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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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the case of the sand concrete. This material differs from ordinary concretes by the absence of gravels and from mortars by the cement content. By definition, it is a concrete which contains only sand as aggregates (without any gravels) and a cement content similar to that of ordinary concretes as defined by AFNOR P 18-500." It belongs to the category of new special concretes and has been the subject of several recent studies. However, it should be noted that apparently its fracture properties have not been studied. Indeed, this work represents a continuation of several previous works already led on sand concrete based on the valorisation of local materials and waste (dune sand, aggregates crushing waste, etc.) (Bederina *et al*. 2005, 2007, 2012, Bouziani *et al*. 2012). It aims to deepen the previous characterization of this material and consists to investigate the ability of this material to resist to existing cracks in the building structures. Because the sand is the main component of sand concrete, we chose to study the effect of the type of sand (nature of sand, maximum size and shape of grains, angularity and particle size distribution, fine elements content, etc.) on the mechanical properties of sand concrete, in particular on its fracture parameters. The sand type effect on concrete properties (beside gravels) has been the subject of several studies (Wakchaure*et al*. 2012, Abdullahi 2012) but on sand concrete properties, it seems that it has not been taken into consideration, particularly on the fracture properties. Regarding the determination of the fracture characteristics of the studied sand concretes, we have used the fracture mechanic approach. Let's note that the experience has shown that sometimes, despite the satisfaction of the regulatory approach with respect to the safety of some buildings, the problems of cracking remain possible. The questions that arise with respect to the produced cracks can be summarized as follow:

- These cracks, are they dangerous for the building security?
- Or, they remain stable if building loads do not exceed a certain value.

The answer to both questions is crucial to the project owner, either at safety or economic levels. It is within this context that opens the reflection on a design philosophy known as "fracture mechanics", which aims to develop a criterion of ruin taking into consideration existing cracks within the material. It's a theory which dates back to 1920, when Griffith studied the cracking of a brittle material (Ted 2004). The first application of this theory was made between 1940 and 1950 for metals, polymers, ceramics and other materials. For concrete, it was first applied in 1961 by Kaplan (Kaplan 1961). This work was followed by other attempts led by other authors for concrete, for mortar and for some special concretes. Although these materials exhibit heterogeneity and anisotropy, fracture parameters such as critical stress intensity factor Kc and the critical energy release rate Gc, have been determined and adopted as ruin criterion (Elices and Rocco 2008, Ragip 2010, Reis 2012). So, what about the sand concrete? Does it behave like current concrete?

Indeed, the present work consists to investigate, both the mechanical strength of this material and its ability to resist to existing cracks in building structures. It especially studies the effect of the sand characteristics mentioned above on fracture and mechanical properties of sand concrete.

2. Materials and experimental methods

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

Four different sands were separately used in this study (Fig. 1): dune sand (DS) from the Northern area ofLaghouat (Algeria), river sand (RS) from M'zi oued (also area of Laghouat), crushed sand (CS) brought back from local quarry waste, near the city of Laghouat, and river-dune

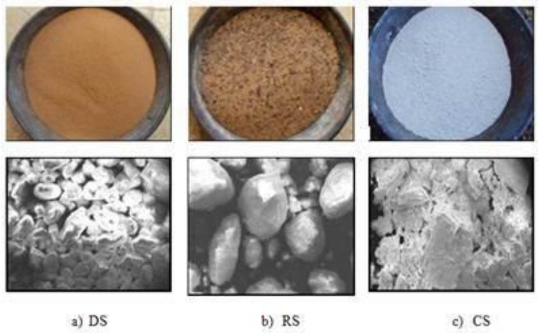


Fig. 1 General aspect of used sands and the grains shape (G = 36)

