtures containing CKD sand remain the most efficient. They illustrate better splitting tensile strengths than those presented by the SCCs, based on hardened cement waste sand and the control mixture. The improvement rates are 25.96% (SCC1); 14.64% (SCC2); 5.52% (SCC3); 45.00% (SCC5); 25.96% (SCC6); 15.74% (SCC7) and 2.76% (SCC9). On the other hand, it should be noted that, after 90 days, the SCCs containing up to 15% CKD sand are still the best, compared to the other mixtures tested. The growth values of these strengths range from 6.3% (SCC7) to 40% (SCC5). However, the two concretes SCC2 and SCC3 display higher strengths than that of the control concrete by 15% and 2.8%, respectively. For some authors, the tensile strength by splitting is conditioned by the adhesion between the aggregates and the cementitious matrix and, generally, the shape of the aggregates is the one that exerts the most influence on the latter. To this end, the weakness of the splitting strengths of SCCs based on cement waste sand, compared to those of SCCs incorporating CKD sand, results from the fact that the grains of the cement waste sand have a smoother surface than those of CKD sand.

4 Conclusion

This research investigates the use of cement kiln dust and hardened cement waste in the production of self-compacting concrete. The properties of fresh and hardened concrete, with different CKD contents, were compared and the following conclusions were obtained:

- All of the concrete met the recommendations of the AFGC.
- Increasing the dosage of recycled sand by up to 20% (substituting quarry sand) positively influences the rheological properties of SCC.
- The introduction of up to 20% hardened cement waste sand or CKD in the control mixture leads to an improvement in the compressive strength at all ages. Nevertheless, the values illustrated by the mixtures based on CKD sand are better than those achieved by the self-compacting concrete containing cement waste sand. 5% CKD-S concrete performed best in both series.
- The flexural tensile strength of self-compacting concretes based on hardened cement waste sand is always better than that of the control and those of concretes based on CKD sand. However, SCCs containing up to 15% recycled sands show acceptable strength.
- The incorporation of CKD sand (up to a rate of 15%) considerably improves the splitting tensile strength of self-compacting concretes. In addition, the rate of 10% hardened cement sand is the optimum for SCCs based on this waste.

Given the results obtained, it can be argued that the use of sands from cement waste in the manufacture of self-compacting concretes can constitute an important economic and technical alternative in certain applications.

References

- [1] Aldikheeli, M., Salih, S., & Al-Zwainy, F. (2018). Physical and mechanical characteristics of sustainable self-consolidating concrete incorporating high volume fly ash and cement kiln dust. *In MATEC Web of Conferences*. 162, 20-25). <https://doi.org/10.1051/matecconf/201816202025>
- [2] Brouwers, H.J.H., Radix, H.J. (2007). Self-compacting concrete: Theoretical and experimental study. *Cem. Concr. Res.* 29, 1–12. doi:10.1016/j.cemconres.2005.06.002.
- [3] Bonen, D., Shah, S.P. (2005). Fresh and hardened properties of self-consolidating concrete, *Prog. Struct. Eng. Mater.* 7 14–26. doi:10.1002/pse.186
- [4] Benabed, B., Kadri, E.H., Azzouz, L., Kenai, S. (2012). Properties of self-compacting mortar made with various types of sand. *Cem. Concr. Compos.* 34, 1167–1173. doi:10.1016/j.cemconcomp.2012.07.007
- [5] De Larrard, F., Belloc, A. (1999). The influence of aggregate on the compressive strength of concretes, *Bull Liaison Des Lab. Des Ponts Chaussées*. 219, 41–52.
- [6] Ramezaniapour, A.A., Esmaili, M., Ghahari, S.A., Najafi, M.H. (2013). Laboratory study on the effect of polypropylene fiber on durability, and physical and mechanical characteristic of concrete for application in sleepers. *Constr. Build. Mater.* 44, 411–418. doi:10.1016/j.conbuildmat.2013.02.076.
- [7] Monteiro, P.J.M., Mehta, P.K., Skalny, C.J.P. (1986). Interaction between carbonate rock and cement paste. *Cem. Concr. Compos.* 16, 127–134. [https://doi.org/10.1016/0008-8846\(86\)90128-6](https://doi.org/10.1016/0008-8846(86)90128-6)
- [8] Lecomte, A., De Larrard, F., Mechling, J.M. (2001). Compressive strength of hydraulic concretes to the unoptimised granular skeleton. Bulletin LPC n° 234, 89-105.
- [9] Rmili, A., Ben Oueddou, M. (2012). Valorization of the crushed sand and of the desert sand in the composition of the self compacting concrete. *MATEC Web of Conferences*. 2, 1- 9. published by EDP Sciences.
- [10] Elbaz, A. A., Aboulfotoh, A. M., Dohdoh, A. M., & Wahba, A. M. (2019). Review of beneficial uses of cement kiln dust (CKD), fly ash (FA) and their mixture. *J. Mater. Environ. Sci.* 10(11), 1062-1073.
- [11] Sreekrishnavilasam, A., Rahardja, S., Kmetz, R., Santagata, M. (2007). Soil treatment using fresh and landfilled cement kiln dust. *Constr. Build. Mater.* 21, 318–327. <https://doi.org/10.1016/j.conbuildmat.2005.08.015>
- [12] Lubna, A. Kh., Salem Al-Mansour. (2012). Stabilization of Dune Sand by Using Cement Kiln Dust (CKD) University College Article.
- [13] Siddique, R. (2006). Utilization of cement kiln dust (CKD) in cement mortar and concrete—an overview. *Resources, Conservation and Recycling*. 48, 315–338. <https://doi.org/10.1016/j.resconrec.2006.03.010>
- [14] Maslehuddin, M., Al-Amoudi, O.S.B., Rahman, M.K., Ali, M.R., Barry, M.S. (2009). Properties of cement kiln dust concrete. *Constr. Build. Mater.* 23, 2357–2361. <https://doi.org/10.1016/j.conbuildmat.2008.11.002>
- [15] Sadek, D. M., El-Attar, M. M., & Ali, A. M. (2017). Physico-mechanical and durability characteristics of concrete paving blocks incorporating cement kiln dust. *Construction and Building Materials*. 157, 300-312. <https://doi.org/10.1016/j.conbuildmat.2017.09.107>

