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# Valorization of marble's waste as a substitute in sand concrete

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**Abstract.** The recovery of waste proves a solution with two impacts: the environmental impact by the reduction of pollution and the gain of the occupied space by this waste, and the economic impact by the use of these lasts in the building and in the area of public works. The present research consists in recovering a waste marble (thrown powder exposed to the different meteorological phenomena) generated by the quarry marble of Fil-fila, located at the east side of Skikda in the north-east of Algeria, and add it, as sand in the composition of sand concrete. To carry out this research, we analyzed the evolution brought by the substitution of ordinary sand by marble waste sand, with 25%, 50%, 75% and 100% on the properties in the fresh state (density, workability and air content) and in the cured state (compressive strength, tensile strength, surface hardness and sound velocity). For durability we tested water absorption by immersion and chloride penetration. The results obtained are compared with control samples of 0% of substitution rate. In order to have a good filling of the voids in the granular skeleton; we added a quantity of limestone recycled fines from the quarries and for a good workability a super-plasticizing additive. The results showed that the partial substitution modified both the fresh and the hardened characteristics of the tested concretes, the durability parameters also improved.

**Keywords:** valorization; sand concrete; substitution; quarry waste; marble; mechanical performance; durability

## 1. Introduction

The sand concrete is a fine concrete consisting of a mixture of sand, cement, additions and water; it usually includes one or more adjuvant(s) and possibly additions. It has been the subject of various studies in which it has been shown that sometimes sand concrete can compete with traditional concrete in certain uses (Sablocrete 1994), it has interesting specific properties, such as the resistance, the lack of segregation and good surface appearance and small particle size, which favor its use in some structures and its lower cost without the use of large aggregates.

The recovery and upgrading of waste, especially those from quarries, is also a hot topic. To do this and to improve the properties of sand concrete, several scientific researches have been done in this area. Among the waste used is marble waste, studied by several authors such as Hebhoub *et al.* (2011, 2011, 2014), Djebien *et al.* (2015). The objective of our research is composed of three main horizons: the protection of the environment by the elimination of the waste of marble's quarries harmful for the nature, the exploitation of colossal quantities of sand existing in the Sahara of our country Algeria, which covers 80% of the total area, about 2 millions km², therefore we will be able to reduce the cost of construction with a possible replacement of ordinary concrete by sand concrete.

Several lines of research were based on the use of marble waste; in many forms; powder, sand and granulate; in the mortar, in the cement and in the different types of concrete.

Corinaldesi *et al.* (2010) they studied the effect of marble powder on mortar and concrete. By using super plasticizing and 10% of substitution of sand by the marble waste powder, the maximum compressive strength at 28 days of curing was obtained, comparing to the reference mixture at the same workability level. Due to its filler ability, marble powder had a positive effect at early ages too. Hebhoub *et al.* (2011) studied the use of marble waste in hydraulic concrete as a substituent; they used 25; 50; 75 and 100% of replacement ratios in volume of sand, properties of fresh and hardened state were enhanced, compared to the initial state and the only use of marble waste in concrete. Hebhoub *et al.* (2011) studied the use of waste marble aggregates in concrete, they found that compressive and tensile strength were been improved; insignificant change in density, but workability decreased when increasing substitution ratios. Omar *et al.* (2012) studied mechanical properties of fresh and hardened concrete, by partial replacement of sand with ratios of 25%; 50%; 75% at first, and by admixture of marble powder with proportions of 05%; 10%; 15%, at second. Better performances were found when both of limestone waste and marble powder were mixed. Compressive strength was increased of 7% when using 50% of limestone replacement with marble. Tensile and flexural strength increased too, especially with 15% of admixture of marble powder. However, strengths became lower when replacement ratio was more than 50%. Aliabdo *et al.* (2014) studied the effect of cement replacement and sand replacement in concrete by

