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Effect of the type of sand on the fracture and mechanical properties of sand concrete

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Abstract. The principal objective of this study is to deepen the characterization studies already led on sand concretes in previous works. Indeed, it consists in studying the effect of the sand type on the main properties of sand concrete: fracture and mechanical properties. We particularly insist on the determination of the fracture characteristics of this material which apparently have not been studied. To carry out this study, four different types of sand have been used: dune sand (DS), river sand (RS), crushed sand (CS) and river-dune sand (RDS). These sands differ in mineralogical nature, grain shape, angularity, particle size, proportion of fine elements, etc. The obtained results show that the particle size distribution of sand has marked its influence in all the studied properties of sand concrete since the sand having the highest diameter and the best particle size distribution has given the best fracture and mechanical properties. The grain shape, the angularity and the nature of sand have also marked their influence: thanks to its angularity and its limestone nature, crushed sand yielded good results compared to river and dune sands which are characterized by rounded shape and siliceous nature. Finally, it should further be noted that the sand concrete presents values of fracture and mechanical properties slightly lower than those of ordinary concrete. Compared to mortar, although the mechanical strength is lower, the fracture parameters are almost comparable. In all cases, the sand grains are debonded from the paste cement during the fracture which means that the crack goes through the paste-aggregate interface.

Keywords: sand; sand concrete; fracture mechanic properties; compliance; energy release rate; J-integral

1. Introduction

It is well known that ordinary concrete strength is influenced by the ratio of cement to mixing water, the ratio of cement to aggregate, the bond between mortar and aggregate and the grading, shape, strength and size of the aggregates (Neville 2012). As all these variables are interrelated, the role of some of them in the fracture and mechanical properties of concrete is still not totally solved. Moreover, for certain special concretes, these studies have not been conducted, which is

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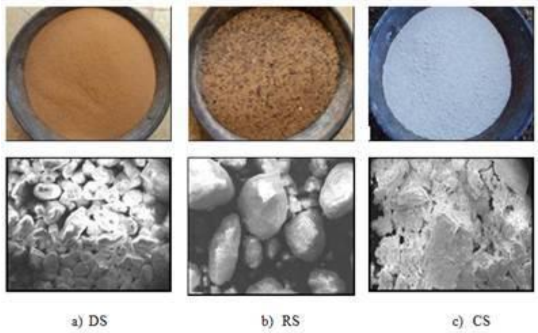


Fig. 1 General aspect of used sands and the grains shape (G = 36)

