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Reuse of local sand: effect of limestone filler proportion on the rheological and mechanical properties of different sand concretes

M. Bédérina[a], M.M. Khenfer[b], R.M. Dheilly[c], M. Quéneudec[c,*]

[a]Laboratoire de Génie Civil, Université A. Tledji de Laghouat, Algeria

[b]Laboratoire de Génie Civil, Université de Ouargla, Algeria

[c]Laboratoire des Transferts et Réactivité dans les Milieux Condensés, Département de Génie Civil, Avenue des Facultés, Université de Picardie Jules Verne, I.U.T d'Amiens, 80025 Amiens Cedex 1, France

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Abstract

This work aims at the promotion of local sand reuse. Two main objectives are present in this research work: (1) to study the possibility of exploiting local sand available in large quantities in a sand concrete and (2) to partially find a solution to substitute scarce coarse aggregate in concrete. Fillers, which derive from calcareous wastes, are utilized to correct the particle size distribution of sands. For this investigation, three distinct sands have been used: a dune sand (DS), a river sand (RS), and a mixture of dune and river sand in predetermined proportions. After characterizing the materials used, the mixture design of the three corresponding sand concretes has been optimized on the basis of compactness and workability criteria. The influence of filler limestone has, in particular, been examined. A microstructural investigation has provided a better analysis of the mechanical behavior of the derived materials.

This study shows the importance of both filler concentration and sand particle size distribution. Using a mixture of dune and river sands in predetermined proportions, in association with limestone filler, allows to obtain a more workable, more compact, and more resistant sand concrete.

Keywords: Microstructure; SEM; Workability; Mechanical properties; Sand concrete

1. Introduction

Most countries have, for many years, been pursuing policies aimed at optimizing the use of local materials. Sand concrete is often included among such materials. Due to the progressive depletion of coarse aggregate deposits in certain regions, there is some interest for such material. The high cost of transportation and ecological problems created by the extraction of river aggregates are other favorable factors. In France, the national "SABLOCRETE" project has allowed establishing sand–concrete mixture proportioning and utilization laws [1]. The specificity of sand concrete has been defined in the Standard NF P 18500 adopted in 1995 [2].

In Algeria, the housing shortage, coupled with the lack of coarse aggregates in certain regions, has made it mandatory to reuse local materials. At present, local sands, which are only slightly or not at all extracted, constitute sizable deposits, and their application as construction materials would respond to the ecological and economic considerations raised by current trends. Projects along these lines were initiated during the 1980s [3]; yet, results tend to remain insufficient and have not allowed for the industrial development of local sand concrete.

The work presented herein represents a logical extension to the work carried out previously. Sands of various morphologies and origins have been used in the production of sand concrete. This study concerns the influence of an

* Corresponding author. Tel.: +33 3 22 53 40 16; fax: +33 3 22 53 40 96.

E-mail address: Michele.Tkint@iut.u-picardie.fr (M. Quéneudec).

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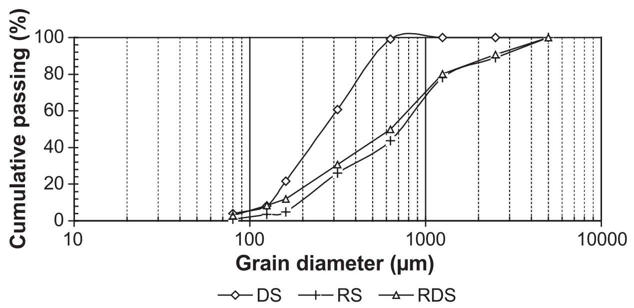

Fig. 1. Granular curve of the different sands.

additional limestone filler on the quality criteria of workability, compactness, and concrete strength.

2. Characterization of the materials used

Sand concrete is a fine concrete consisting of a mixture of sand, cement, additives, and water. Besides these basic components, sand concrete typically includes one or more admixtures.

The incorporation of fine gravel (d/D) authorizes the use of the name sand concrete as long as the mass ratio G/S remains below 0.7 (with G=gravel, S=sand). This material is to be distinguished from a conventional concrete by its high proportion of sand, the absence or small proportion of fine gravel and the incorporation of additive(s). It is also distinguished from a mortar by its composition (mortar generally contains high concentration of cement) and especially by its destination, as sand concretes are primarily intended for more traditional uses [1].