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waste marble dust, using ratios of: 5%; 7.5%; 10% and 15% by weight and water to powder ratio (w/p) or water to cement ratio (*w/c*) were 0.50 and 0.40 in case of cement replacement and in case of sand replacement respectively. Mechanical and physical properties have been enhanced, especially when using sand replacement. Marble dust had a filler effect in concrete without affecting the hydration process; but it had no effect on ultrasonic pulse velocity. Hebhoub *et al.* (2014) studied the introduction of sand marble waste in the composition of mortar. Results show that marble waste improved density; workability was found to decrease when increasing replacement ratio; good compressive strength at early age only, presence of carbonates in marble waste gave good bonding (matrix/granulates), resulting a good tensile strength. Rodrigues *et al.* (2015) studied the mechanical properties of structural concrete containing very fine aggregates from marble cutting sludge at 0%, 5%, 10% and 20% of the total volume of cement, with incorporation of plasticizers; results show that these properties tend to be lower, but they were improved when using plasticizer with replacement ratio up to 10%. Djebien *et al.* (2015) studied the effect of marble waste fines on rheological and hardened properties of sand concrete, they concluded that marble fines enhanced fresh properties by increasing the bond strength of concrete; the best mechanical properties were found at 10% of substitution of dune sand. Gulden *et al.* (2015) investigated the properties of hardened concrete produced by waste marble powder. It was found that using of waste marble in the conventional concrete as binder or fine/coarse aggregate had positively affected the properties of hardened concrete. But, the mechanical properties of self-compacting concrete have been decreased. Aditya *et al.* (2015) studied sustainable use of marble slurry MS in concrete, it was found that 10% Portland cement can be substituted by MS. Workability was reduced and durability properties were enhanced, as water permeation, chloride migration and corrosion. Gulden *et al.* (2016) the study was done about durability properties of concrete produced by marble waste as aggregate or mineral additives to conventional or self-compacting concrete; so, water absorption; permeability; resistance of chloride penetration and sulfate attack were improved. Manpreet *et al.* (2017) investigated the effect of partial replacement of cement by waste marble slurry. It was found an improvement of mechanical properties when 15% of dried marble slurry was used to replace cement. Addition of marble slurry, in concrete, increased bond strength. Otherwise, no significant result on ultrasonic pulse velocity. Djebien *et al.* (2018) studied used waste marble as sand in formulation of self-compact concrete; it was found that density, air content and the ability of SCC to flow were decreased. Marble waste confers more cohesion and resistance to segregation.

In our work, we introduced in the formulation of a sand concrete, a sand of white marble waste (powder thrown exposed to the various meteorological phenomena), of the derivatives quarry of Fil-fila located at 25 km in the east of the city of Skikda in the north-east of Algeria; in addition to the ordinary sand, we also find the fine limestone recovered from quarry's filters, that the quantities are abundant.

The marble waste of this quarry presents 20% of the production of the CHATT (Fil-fila) derivatives quarry marble, that is to say 10 440 tones for the year 2017. This waste occupies a huge space to the detriment of the space green, in addition and because of its fineness it flies and pollutes the air we breathe and contaminates the groundwater, through its infiltration into the ground, with the contribution of rainwater.

Table 1 Chemical and mineralogical composition of cement CEM I

| Components | Percentage (%) | Components | Percentage (%) |
|---|---|---|---|
| CaO | 63,69 | $SO_3$ | 2,08 |
| $Al_2O_3$ | 4,55 | $C_4AF$ | 16,20 |
| $Fe_2O_3$ | 5,03 | PAF | 0,70 |
| $SiO_2$ | 20,90 | CaO free | 0,75 |
| $Na_2O$ | 0,18 | MS | 0,75 |
| $K_2O$ | 0,33 | $C_3S$ | 67,35 |
| $Cl^-$ | 0,001 | $C_2S$ | 9,42 |
| $C_3A$ | 3,33 | | |

## 2. Used materials

The cement is a CEM I with low content $C_3A$ manufactured in Algeria, whose absolute density is 3,220 g/cm$^3$ with a specific Blaine surface area of 3025 cm²/g. the chemical and mineralogical composition is shown in Table 1.

- Siliceous dune sand, class 0/1 from Oued Z'hor in the west of Skikda, N-E of Algeria;

- Calcareous sand, class 0/3 from the quarry of Ben Brahim of Constantine, N-E of Algeria

- Class 0/2 limestone marble waste sand from the Fil-fila quarry, East of Skikda N-E of Algeria;

The particle size distribution of the three types of sand is shown in Fig. 1;

- The adjuvant is a super high plasticizer water reducer "Polyflow SR5400", in the form of light brown liquid with a PH = 5 and a density of 1.07.

- The fine limestone (fillers), recovered from the filters of the quarry of Ben Azzouz located in the East of Skikda (Algeria), passing through the 80 µm sieve to more than 80%.

- The different physical and chemical properties of aggregates are shown respectively in Tables 2-3.

According to the characterization tests, we find that:

The density of marble waste sand is high compared to that of dune sand (Table 2), but it is close to that of quarry sand, so the marble waste sand is the densest.

The fineness modulus of the marble waste sand is the lowest (Table 2) and indicates a predominance of fine-grained sand, an ease of implementation at the probable detriment of the resistance and a high demand for water, this result is consistent with that found by Hebhoub *et al* (2011).