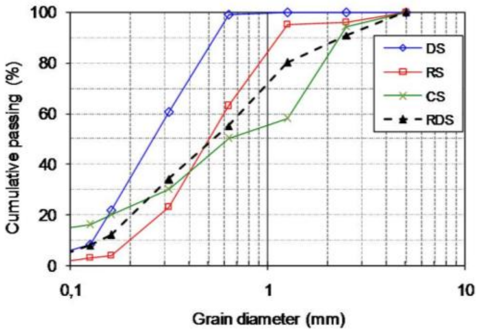


Fig. 2 Particle size distribution of the sands used

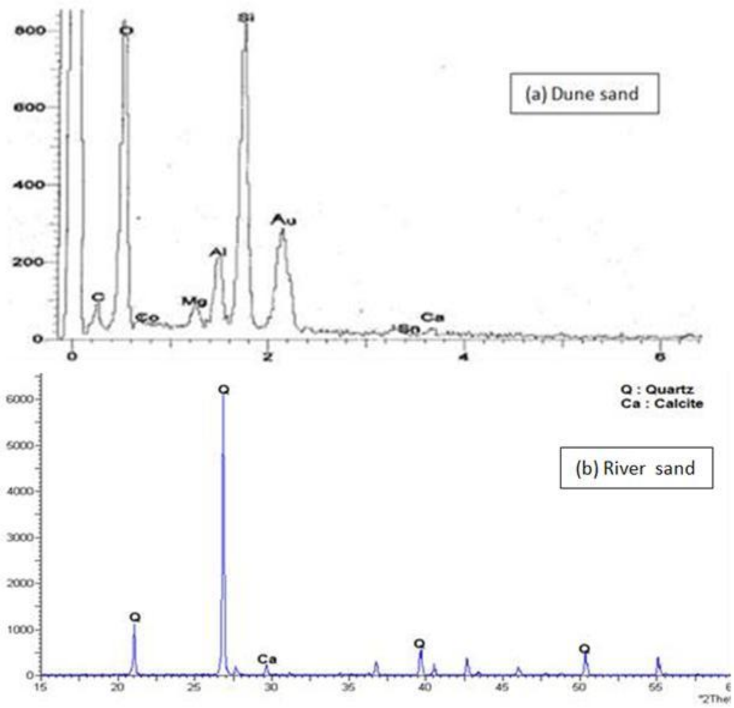


Fig. 3 EDX analysis of used sands

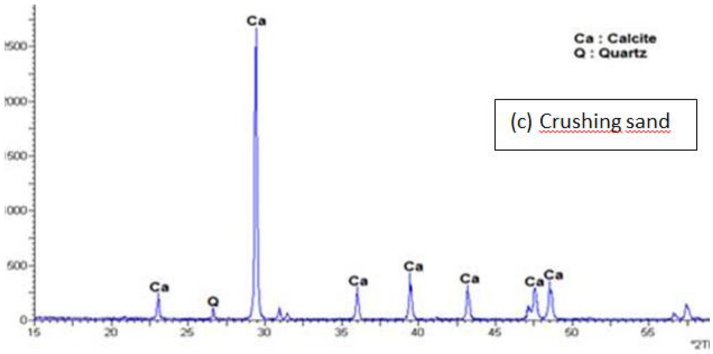


Fig. 3 Continued

Table 1 Physical properties of sands.

Physical characteristics	RS	DS	CS	RDS
Specific density (kg/m^3)	2570	2590	2700	2580
Apparent density (kg/m^3)	1480	1430	1530	1510
Compactness (%)	57.3	55,0	56.7	58,0
Porosity (%)	42.7	45,0	43.3	42.0
Fineness modulus	2.45	1.18	2.30	2,28
Visual sand equivalent (%)	84.0	78,0	71.3	80.0
Piston sand equivalent (%)	88.0	86,0	76.5	87.0
Absorption coefficient	0.58	2.04	4.3	0.42

Table 2 Comparison between used sands

Sand type	Nature	Grain shape	d/D(mm)	Fineness	% of fine elements	Particle size distribution
DS	Siliceous	Rounded	0/0.63	Fine	More or less low (4%)	Continuous very tight
RS	Siliceous	Rounded	0/5	Coarse	Very low (2%)	Continuous More or less spread out
CS	Limestone	Angular	0/5	Fine	High (14%)	Continuous More or less spread out
RDS	Siliceous	Rounded	0/5	Normal	Low (3%)	Continuous spread out

sand which is a mixture of river and dune sand.Their particle size distributions are showed in Fig.2. The DS and RS present a continuous particle size distribution ranging from 0 to 0.63 mm and 0 to 5 mm respectively, with a fraction of grains smaller than 0.08 mm below 5% (Fig. 2). The CS presents also continuous particle size distribution with a maximum grain diameter of 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