- [16] Yaseri, S., Verki, V.M.& Mahdikhani, M. (2019). Utilization of high volume cement kiln dust and rice husk ash in the production of sustainable geopolymer. *J. Clean. Prod.* 230, 592-602. <https://doi.org/10.1016/j.jclepro.2019.05.056>.
- [17] Alnahhal, W., Taha, R., Al-Nasseri, H., & Nishad, S. (2018). Effect of using Cement Kiln Dust as a nano-material on the strength of cement mortars. *KSCE Journal of Civil Engineering*. 22(4), 1361-1368.
- [18] Saleh, H. M., Salman, A. A., Faheim, A. A., & El-Sayed, A. M. (2020). Sustainable composite of improved lightweight concrete from cement kiln dust with grated poly (styrene). *Journal of Cleaner Production*. 277, 123491.<https://doi.org/10.1016/j.jclepro.2020.123491>
- [19] Agwa, I. S., & Ibrahim, O. M. O. (2019). Fresh and hardened properties of self-compacting concrete containing cement kiln dust. *Challenge Journal of Concrete Research Letters*, 5(1), 13-19. <https://doi.org/10.20528/cjcr.2019.01.003>
- [20] Najim, K. B., Al-Jumaily, I., & Atea, A. M. (2016). Characterization of sustainable high performance/self-compacting concrete produced using CKD as a cement replacement material. *Construction and Building Materials*. 103, 123-129. <https://doi.org/10.1016/j.conbuildmat.2015.11.037>
- [21] Okamura, H., & Ouchi, M. (2003). Self-compacting concrete. *Journal of advanced concrete technology*,1(1), 5-15. <https://doi.org/10.3151/jact.1.5>
- [22] AFGC, 08 : Recommandations pour l'emploi des bétons autoplacants, 2008.
- [23] Flatt, R. J., & Houst, Y. F. (2001). A simplified view on chemical effects perturbing the action of superplasticizers. *Cement and concrete research*. 31(8), 1169-1176. [https://doi.org/10.1016/S0008-8846\(01\)00534-8](https://doi.org/10.1016/S0008-8846(01)00534-8)
- [24] A. Ville, « Propriétés des bétons ». Sherbrooke, Canada, éd. Paris,Eyrolles, 2000.
- [25] R.Bucher, T.Vidal, A. Sellier, and J. Verdier. (2017). Effect of drying on the mechanical properties of cementitious materials, 23rd French Congress of Mechanics, S27- Coupling Sustainability - Mechanical Behavior in Civil Engineering Structures, August 28 - September 1, Lille, France. <http://hdl.handle.net/2042/63477>
- [26] A.M. Soliman, M. L. Nehdi. (2011). Self-Accelerated Reactive Powder Concrete Using Partially Hydrated Cementitious Materials. *ACI Mater Journal*. 108, 596–604.
- [27] Y.Wang, W. Wang, X. Guan. (2011). Physical Filling Effects of Limestone Powders with Different Particle Size. *Advanced Materials Research Journal*. 163-167, 1419–1424. <https://doi.org/10.4028/www.scientific.net/AMR.163-167.1419>
- [28] J. M. Khatib. (2005). Properties of concrete incorporating fine recycled aggregate. *Cem. Concr. Res.* 35(4), 763–769. <https://doi.org/10.1016/j.cemconres.2004.06.017>
- [29] G. Konig, K. Holschemcher, F. Dehn, & D. Weiße. (2001). Self-compacting concrete time development of material properties and bond behaviour. Proceeding of 2nd International RILEM Symposium on Self-Compacting Concrete (Pro 33), Tokio, Japan :507–516.