Granulometric curves (Fig. 1) indicate that dune sand has a continuous granularity, quarry sand is normal while marble waste sand is predominantly fine-grained.

Marble waste sand has the highest fines content (6.12%)

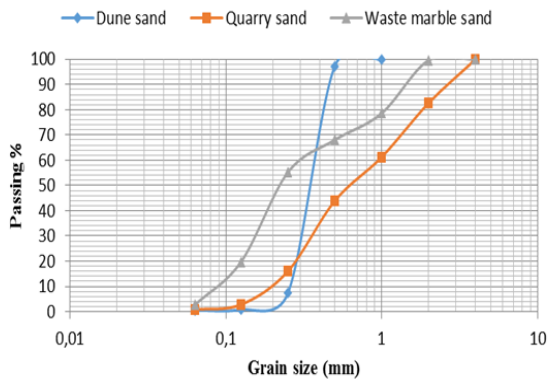


Fig. 1 Granulometric curves

Table 2 physical characteristics of granulates

| Characteristics | Dune sand 0/1 | Quarry sand 0/3 | Waste marble sand 0/2 | Quarry fillers |
|---|---|---|---|---|
| Apparent Density (g/cm³) | 1,52 | 1,45 | 1,680 | 1,05 |
| Real density (g/cm³) | 2,591 | 2,614 | 2,666 | 2,74 |
| Sand equivalent (%) | 86,30 | 60 | 67,10 | / |
| Water absorption (%) | 3,35 | 2,01 | 5 | / |
| Fineness modulus | 1,95 | 2,93 | 1,79 | / |
| Blue methylene value | 0,7 | 0,8 | 0,6 | / |

compared to quarry sand with 0.84% and sand dune with 0.01%.

According to the chemical analyzes in Table3, the marble waste sand is limestone (98% $CaCO_3$) so a good matrix/granulate bonding, (Dreux and Feasta 1996, Hebhoub *et al*. 2014) this sand is rich in CaO which offers a lot of C3S generating high resistance at young age.

## 3. Program

The Concrete formulation was established according to the experimental method of Sablocrete project (1994) based on the determination of the volumes of the various components, the properties of control concrete, fresh or hardened and the methods of verification of these properties are identical for the sand concrete (Omar *et al.* 2012). The substitution is made by replacing a volume of ordinary sand with the same volume of the marble waste sand; afterwards the quantities were calculated by weight. The water to cement ratio, the cement dosage and the amount of the adjuvant are then set, while varying the 25%, 50%, 75% and 100% substitution rates of two types of ordinary sand. The fines content is a function of the nature of ordinary sand.

*Prepared mixes of sand concrete:*

DSC 0%: Dune sand concrete (control mix)
DSC 25%: Dune sand concrete with 25% of waste marble sand
DSC 50%: Dune sand concrete with 50% of waste marble sand

Table 3 Chemical composition of granulates

| Chemical components | Dune sand 0/1 | Quarry sand 0/3 | Waste marble sand 0/2 | Fillers |
|---|---|---|---|---|
| $CaCO_3$ | 8,80 | 82,80 | 98 | 84,60 |
| CaO | - | 55,45 | 55,29 | 55,80 |
| $SO^{--}_4$ | - | - | - | - |
| $Cl^-$ | 0,21 | 0,000 | 0,24 | 0,21 |
| $Al_2O_3$ | - | 0,18 | 0,08 | 0,01 |
| $Fe_2O_3$ | - | 0,08 | 0,04 | 0,01 |
| $SiO_2$ | 95,21 | 0,33 | 0,15 | 0,14 |
| MgO | - | 0,25 | 1,03 | - |
| $Na_2O$ | - | 0,080 | 0,01 | 0,01 |
| $K_2O$ | - | 0,020 | 0,01 | 0,01 |

DSC 75%: Dune sand concrete with 75% of waste marble sand
QSC 0%: Quarry sand concrete (control mix)
QSC 25%: Quarry sand concrete with 25% waste marble sand
QSC 50%: Quarry sand concrete with 50% waste marble sand
QSC 75%: Quarry sand concrete with 75% waste marble sand
MWSC: Marble waste sand concrete, 100% of substitution.