Fig. 4 Notched specimen geometry

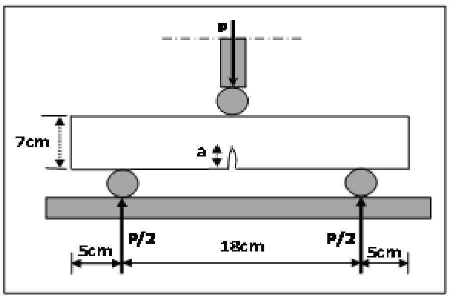


Fig. 5 Loading set-up test

Table 3 Compositions used for each sand concrete

	Sand (kg/m^3)	Cement (kg/m^3)	Fillers (kg/m^3)	Water (l/m^3)	Superpla-sticiser * (%)
DS-Concrete	1305	350	200	245	1.5
RS-Concrete	1460	350	150	210	1.5
CS-Concrete	1498	350	-	210	1.5
RDS-Concrete	1473	350	140	207	1.5

* Mass percentage relative to the amount of cement.

at the tip of the crack, the latter was slightly extended by a small crack having a smaller width (1 mm) using a hacksaw. Four crack lengths were considered:

a_1 = 2.00 cm, a_2 = 2.50 cm, a_3 = 3.00 cm, a_4 = 3.50 cm

The performed test is stable three-point bend tests (Fig. 5) and the used samples are prismatic notched specimens, as recommended by RILEM (RILEM 1985). The load and the displacement at the loading point were measured using universal press related to an acquisition computer which gives the load values according to displacements. To plot Load-displacement curves, 48 notched specimens (04 sand concrete, 04 different crack lengths and 03 tests for each measure) with different crack lengths (a_1, a_2, a_3 and a_4) were subjected to three-point bend tests. The tests have been pushed until the breaking to allow the determination of the load and the displacement at fracture. The tests were performed according to the scheme showed in Fig. 5.

The first determined parameter is the compliance which is defined as the property of a material of undergoing elastic deformation or change in volume when subjected to an applied force. It is equal to the reciprocal of stiffness. This parameter is related to the displacement of the load applied to the specimen. It has been found using the following ratio

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

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

Table 4 Compliance values according to crack length

Crack length	(×10^{-7} m/N)							
	DS-Concrete		RS-Concrete		CS-Concrete		RDS-Concrete	
	$\partial P/\partial \delta$	C	$\partial P/\partial \delta$	C	$\partial P/\partial \delta$	C	$\partial P/\partial \delta$	C
a_1	1.72	0.58	2.13	0.47	11.11	0.09	2.27	0.44
a_2	1.61	0.62	1.96	0.51	8.33	0.12	2.08	0.48
a_3	1.45	0.69	1.78	0.56	6.25	0.16	1.85	0.54
a_4	1.30	0.77	1.59	0.63	4.54	0.22	1.61	0.62

that of limestone concrete. It is highly possible that by correcting the particle size distribution of the CS, the CS-Concrete resumes its first place. In addition to the granular distribution, the increase of the maximum diameter of sand grains increases also the mechanical strength: With similar nature, the RS (Dmax = 5 mm, siliceous nature) presented results better than those of DS (Dmax = 0.6 mm, siliceous nature).

3.2 Fracture properties

In order to determine the critical energy release rate (Gc), we have first to determine the load-displacement curves, then compliance according to the crack length and finally the energy release rate (G).

The displacements are measured and recorded, as a function of applied load, at the level of the load application point. These curves are traced, for each sand concrete, in their elastic portions in order to determine their slopes in their linear part. The obtained values are showed in table 4.