The various components introduced during this work will be characterized hereafter.

2.1. Sands

For the purpose of this study, three different sands have been used.

The first one is a dune sand (DS) extracted from Algeria's northern region, near the city of Laghouat, and featuring a maximum grain diameter of approximately 0.630 mm; the proportion of grains smaller than 0.08 mm is below 5%.

A river sand (RS), from the oued M'zi (another region around Laghouat), presents continuous particle size distribution ranging from 0.08 to 5 mm; but the fraction smaller than 0.16 mm remains very small.

A river-dune sand (RDS), which represents a mixture of these two sands, displays a ratio RS′/DS′ equal to 1.7 (by mass):

- DS′ is composed of dune sand elements whose diameter remains smaller than or equal to 0.4 mm.
- RS′ is composed of river sand elements with a diameter greater than 0.4 mm.

The particle size distributions of the various sands used are shown in Fig. 1. In a schematic manner, the preceding observations can be summarized by noting that dune sand is finer than the river sand is. The particle size distribution of the river-dune sand, which constitutes a mixture in preestablished proportions, has been assessed within the spindle recommended for ordinary concrete in the aim of controlling both the water content during mixing and workability.

Table 1 lists the set of physical characteristics for the three types of sand. The modulus of fineness is defined as the sum of the cumulative percentages retained on the sieves of the standard series presented in relation (1) and defined by NF P 18-541 Standard. In the case of the sands used herein, relation 1 was employed.

$$\Sigma \text{ cumulative refusal on the sieve: } 0.16,\ 0.315,\ 0.63,\ 1.25,\ 2.5,\ 5 \text{ mm } (\%) \quad (1)$$

The modulus of fineness of an aggregate allows for the total representation of particle size distribution by means of a numerical index.

The compactness is obtained using relation 2.

$$C = \rho_{\text{apparent}}/\rho_{\text{absolute}} \quad \text{with } \rho : \text{bulk density} \quad (2)$$

Table 1 reveals that RDS is the most dense and compact sand. Its modulus of fineness is 2.28. The DS sand is the least dense and compact and finest. The fineness modulus of this sand is 1.18. The river sand exhibits relatively average properties. The high values of the sand equivalent, which is measured according the NP 18 598 Standard, show that the studied sands are clean. Let us recall that the sand equivalent makes it possible to control for the cleanliness of sand, i.e., the percentage of elements less than 0.5 mm. To perform this step, the tested sand is placed to soak in a solution, thereby making it possible to flocculate fine particles. The sand equivalent is measured using the height of deposited flocculate. Table 1 also shows that all sands used are clean. The maximum content of fines in the most efficient sands is lower than 12%.

Table 1
Physical properties of the various sands used

Sand	Apparent density (kg/m^3)	Specific density (kg/m^3)	Fineness modulus	Compactness (C_P)	Sand equivalent
DS	1428	2596	1.18	55	86
RS	1482	2576	2.45	57	88
RDS	1511	2583	2.28	58	87