*Used tests*

√ Slump test (Abrams cone) according to NF EN 12350-2 (2009)
√ Bulk density according to NF EN 12350-6 (2009)
√ Air content according to EN12 350-7
√ Compressive strength at 2, 7, 28 and 90 days according to NP EN 12390-3 (2011)
√ Splitting tensile strength at 2, 7, 28 and 90 days according to EN NF 12390-5
√ Ultrasonic pulse velocity according to NP EN 12504-4 (2004)
√ Schmidt hardness according to NF EN12 504-2
√ Water absorption by immersion according to NBN B15-215
√ Chloride penetration according to UNI 7928

## 4.Results and discussion

### *4.1 Density*

The introduction of marble waste sand by substituting quarry sand or dune sand in sand concrete increased the density of control mixtures (Fig. 2); an optimum density is observed for QSC 25%, as Hebhoub *et al.* (2011) and DSC50%. Those are the most compact mixtures. At 100% of substitution, the density obtained is higher than those obtained for the control concretes DSC 0% and QSC 0%, because the marble waste sand has the highest density according to Djebien *et al.* (2015). If we compare the occluded air rates (Fig. 4) with the densities, we find that this variation is logical.

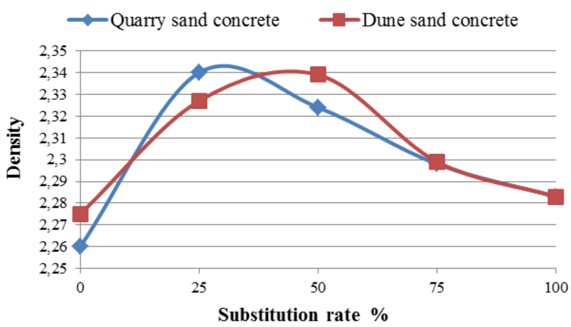


Fig. 2 Evolution of density

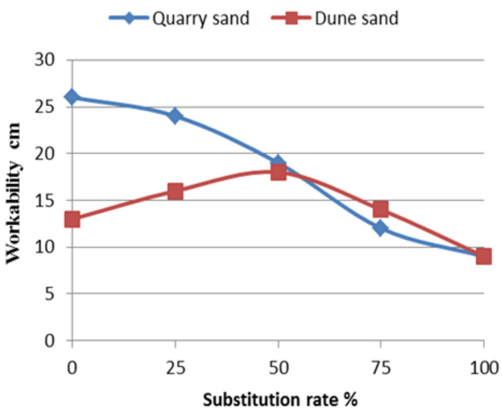


Fig. 3 Evolution of workability

### *4.2 Workability*

Fig. 3 shows that for the same water to cement ratio *W/C* and the same content of adjuvant and the same content of limestone fillers; the workability of DSC, increases with the increase of the substitution rate up to 50%, beyond this value the effect is reversed. On the other hand, the workability of the quarry sand concrete, decreases continuously with the increase of the substitution rate, at 50% and 75% the two concretes have almost the same workability.

It can be said that above 50% of the substitution rate the workability of both types of concrete decreases; this may be due to the water absorption capacity by the marble waste sand; what was found by Bicini *et al.* (2007), Hebhoub *et al.* (2011), Belaidi *et al.* (2012), Djebien *et al.* (2015).

The decrease in workability is also due to the angular shape of the grains of the marble waste sand, leading to a high friction between its grains (Djebien *et al.* 2018).

In general manner, DSC mixes are less workable than QSC mixes, because dune sand has a high water absorption coefficient, and a modulus of fineness lower than 2.2, according to Manpreet *et al.* (2017).

### *4.3 Air content*

The introduction of marble waste sand decreases the air content in DSC (Fig. 4); this decrease is due to the fineness of the marble waste sand, which leads to a good compactness. What has been observed by Hebhoub *et al.* (2011), Manpreet *et al.* (2017).

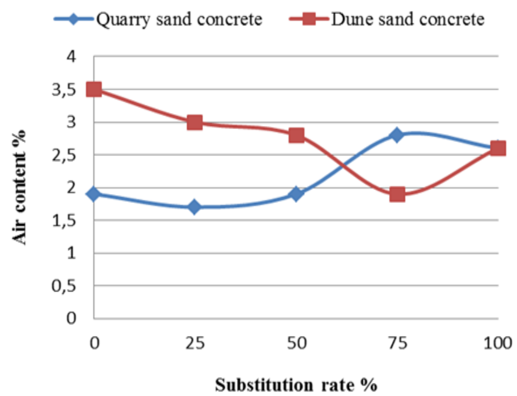


Fig. 4 Variation of air content function to substitution rate

For the QSC quarry sand concrete, the occluded air content increases with the increase in the substitution rate due to the crushed nature of the marble waste sand and quarry sand.