It is clear and quite normal that their slopes decrease with increasing crack length. Moreover, they are slightly higher in the case of CS-Concrete and lower in the case of DS-Concrete, which explains the effect of the sand type on the elasticity of the sand concrete. By comparing the effect of dune sand and river sand which have the same nature (Silica) and differ only in their particle size, we noted that the river sand gives the highest slope. By the good granular distribution of RDS, the RDS-Concrete gives higher values than RS and DS concretes. This finding demonstrates that the increase of the maximum diameter of sand, as well as the improvement of its granular distribution, increase this slope. Moreover, the grain shape of sand also marks its influence on the elasticity of sand concrete, since the limestone sand, whose grains are angular, gives high slopes comparing to other sands where the grains are rounded. It is also quite obvious that the slope decreases when the crack length increases.

Finally, let's note that the purpose of the determination of these slopes is to calculate the compliance which is required for determining the rate of energy release.

3.2.1 Compliance

The compliance is determined for each sand concrete and for all studied crack lengths using Eq. (1). The obtained results are summarized in table 4. To well appreciate the evolution of the compliance according to the crack length "*a*", we plot the curves shown in Fig. 6. For all the types 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),

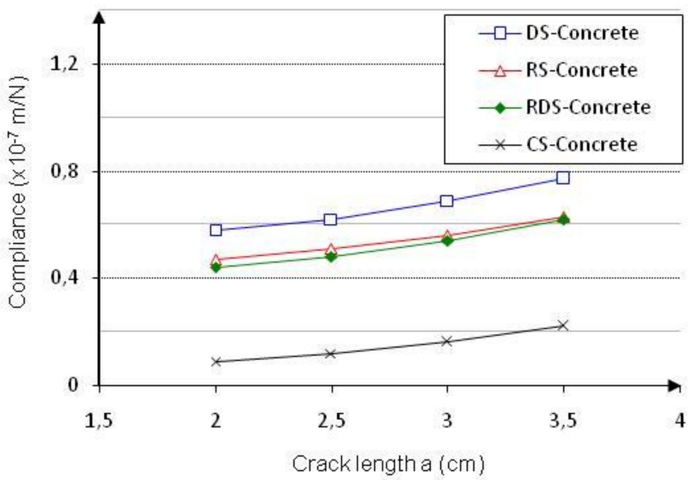


Fig. 6 Compliance according crack length

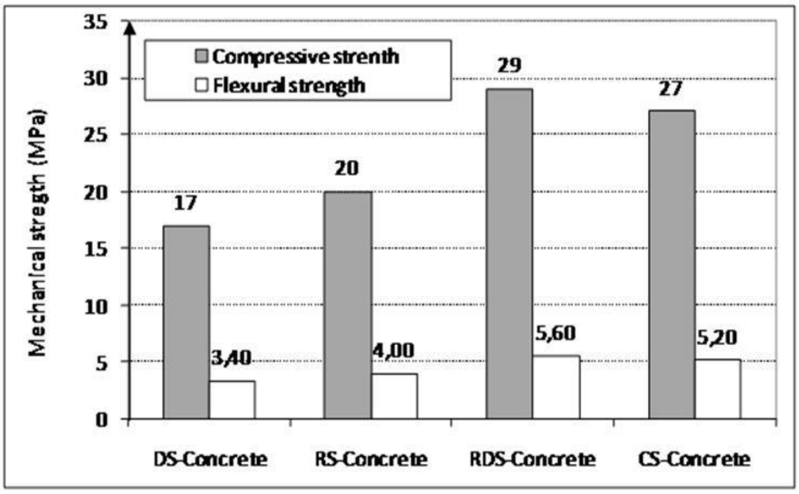


Fig. 7 Mechanical strength according to the sand type

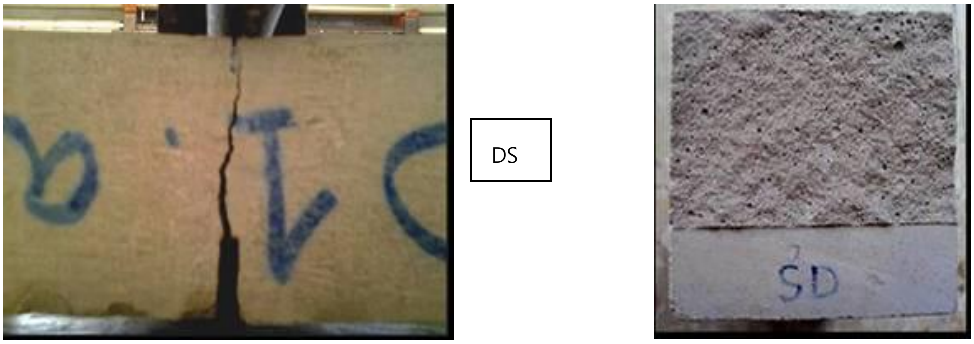
the values " $\partial C(a)/\partial a$ " are determined from the derivative of the function of the trend curves (C = f(a)) using Fig. 6. The obtained results of the energy release rates are shown in table 5.