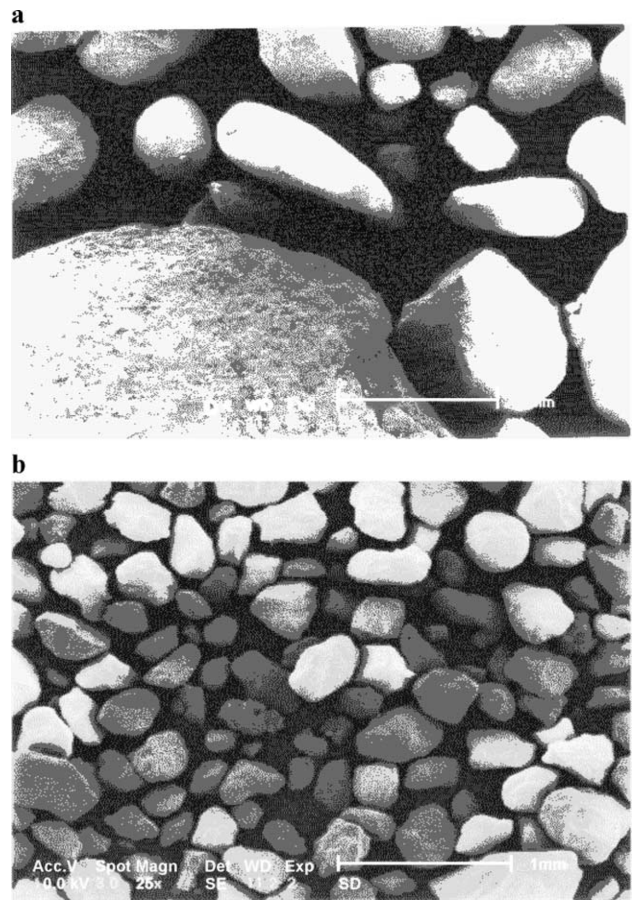

Fig. 2. Scanning electron micrographs of river (a) and dune (b) sands, G=20.

The EDX analysis of both river and dune sands demonstrates their essentially siliceous nature. A SEM investigation reveals the rounded shape of the grains (Fig. 2). The basic difference between these two sands lies, therefore, in the particle size distribution.

If these sands are compared with the aggregates of an ordinary concrete (gravel+sand), it could be observed that the porosity of concrete is higher. This porosity imposes the use of fillers to eliminate pores between particles [4].

2.2. Cement

The cement used is a CPA CEM I 32.5; its chemical analysis and composition are given in Table 2. The physical characteristics are the following: specific density 2900 kg/m^3 and Blaine specific surface area 407 m^2/kg.

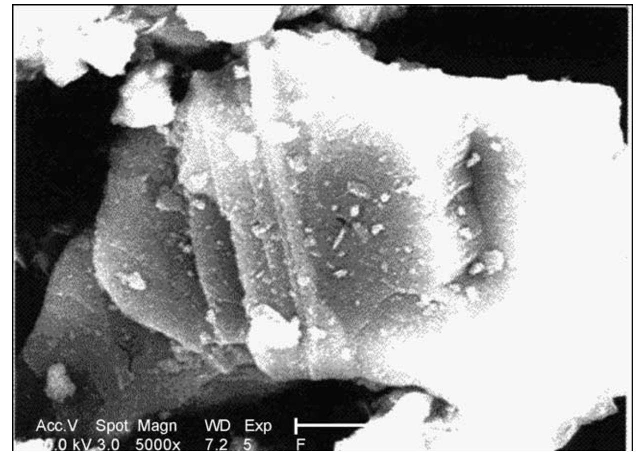

Fig. 3. Scanning electron micrograph of the used filler, G=5000.

2.3. Fillers and admixture

The fillers used have been obtained by sifting (to a sieve opening of 80 μm), crushing waste generated in the Laghouat region, and are mainly composed of limestone (97.5 mass% of $CaCO_3$). The EDX analysis has highlighted the calcic nature of these fillers [5]. Fig. 3 shows the shape of the grains. The low percentage of harmful components that can influence the cement hydration has been verified by Benmalek [6], who has used the same filler in his work.

Their physical characteristics are the following: specific mass 2900 kg/m^3 and Blaine specific surface area 321 m^2/kg.

The admixture used is a superplasticizer (a typical MEDAPLAST-SP product), with a dry matter content of 1.5% of cement mass (recommended concentration for concrete). This product is a polynaphtalene sulfone in liquid form with 40% of dry matter content.

3. Preparation of sand concrete and testing

The tests were undertaken in a similar fashion on three different sand concretes. Each concrete was prepared using one of the previously indicated sands (DS, RS, and RDS).

To obtain a high level of homogeneity in the sand concrete, an initial dry mixing was undertaken, followed by a second mixing after introducing the mixing water. Mixing then continued for each composition until obtaining a homogeneous mix according the EN 196-1 Standard. Tightening was achieved, thanks to vibration on a vibrating table, with the time of vibration being a function of concrete workability.

Table 2
Chemical analysis of the cement used

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	CaO free
21.47	4.30	2.82	60.13	1.08	2.23	0.48	0.81	2.91

The specimens produced were cured in air at 20±2 °C and 50% RH. After 24 h, they were removed from the molds and placed in water for another 24 h and then open-air stored until the day of testing. Such curing has been chosen according the normal manufacturing of sand concrete in Algeria. This procedure was respected for all compositions and all tests.