### *4.4 Compressive strength*

Fig. 5 clearly shows that the resistances obtained for QSC are much better than those obtained for DSC; Ceylan *et al.* (2013) found that the compressive strength obtained with a quarry aggregate is better than that obtained with 100% marble waste. Since the young age (Figs. 5(a) and 5(b)), 25% of substitution gave the best resistance either with the quarry sand or with the sand of dune, at a young age the concrete of sand of marble waste gave a resistance lower than that obtained for the others mixtures except the control DSC, unlike Hebhoub *et al.* (2011); this trend will change from seven days of cure until 90 days (Fig. 5(d)). The development of compressive strength may be due to active $SiO_2$ in marble waste reacting with $Ca(OH)_2$ to form the secondary hydrates of calcium silicates to be chemically stable and denser on the structure according to Omar *et al* (2012). The compressive strength of DSC increases only for the 25% rate, before decreasing by raising the rate of substitution. The same trend of variation is observed for all cure ages, so the latter was affected by the presence of marble waste as a partial substituent at 25% (Fig. 6).

The evolution of the compressive strength (Fig. 7) of the QSC has the same tendency as in the DSC but, the QSC have reached a resistance very close to an ordinary concrete, already having a value of 22 MPa at 7 days and 25 MPa after 28 days of cure, and this for a partial substitution of 25%, according to Hebhoub *et al* (2011), and Abdo *et al* (2014) who found an optimum of resistance with 15% substitution of sand.

MWSC marble waste sand concrete gave a higher compressive strength than the DSC control mix, but it remains lower than that obtained with the QSC 0%, because of the crushed shape of the quarry sand and the marble waste sand that gives more cohesion compared to rolled sand.