From these results, we note that:

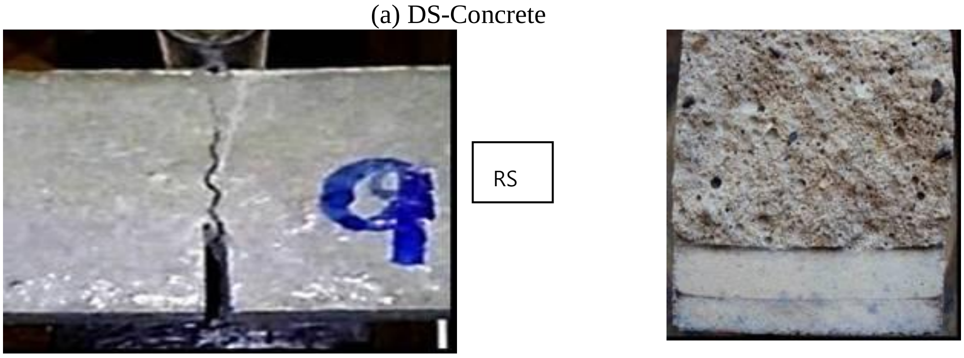
For most results, the changes in Gc, with respect to the crack length do not exceed 15%. Indeed, it is because of the heterogeneity of concretes that the crack, during its propagation, is confronted to hard points (aggregates) and weak points (flaws in cement paste). So in general, the crack goes through the interface 'cement paste – aggregate' while avoiding aggregate grains. Although the size of the used specimens ($7 \times 7 \times 28$ cm^3) is much higher compared to the maximum diameter of the sand grains (5 mm), the small size of the used specimens can be another factor which influences these variations: at the extremity of the crack, there is an inelastic zone whose dimensions must be very small compared to the dimensions of the elastic field which is around it. ENTOV and YAGUST were the first to make these findings and to perform tests on samples of large sizes (Shah 1991). Regarding the particle size distribution of aggregates, and comparing the effect of RS with DS which are characterized by the same nature and the same grain shape, it appears that for the sand concrete with rounded aggregates, the energy release rate increases when the aggregate size increases. RS-Concrete (Dmax =5 mm) seems to be the best to resist to the crack propagation compared to DS-Concrete (Dmax = 0.63 mm). The RDS-Concrete (spread particle size distribution) presents high values compared to DS-Concrete (tight particle size distribution).This remark explains once again the influence of the particle size of sand. So, the increase in the maximum grain diameter increases the resistance to crack propagation and improving the particle size distribution gives the better results. These results also come to confirm the results previously found in mechanical properties (Fig. 7).