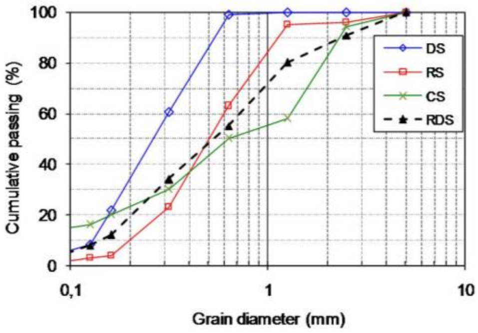


Fig. 2 Particle size distribution of the sands used

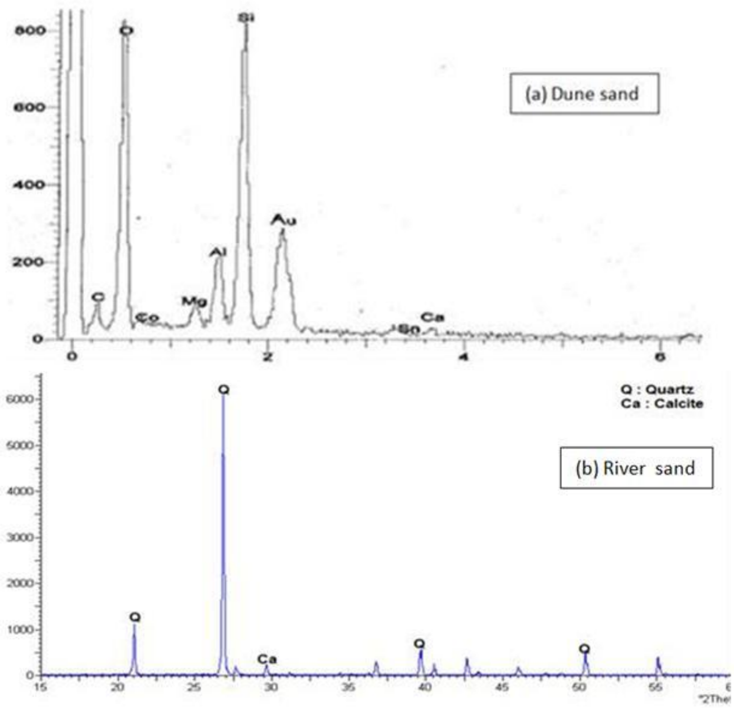


Fig. 3 EDX analysis of used sands

approximately 5 mm but the proportion of grains smaller than 0.08 mm is below 14%. It should be noted that these proportions of fine grains remain acceptable concerning their use in concrete and particularly in sand concrete where the presence of fillers is essential (Neville 2012, bederina *et al.* 2005). In a schematic manner, the particle size distribution of crushed sand is slightly more spread out than that of river sand. On the contrary, the dune sand presents a tight particle size distribution. In addition, RS and DS grains present rounded shapes (Fig. 1a,b), while CS grains present angular shapes (Fig. 1c). In order to assess the effect of the granular distribution of sand, we formed a new sand (RDS) by mixing RS and DS (Sands having the same nature) (Bederina *et al.* 2005). RDS is, in fact, obtained by correcting the particle size distribution curve of RS in its fine part by addition of DS (RS/DS = 1.7). Table 1 lists the set of physical characteristics for all types of sand. This table reveals that the density of CS is slightly higher than RS and DS, but the RS is slightly the most compact. The highest modulus of fineness value is presented by RS (2.45); however the DS presents the smallest one (1.18) which means that RS is the coarsest sand and the DS is the finest. The high values of the "RS sand equivalent", which are measured according to NF P 18-598 standard, show that RS and DS are clean. While the "CS sand equivalent" is lower (76.50), but it remains above the limit value recommended for concrete and mortar. EDX analysis of sands demonstrates the essentially siliceous nature of RS and DS (Figs. 3(a), (b)) and the essentially limestone nature of CS (Fig. 3(a)).

Finally, it should be noted that the basic difference between these sands lies, therefore, in the nature, the grain shape, the granularity and the proportion of fine elements (Table 2).

A Portland cement (type II) of class 45 was used ("CPJ-CEM II/A"). Its physical characteristics are the following: specific density 3078 kg/m^3 (measured with pycnometer) and Blaine specific surface area 389 m^2/kg.

The fillers used have been obtained by sifting (to a sieve opening of 80 µm), crushing waste (the used crushed sand) generated in Laghouat region, and are mainly composed of limestone (Fig. 3c). The EDX analysis has highlighted the limestone nature of this filler (Fig. 3c). A low percentage of harmful components that can influence the cement hydration had been recorded. Their physical characteristics are the following: specific density 2900 kg/m^3 (measured with pycnometer) and Blaine specific surface area 312 m^2/kg.

The admixture used is an Algerian superplasticiser of MEDAPLAST (SP40).

2.2 Experimental methods

The studied compositions for each sand concrete (RS-Concrete, DS-Concrete, CS-Concrete and RDS-Concrete), which have been optimized in previous studies, are given in Table 3. Since the grain diameter doesn't exceed 5 mm in all studied cases, flexural strength was determined (using three points bend test) on six 4 × 4 × 16 cm prismatic samples. The half-samples resulting from this test were then subjected to compression on a 4 × 4 cm test section (EN 196-1). Furthermore, in fracture mechanic approach, it is assumed that there are always flaws in the material from which cracks can begin. For this reason, we tried to create an initial crack (flaw) in prismatic specimens in order to study the resistance of each sand concrete to the propagation of crack. The cracking parameter in Mode I, which has been identified, is the critical energy release rate (Gc). Concerning the preparation of specimens, three prismatic samples of 7, whose dimensions are 7 × 7 × 28 (cm^3) were partially cracked at the middle using an electric chainsaw (Fig. 4) for each composition. The width of the crack is about 4 mm (thickness of the saw blade). To decrease the radius of curvature

$$C = \left(\frac{\partial \delta}{\partial P}\right) \tag{1}$$

Indeed, this ratio represents the inverse of the slope of the linear part in the load-displacement curve.

Then the energy release rate is calculated using the following equation

$$G_c = \left(\frac{P_R^2}{2B}\right) \cdot \left(\frac{\partial C(a)}{\partial a}\right) \tag{2}$$

where P_R is the fracture load,
and B the width of the specimen.

Finally, an attempt to calculate J-integral is made. The J-integral value is calculated by the simplified compliance method, using the technique presented by LANDES and BEGLEY(Chuang *et al*. 2001). This method is based on the fact that under an imposed displacement δ, J is equal to the change in elastic strain energy "*U*" per thickness unit. The latter can be defined as the energy that is stored in a material due to deformation and can be determined by calculating the area under the load-displacement curve. In our case, this has been done for different lengths of crack. The curves "$U = f(a)$" corresponding to the selected displacements δ_1, δ_2….., δ_n which are used to calculate the value of "J" are determined by the opposite slope of these curves for a chosen crack lengths. The critical J-integral value 'Jc' is obtained using the critical displacement δ_c.