### *4.5 Tensile strength*

For the tensile strength; the highest one were obtained

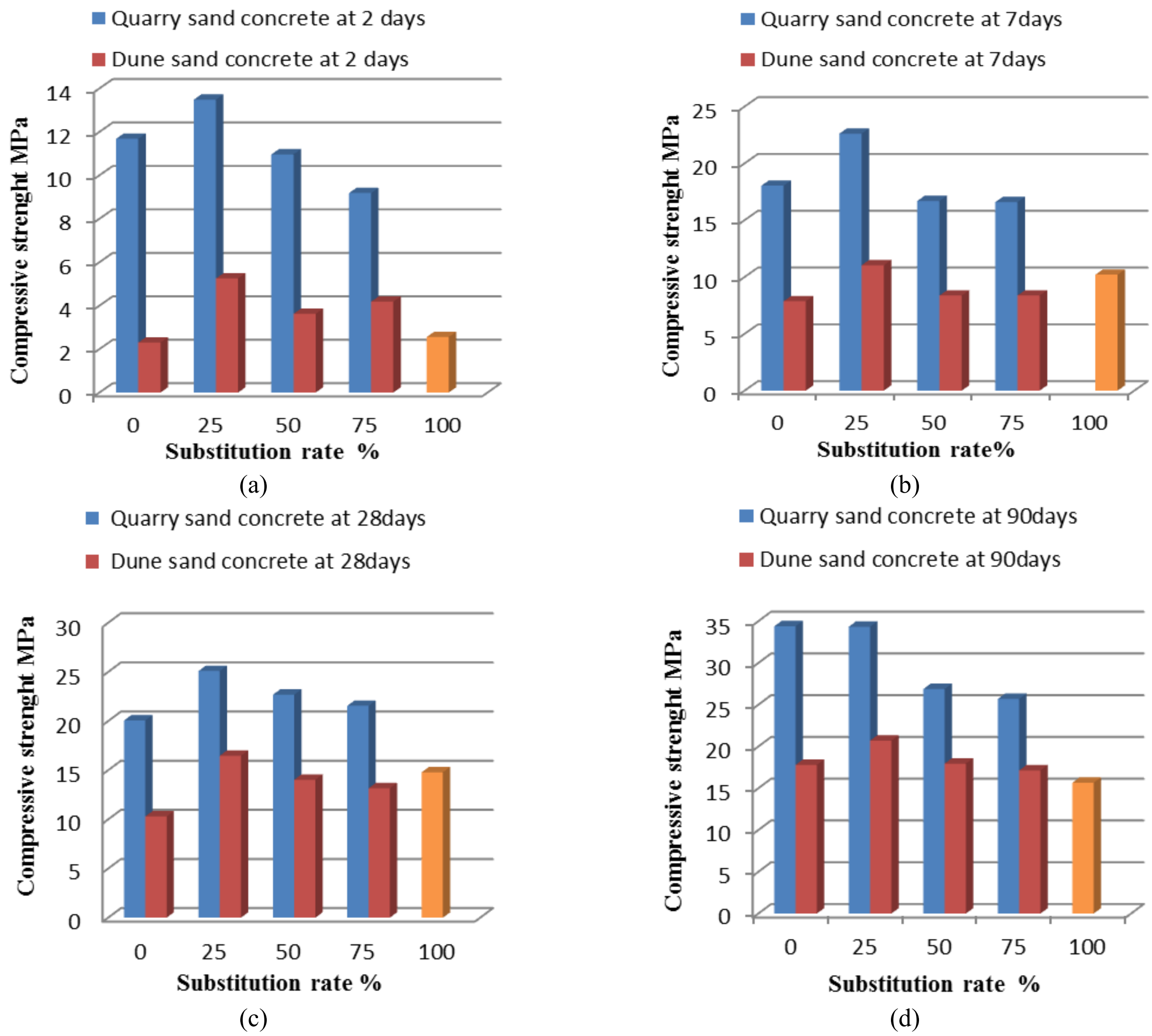


Fig. 5 Compressive strength of QSC versus DSC at: (a) 02days; (b) 07days; (c) 28days; (d) 90days

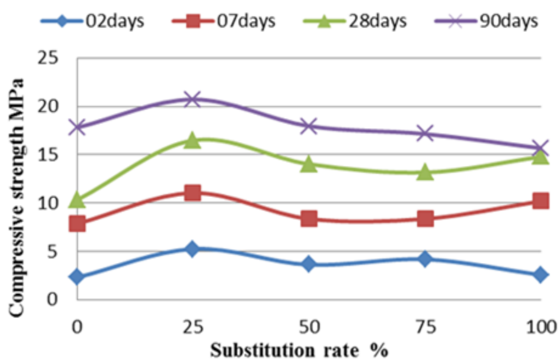


Fig. 6 Compressive strength of dune sand concrete at different cure ages

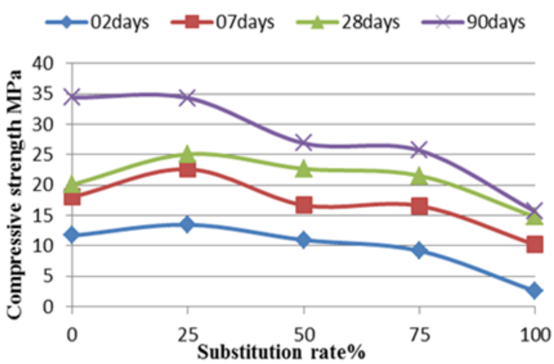


Fig. 7 Compressive strength of quarry sand concrete at different cure ages

by the control QSC mix and the QSC 25%. The tensile strength dropped with the substitution rates of 50%, 75% and 100%. We can say that the substitution did not improve the tensile strength of our mixtures; (Omar *et al.* 2012); Aliabdo *et al.* (2014) found an optimum around 10% substitution, (Figs. 8 and 9) At young age (Fig. 10a); QSC achieved a fairly high tensile strength, compared to DSC, due to the good cohesion of quarry sand because of its crushed nature and CaO content. With 25% substitution in the QSC, the tensile strength decreased, while there was a small increase in the control DSC, at 50% the two concretes were equal, to increase at 75%.

The marble waste sand concrete MWSC has a resistance equal to that obtained with DSC control mix; at the age of 7 days (Fig. 10b), we have the same trend as for the 02 days, but here the marble waste concrete has exceeded the DSC