Flexural strength was determined (using three points) for each composition on six 4×4×16 cm prismatic samples. The half-samples resulting from this test were then submitted to compression on a 4×4 cm test section (EN 196-1). Sample size is significant in comparison with the size of aggregates.

4. Experimental results and analysis

The objective of this research was to get the best possible mechanical strength at an acceptable level of workability. It is therefore necessary to determine an optimal granular skeleton (higher compactness, consequently high strength) while preserving good workability, without requiring too much additional water (which decreases the strength of hardened concrete [7]).

For this task, the composition corresponds to a concrete mass volume of approximately 2100 kg/m^3, with a cement content of 350 kg/m^3.

4.1. Influence of the filler content on the compactness of the dry mix

This study is based on determining the mass volume of the mixture [4]: The cement content is fixed, the filler (F) content is selected, and the cement–filler mixture is completed by adding sand until obtaining a volume determined after dry mixing and 15 s of vibration on a vibrating table.

It was observed that by increasing the filler/sand (F/S) ratio, the mass volume of the mix increased until a certain optimum and then decreased (Fig. 4); this suggested that before reaching maximum compactness, fine particles filled spaces between grains of sand, thereby increasing the mass volume of the mix [4]. Once the voids were completely filled, fine particles then began to occupy the place of sand grains, which decreased the proportion of sand grains, and consequently the density of the mix.

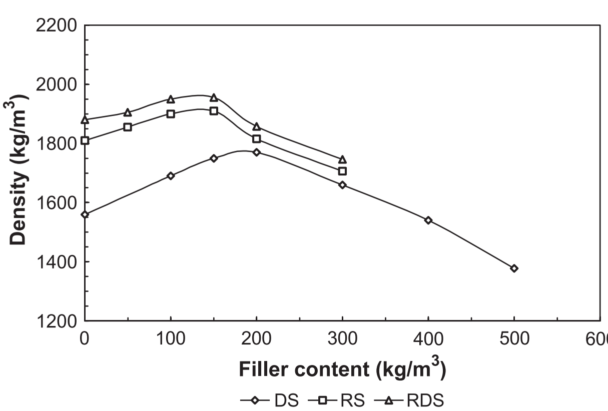

Fig. 4. Evolution in compactness vs. filler concentration.

Table 3
Optimal F/S ratio for the three sand concretes

Sand	F/C	Fopt (kg/m^3)	F′opt (kg/m^3)	F/S
DS	0.57	200	550	0.16
RS	0.43	150	500	0.10
RDS	0.40	140	490	0.09

The optimal F/S ratio is presented in Table 3. It may be pointed out that this ratio is higher when the sand contains a greater proportion of finer particles. For river and river-dune sands, which both display rather similar particle size distributions; the optimal F/S ratios are also very similar.

Inasmuch as the cement is playing the role of filler as well, the concentrations in terms of total fine particles (F′=filler+cement) are also given in Table 3.

4.2. Influence of filler content on the workability of fresh concrete

The VEBE machine was used to measure workability as a function of filler content for different W/C ratios, the quantity of cement was fixed at 350 kg/m^3.