3. Results and discussion

3.1 Mechanical properties

The mechanical strength (in flexion and compression) of limestone (CS) sand concrete is better than that of siliceous sand concrete (RS and DS) (Fig. 6). Due to the higher absorption of the limestone sand compared to siliceous sand, the quantity of the mixing water in limestone sand concrete is decreased. The water excess which should normally remain to create pores in the composite is therefore smaller. The pore volume (porosity) of limestone sand concrete is consequently reduced which improves the compactness and the mechanical properties of the material (Makhloufi *et al*. 2012). In addition, the limestone sand grains have an angular shape, which makes the propagation of the crack in the sand concrete more difficult. Moreover, limestone aggregate produces a dense transition zone (interface between aggregate and hydrated cement paste (Neville 2012)). Kilic *et al*., by studying the effect of the type of aggregates on concrete mechanical strength, showed that in the case of limestone aggregates, compressive strength at the 90^{rh} day is slightly higher than that found in the case of quartz aggregates (Kılıc *et al*. 2008). Aquino *et al*. also showed that the strength and the modulus of elasticity in concrete increase with the increase in limestone sand. They noted that this increment is relatively small, but test results show that limestone makes the concrete stronger and more elastic (Aquino *et al*. 2010).

Finally, it should be noted that by correcting the particle size distribution of the river sand by adding dune sand, the mechanical strength of sand concrete (RDS-Concrete) is slightly better than

of sand concrete, the compliance increases with increasing crack length in the same manner. DS-Concrete (Dmax = 0.63 mm) presents values of compliance higher than those of RS-Concrete (Dmax = 5 mm) and the RDS-Concrete presents the lowest values. This finding highlights the influence of particle size of the sands, particularly the maximum diameter of the grains and the particle size distribution. DS-Concrete presents therefore a relatively more deformable concrete. However, The CS-Concrete presents the lower values.

3.2.2 Energy release rate

The energy release rate is the energy dissipated during fracture per unit of newly created fracture surface area. It is the energy released per unit thickness and unit extension of the crack length. In our case, the energy release rate is calculated using Eq. (1). For each crack length (ai),