Indeed, it should be noted that the presence of coarse grains in concrete opposes to the propagation of the crack, or at least force it to bypass around them which is more difficult and increases the resistance of sand concrete to the crack propagation. Fig. 8 shows the general aspect of the crack during its propagation. It's clear that the coarse grains make the crack more corrugated (cases of RS, RDS and CS-Concretes). In the case of fine grains (case of SD), the crack seems more rectilinear and direct. In addition, the angular shape of grains (case of CS) makes the crack line more broken and opposes further to crack propagation compared to rounded grains (case of RS). So, comparing the effect of the type of sand, the CS-concrete presented the higher results concerning the energy release rate compared to DS and RS-Concretes. This is due, in particular, to the limestone nature of sand and its angular shape. However due to its good particle size distribution, RDS-Concrete presented the highest values. But the difference is relatively low, which suggests that it is highly possible that by correcting the particle size distribution of the CS, the CS-Concrete resumes its first place. This observation is also made in mechanical properties study (Fig. 6) (Rocco and Elices 2009). In fact, the angular shape of crushed grains, gives good entanglement of granular skeleton, which makes the crack propagation more difficult. Moreover, the increase of the maximum diameter of sand grains increases also the fracture properties: with similar nature, the RS (Dmax = 5 mm, siliceous nature) presents results better than those of DS (Dmax = 0.6 mm, siliceous nature).

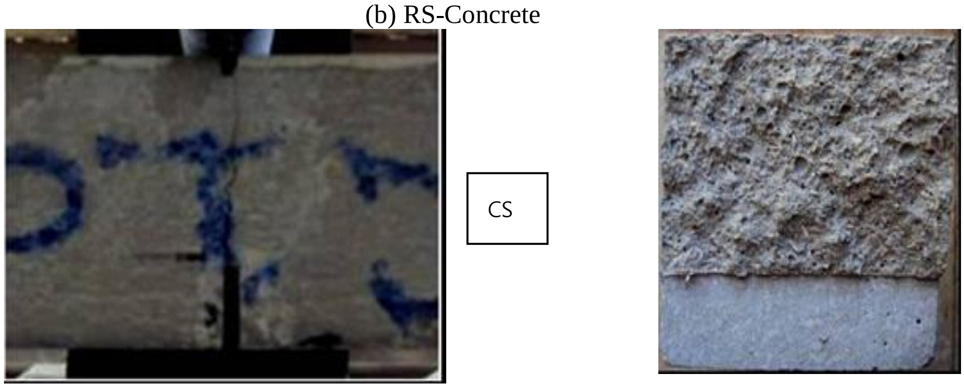
It should be noted that, fracture surfaces of all studied sand concretes show relatively weak matrix–aggregate interfaces, since they revealed that almost all aggregates were debonded and not broken (Fig. 8), i.e. the crack had passed through the interface zones (inter-granular fracture). Fig. 8 also shows that the high energy release rate values found in the case of RDS and CS-Concretes are due to the high compactness of the latter.