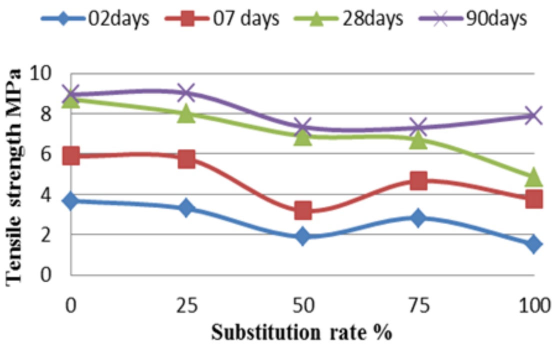


Fig. 8 Tensile strength of quarry sand concrete at different cure ages

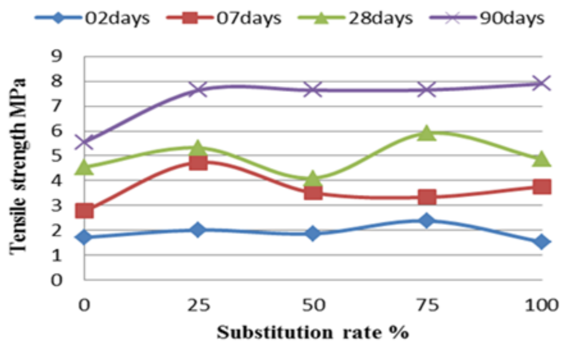


Fig. 9 Tensile strength of dune sand concrete at different cure ages

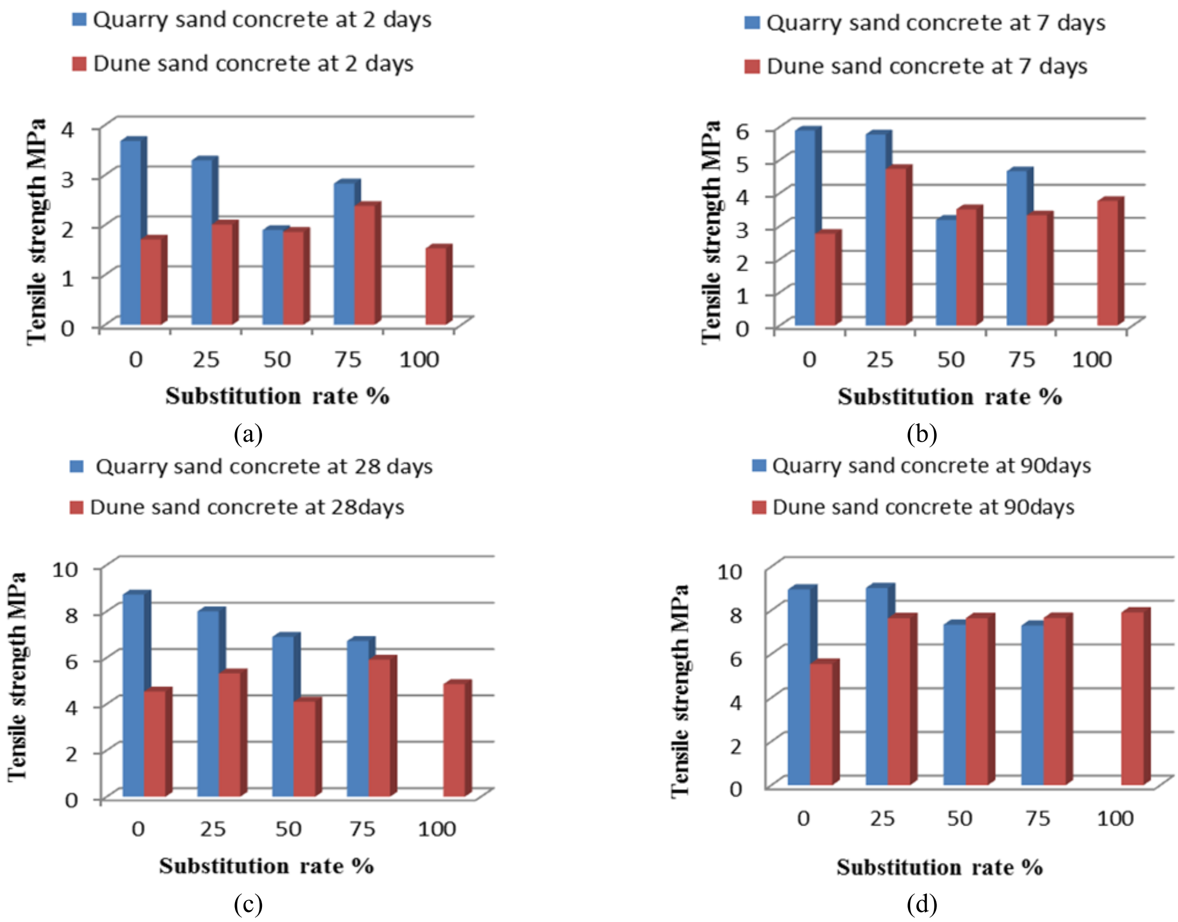


Fig. 10 Tensile strength of QSC versus DSC at: (a) 02days; (b) 07days; (c) 28days; (d) 90days

control mix (Fig. 10b); at middle age of 28 days (Fig. 10c); the tensile strength decreases with the increase of the substitution rate for the QSC, while at 75% in the DSC, the resistance increases because of the predominance of the marble waste which has improved the cohesion of the dune sand. After 90 days of cure (Fig. 10d), it is clear that the tensile strength has exceeded 7 MPa for all substitution rates either in quarry sand or dune sand, except for the DSC 0% whose resistance is remained lower than 6 MPa, it can be said that marble waste has improved the tensile strength especially with the use of dune sand; thanks to the good cohesion and the presence of carbonates, the same thing was observed by Hebhoub *et al.* (2011).