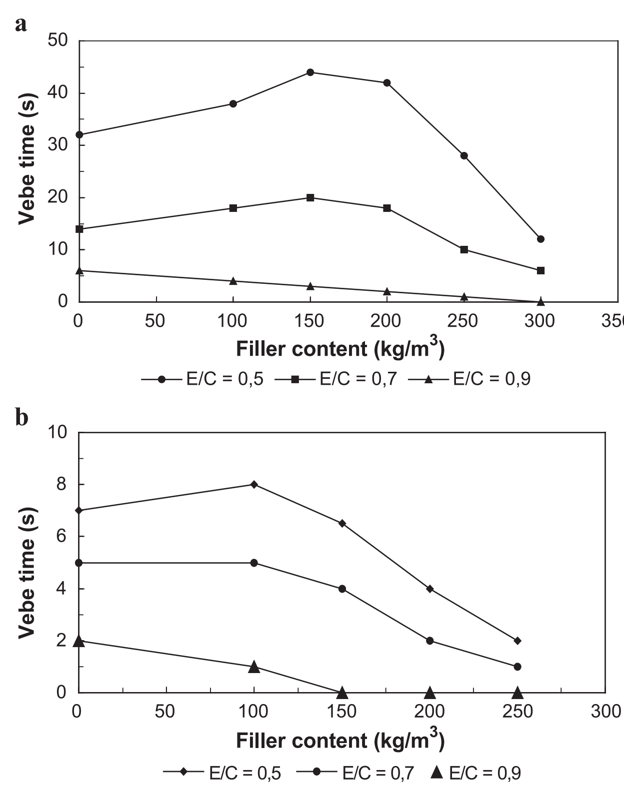

Fig. 5. Evolution in workability of dune (a) and river dune (b) sands vs. filler concentration.

A superplasticizer has been added to the mixture in accordance with the indications given in Sections 2–3.

The filler proportion varied from 0 to 300 kg/m^3 for DS and from 0 to 250 kg/m^3 for RS and RDS. It was observed that the workability of sand concrete depended on both water and filler contents [8]: It increased considerably with an increase in the W/C ratio. An increase in the filler content decreased workability until an optimal F/S proportion was reached, at which point it was expected to rise (Fig. 5). This effect was even more pronounced when the proportion of water was small and the sand contained a high proportion of fine grains. The work performed by Chaouche [9] showed that before voids are entirely filled, the sand grains circulate with difficulty and the low percentage of filler only serves to constrict their movement. The influence of the proportion of water would seem to confirm this hypothesis. On the other hand, once voids have become totally filled, the increase in filler concentration contributes to improve workability of concrete by facilitating the sand grain movement.

In the curves shown in Fig. 5, it can also be observed that the coarse grain proportion of the sand considerably increased workability for an identical water content and that minimum workability was obtained with higher filler contents when the proportion of grain sizes above 0.630 was zero (i.e., DS). Even if this point corresponds to the declining segment of the flow time curve, the optimal F/S

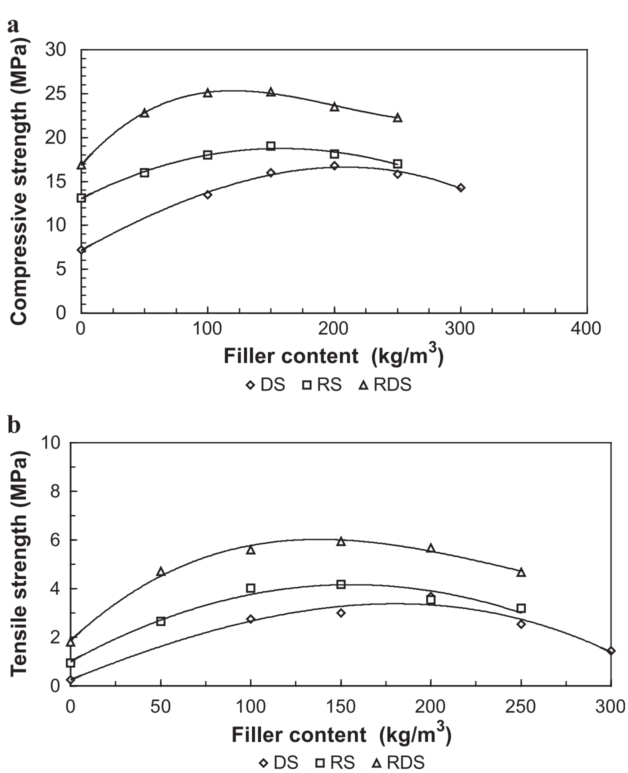

Fig. 6. Influence of filler concentration on 28-day compressive (a) and flexural (b) strengths.