(a) DS-Concrete

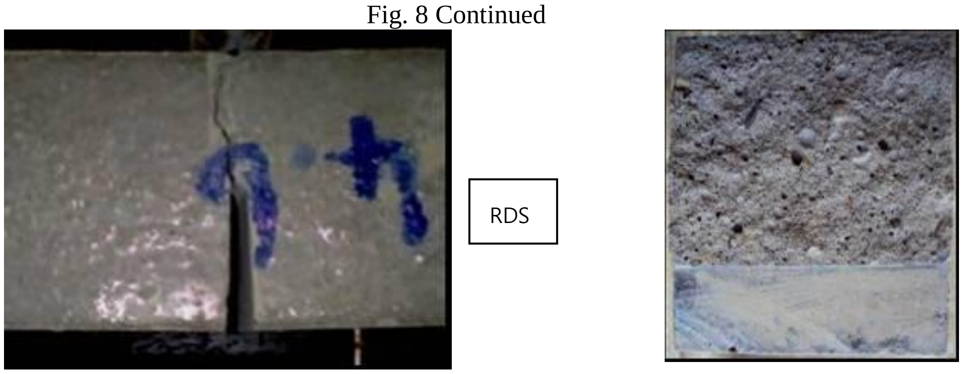


(b) RS-Concrete



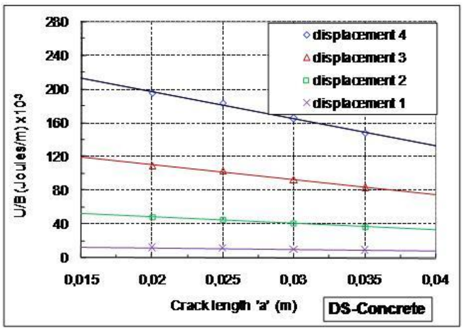
(c) CS-Concrete

Fig. 8 Continued

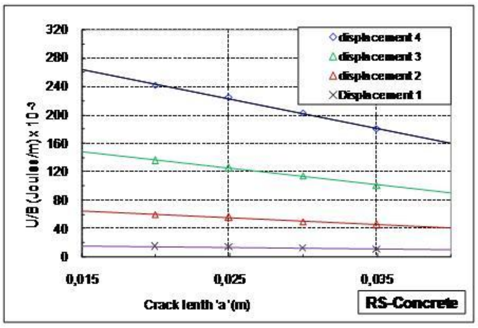


(d) RDS-Concrete

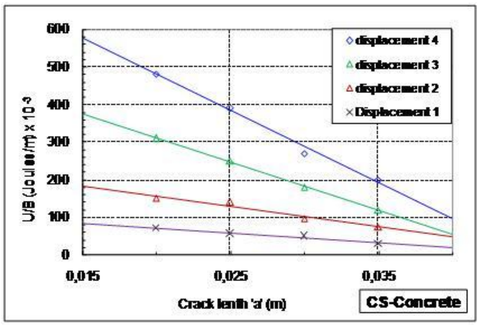
Fig. 8 Aspect of crack and fracture surface.



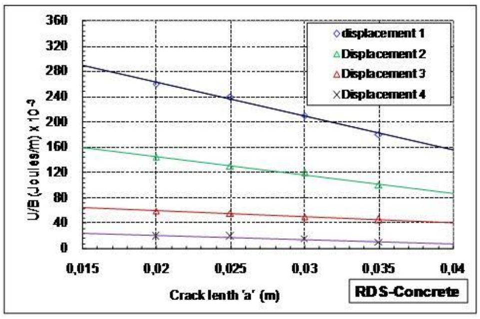
(a) DS-Concrete



(b) RS-Concrete



(c) CS-Concrete



(d) RDS-Concrete

Fig. 9 Strain energy versus crack length for different displacements

3.2.3 J-integral value (J_c)

The J-integral is perhaps the most useful quantity for the analysis of the mechanical fields near crack tips in both linear elastic and non-linear elastic materials. In our case, the J-integral is also determined for the four studied sand concretes. To do this, the strain energy curves (per unit thickness) for various displacements ($\delta 1$, $\delta 2$, $\delta 3$, $\delta 4$) and for the crack lengths a_1, a_2, a_3 and a_4 are used (Fig. 9).

Linear smoothing gives good results. The shape of experimental curves $U = f(a)$ for δ constant, suggests a relationship of the form

$$U = \alpha . \alpha + \beta \tag{3}$$

where α and β are constants which can be determined for each value "δ"

J-values are determined using the relationship having the following form

$$J = \left(\frac{1}{B}\right) \cdot \left(\frac{\partial U}{\partial a}\right) \tag{4}$$

where

U: is the strain energy,

B: is the width of the specimen,

a: is the crack length.

The obtained values are presented, for all studied sand concretes, in Table 5.

The calculated values of Jc are independent of crack length, which allows it to be considered as a material-specific characteristic. Similarly, they are found almost slightly higher than the corresponding Gc values (Fig. 10), which can confirm that the sand concrete behaves as a quasi-brittle material. It therefore has the same behaviour presented by ordinary concrete. Let's note that the fracture behaviour of quasi-brittle materials (like cement mortar for example) is greatly influenced by the fracture process zone ahead of the crack tip.

Moreover, the obtained results show that the fracture parameters of the sand concrete are slightly lower than those of ordinary concrete (due to the particle size effect) and comparable to those of mortar. According to well-defined compositions, Elices M.*et al*. found fracture energy values of about 31-36 J/m^2 in the case of concrete and 23 J/m^2 in the case of mortar (Elices and Rocco 2008).