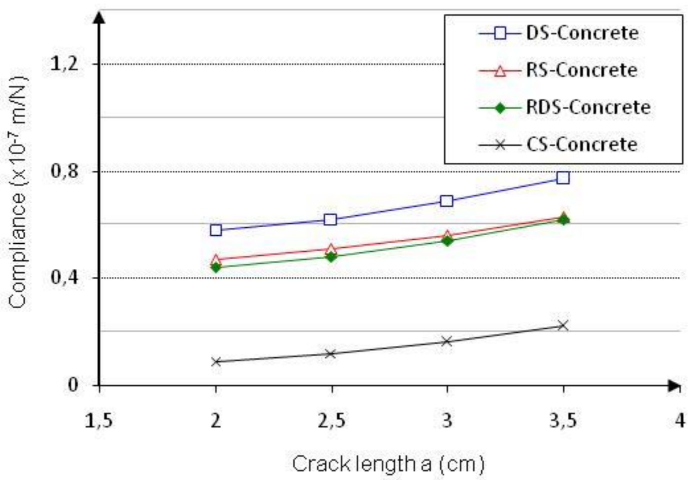


Fig. 6 Compliance according crack length

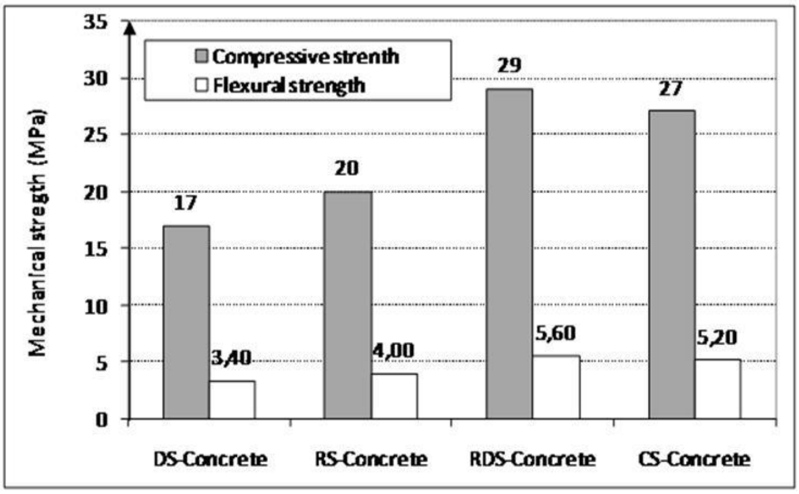
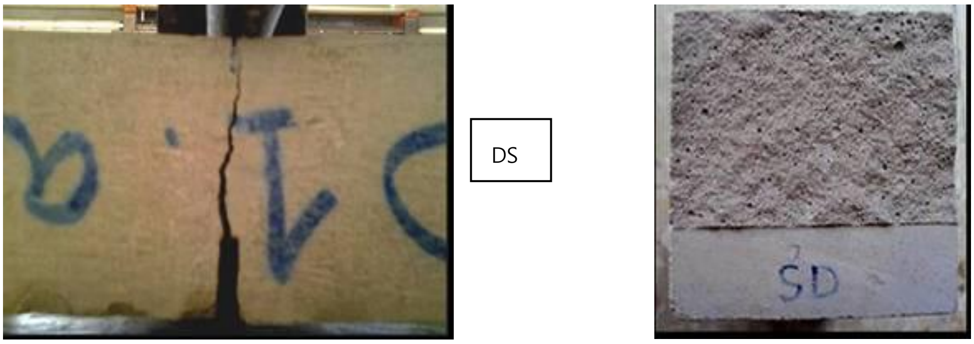
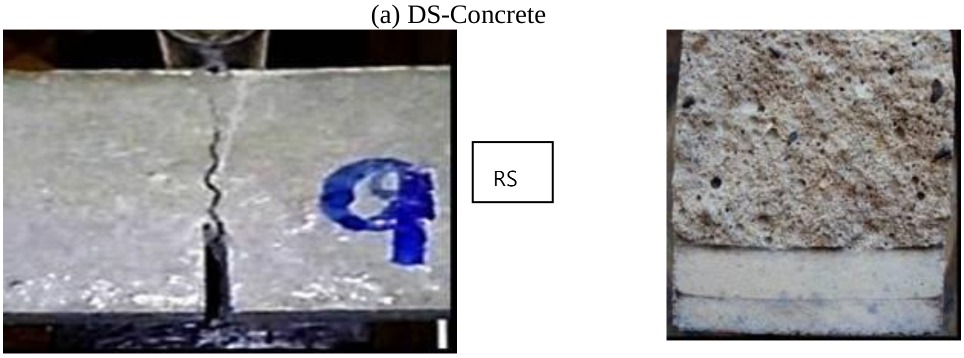


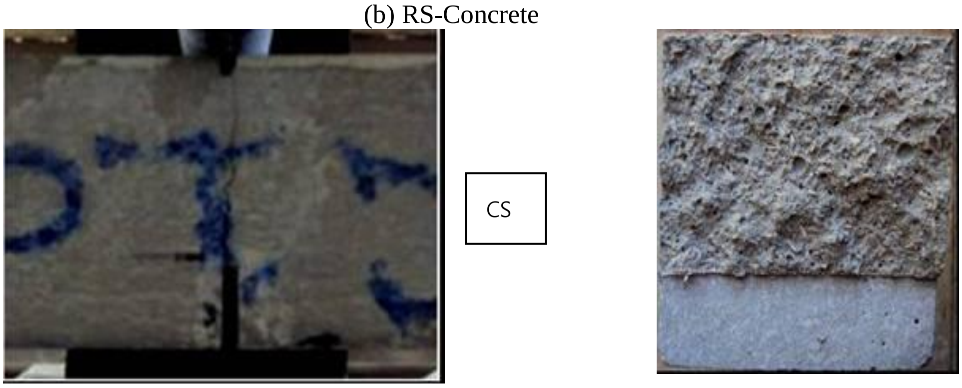
Fig. 7 Mechanical strength according to the sand type



(a) DS-Concrete

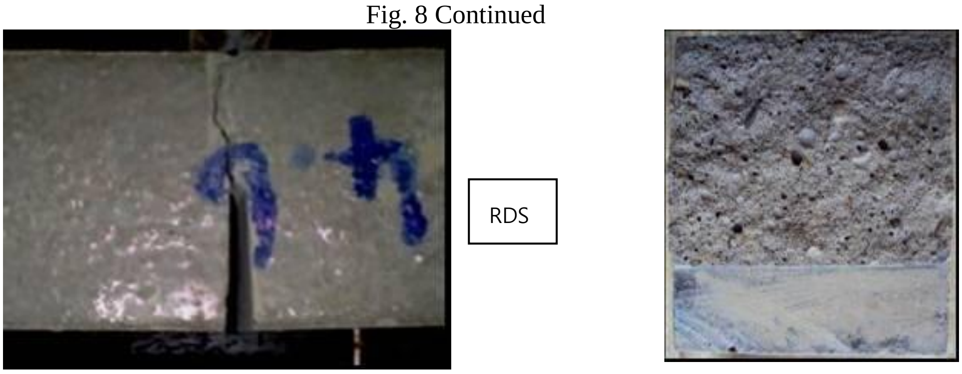


(b) RS-Concrete



(c) CS-Concrete

Fig. 8 Continued



(d) RDS-Concrete

Fig. 8 Aspect of crack and fracture surface.

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