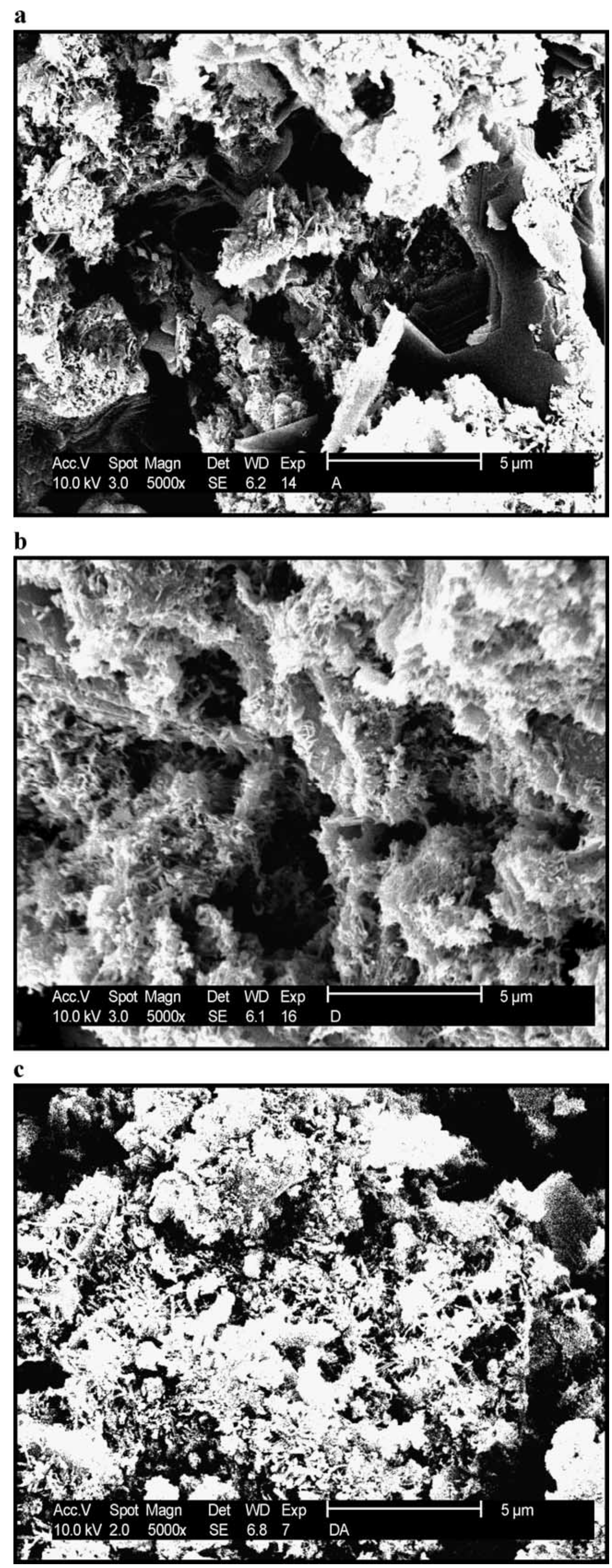

Fig. 7. Scanning micrographs of dune (a), river (b), and river-dune (c) sand concretes; general shape of hydrates (G=5000).

ratio for compactness of the granular skeleton decreased workability when the sand contained a significant proportion of fine grains (DS), coupled with a low W/C ratio. In the case of RS and RDS containing a higher coarse grain proportion, the optimal F/S ratio for compactness of the skeleton moved towards equal or slightly greater workability than that of the mix without filler. When W/C was high (i.e., 0.9), workability increased with filler proportion, regardless of the type of sand. This behavior may be explained by the fact that in the presence of a large quantity of water, sand grain movement is not constricted by the presence of filler. Nevertheless, excess water can compromise mechanical properties.

4.3. Influence of the filler content on the strength of hardened concrete

Due to their influence on dry mix compactness, fillers also affect the strength of sand concrete [1]. For this study, the cement concentration remained fixed at 350 kg/m^3, and the dosage of superplasticizer was 1.5% of the cement mass.

The W/C ratio remained constant (W/C=0.6). The strength variation in function of filler content is presented in Fig. 6.

The analysis of experimental results reveals the existence of an optimal filler concentration for each type of sand. This finding has also been derived from the study on dry mix compactness. The sand concrete with RDS exhibits the highest mechanical strength and that with DS exhibits the lowest strength, which means that as maximum grain diameter increases, strength rises as well. At equal granular limits (for both RS and RDS), the sand with the best granular distribution over the fine grain part (RDS) yields the highest strength concrete.