Finally, it should be noted that although the mechanical properties of sand concrete are slightly lower than those of ordinary concrete, it has other best properties such as thermal properties, surface appearance, ease of pumping and projection, absence of segregation, etc. due to its low granularity. In addition, we also notice that the resistance of the concrete to the crack propagation is not only related to the type of sand (nature, grains shape, particle size distribution, etc.), but also

Table 5 PR, G_c and Jc obtained for different crack lengths.

Sand	a (cm)	2	2.5	3	3.5
DS-Concrete	P_R(N)	1750	1350	1150	1110
	G (J/m^2)	14.70	16.0	14.40	13.10
	G_{moy}(J/m^2)	14.55 ± 1.45			
	J_{moy}(J/m^2)	15.82			
RS-Concrete	P_R(N)	2010	1660	1430	1210
	G (J/m^2)	16.90	16.90	17.70	17.30
	G_{moy}(J/m^2)	17.20 ± 0.40			
	J_{moy}(J/m^2)	19.94			
CS-Concrete	P_R(N)	2555	2465	1900	1445
	G (J/m^2)	26.25	28.68	24.7	21.7
	G_{moy}(J/m^2)	25.33 ± 3.49			
	J_{moy}(J/m^2)	27.46			
RDS-Concrete	P_R(N)	2300	1850	1580	1400
	G (J/m^2)	22.10	25.80	25.70	24.40
	G_{moy}(J/m^2)	24.50 ± 1.49			
	J_{moy}(J/m^2)	26 ± 4.52			

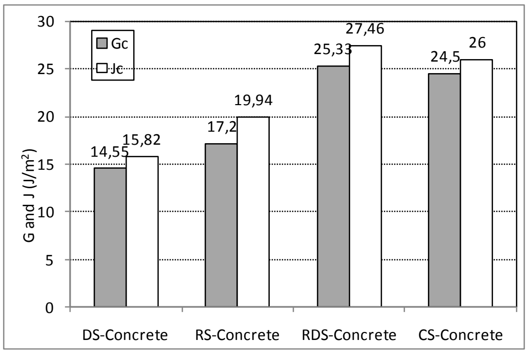


Fig. 10 Gc and Jc according to the sand type

depends on the nature and morphology of the hydration products in paste cement. It is obvious that these products present different morphologies and different shapes (Reis 2012). However, it's obvious that in most cases of concrete and mortar, the crack passes through the interface "ement paste-aggregate"zone.

4. Conclusions

This study was conducted to assess the effect of the type of sand on the fracture properties of sand concrete. This study led to the following conclusions:

- The mechanical and fracture properties of sand concrete are influenced by the nature and physical properties of sand: an angular shape, a high maximum diameter, a good granular distribution, a limestone nature give the best results.
- The values of critical energy release rate obtained for all studied sand concretes are lower than those of concrete and almost comparable to those of mortar.
- The sand concrete behaviour can be considered as elastic quasi-brittle material.
- Regarding the effect of the type of sand, we immediately notice that the particle size distribution has significant influence: a high maximum diameter (RS and RDS) and a good size distribution (RDS) improve the resistance of the sand concrete to the crack propagation; By increasing Dmax of sand grains from 0.63 mm (DS) to 5 mm (RS), Rc and Gc increase of about 17.65% and 18.21% respectively.
- The most important conclusion which can be noted is that the angular shape of sand grains (CS) gives more resistant sand concrete to crack propagation than rounded shape (DS and RS) and similarly, the sand nature has also an important influence on the fracture properties of sand concrete: By replacing the siliceous nature (RS) of sand by limestone nature (CS) and by modifying the rounded shape of grains (RS) by angular shape (CS), Rc and Gc increase of about 35% and 47.26% respectively.
- Good granular distribution also gives better results.
- In addition, CS-Concrete also presents another advantage of economic nature: thanks to its high content of fine elements, CS does not need the use of any filler.

Finally it should be noted that these results confirmed the results already found in the previous works of physico-mechanical characterization.

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