A SEM examination of a 28-day-old concrete with an optimally proportioned F/S admixture serves to confirm these results. Fig. 7 shows the appearance of hardened cement paste for the three types of sand concrete. In the case of dune-sand concrete, an agglomerate (featuring small crystals of disordered fine-needled C-S-H in very small proportions) appears. Note that, in this context, the small proportion of C_3A in the cement explains the distinctly small presence of ettringite. The river sand concrete is less compact and displays a sizable number of tablets of portlandite covered, more or less, by C-S-H crystals. The cement paste is more compact in the case of river-dune sand concrete and exhibits a mixture of tablets and relatively ordered crystals. Given the current state of the study, it is difficult to determine the reason for this difference in the crystal growth of hydrates. Nevertheless, be reminded that Uchikawa and Hamhara [10] have shown that adding mineral powder in concrete reduces the size of hydration products, inhibits the deposit of $Ca(OH)_2$ by virtue of their filling role, and, consequently, decreases pore size. Other works have demonstrated that limestone cannot be considered an inert filler. It has notably been shown that the

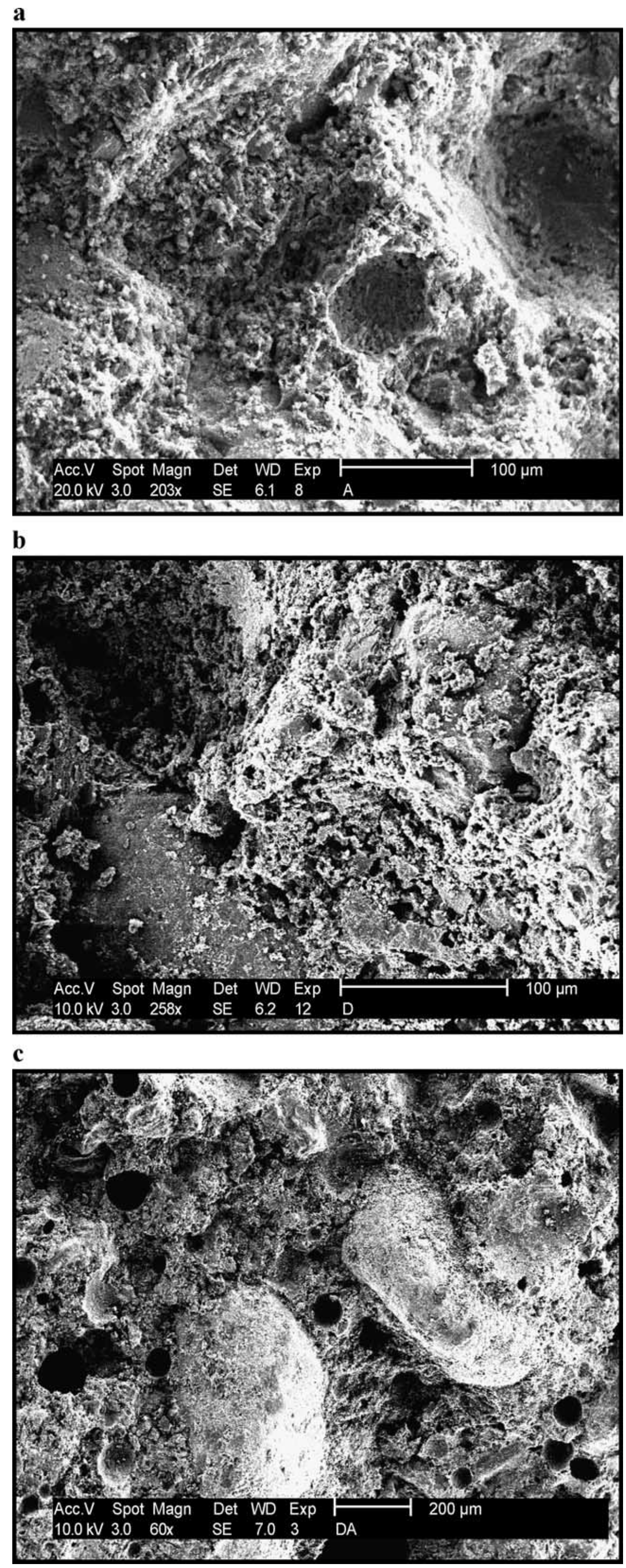

Fig. 8. Scanning micrograph of dune (a), river (b), and river-dune (c) sand concretes; general shape of sand grains in the matrix (*G*=60).

carboaluminates of hydrated calcium precipitate during the hydration of the cement containing ground limestone when C_3A is abundant [11]. In the course of ettringite formation, sulfate ions can be replaced by carbonate ions without modifying the reaction sequences [12]. It has also been shown that an interaction takes place between calcium silicate (alite) and calcium carbonate: The latter accelerates the hydration of C_3S and modifies the Ca/Si ratio of C-S-H [12]. More specifically, Péra et al. [12] have studied reactions that occur during the hydration of C_3S in the presence of calcium carbonate and have proved that, in cement paste, calcium carbonate has an accelerator effect on cement hydration and leads to the formation of carbosilicates and hydrated calcium carboaluminates.

The cement–limestone paste displayed high mechanical strength for quantities of limestone filler greater than 30%, which is the case for all of the various mix designs studied herein. Therefore the physico–chemical consequences of the presence of limestone fines could not be distinguished. These fines, by modifying the nature of hydrates, influence mechanical strength. A major structural difference, however, can be observed between river and river-dune sand concretes, although the limestone proportion and dry material compactness remain very similar. It should be noted that those elements highlighted in the EDX analysis are the same for the two basic sands, except for the traces of iron appearing in the river sand.

Furthermore, the hardened cement paste presents only a few microcracks. It has been observed that, regardless of the sand used in manufacturing the concrete, these microcracks are short, nonconnected, and distributed randomly. They probably result from the considerable shrinkage occurring due to the self-desiccation that typically characterizes sand concrete [13]. It is certainly due to the curing in air. This phenomenon has already been identified and explained [14]. A smaller density of microcracks is also observed in the case of the dune sand, which nonetheless exhibits poorer mechanical strength. This finding can be linked to the absence of elements greater than 0.630 mm. These microcracks, due to their limited number, are therefore not responsible for the mechanical behavior of the concrete specimens produced.

Lastly, an examination of the interface between paste (cement+ limestone) and aggregates (Fig. 8) shows that for all three compositions, sand grains are well embedded by the paste and are well distributed. Moreover, no interfacial cracks are apparent.

As opposed to the other experimental results, the SEM observation serves to highlight that the compactness of the concrete is not directly related to that of the granular skeleton. The RS+FILLER skeleton is indeed more compact than the DS+FILLER skeleton is at its optimum: The compactness of the corresponding concrete is thus less. The compactness of RDS+FILLER at its optimum is very close to that of RS+FILLER, whereas the compactness of the corresponding concrete is higher. The mechanical strength of the concrete is not directly related to its compactness but also depends on the nature and morphology of the hydration products, which are directly related neither to the compactness of the granular skeleton nor to the granular distribution of the basic sand (i.e., the case of sands RDS and RS). It seems that the chemical nature of sand must also be taken into account. A more thorough study of the species formed will remove any ambiguity.

5. Conclusion

This study has concerned the influence of limestone fillers on the properties of sand concrete produced either from dune sand (DS) or river sand (RS) and has been aimed at enhancing the reuse of local materials. The criteria examined have been the workability of fresh concrete and mechanical strength of hardened concrete. These two siliceous sands display different extensive granular properties, and the dune sand is characterized by the absence of grains larger than 0.630 mm.

The maximum compactness of the dry mix has been obtained using an optimal filler concentration; in contrast, the concrete is only sufficiently workable around this optimum if the W/C ratio is raised. The increase in this ratio serves to reduce strength and therefore tends to ensure a compromise between compactness and workability, whereby admixtures, plasticizers, and water reducers have all been used.

Correction of the granular distribution by means of mixing two local sands in predetermined proportions has allowed optimizing compactness and workability, while at the same time reaching an attractive level of mechanical strength with reasonable quantities of cement. In conclusion, the microstructural study, by virtue of analyzing the hardened concrete under a scanning electron microscope, reveals a compact and homogeneous cement paste, without major cracks and with a perfected paste–aggregate connection. A number of points still need to be explored further, e.g., the nature and granular distribution of the filler along with durability. However, the results presented have already substantiated the possibility of using these sands in local construction.

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