### *4.6 The sound propagation speed (ultrasonic test)*

The replacement of ordinary sand with 25% marble waste sand has slightly increased the density of the QSC mixture, which is justified by the rapid passage of sound (Fig. 11). It is recalled that this same mixture gave the maximum compressive strength with the destructive test. While in the DSC mix the propagation of the sound was slow with the mixture replaced by 50% of marble waste sand, so this mixture is the least dense. Because the waste marble sand has created porosity in sand dune, this mixture is the least resistant.

Velocities ranging from 3.2 Km/s to 3.7 Km/s have

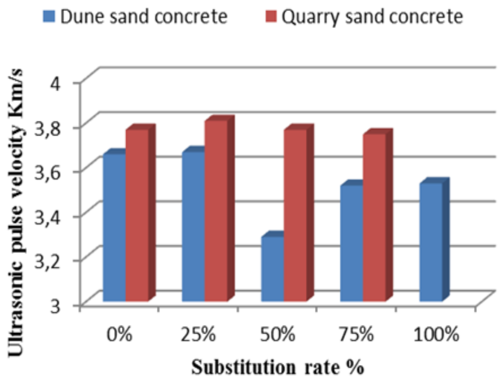


Fig. 11 Ultrasonic pulse velocity versus replacement ratios

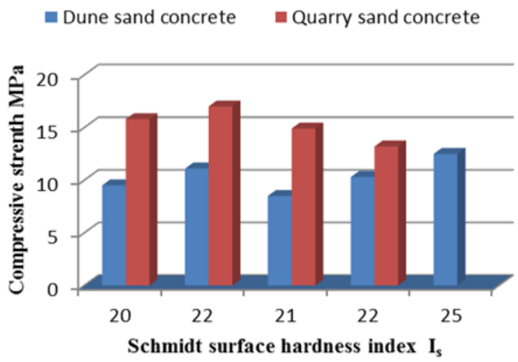


Fig. 12 Compressive strength versus Schmidt hardness index of QSC and DSC

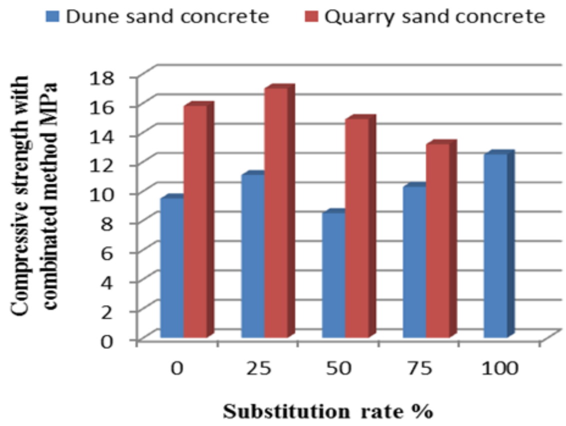


Fig. 13 Compressive strength calculated with the combined formula

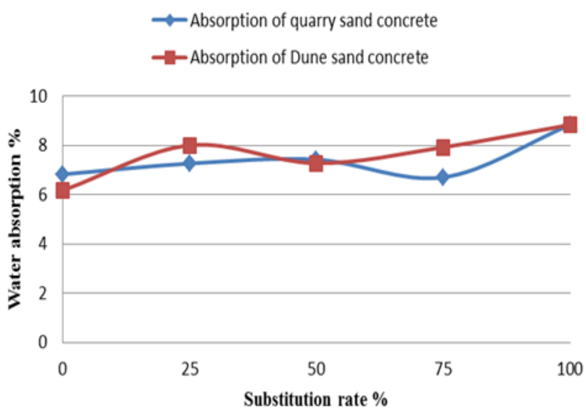


Fig. 14 Water absorption by immersion

average strengths, which is the case of DSC and MWSC marble waste sand concrete; while velocities ranging from 3.7 Km/s to 4.2 Km/s have high resistance, this is the case of the QSC quarry sand concrete (Demirel 2010), Aliabdo *et al.* (2014), Manpreet *et al.* (2017) found that the marble waste powder had no significant effect on the value of the speed of propagation of sound; the slight variation is due to the fact that the latter is proportional to the square root of the compressive strength. In contrast to Demirel *et al.* (2010) who states that the speed of sound propagation is improved with the increase of the substitution rate.

### *4.7 Compressive strength (bounce index/ultra sound velocity)*

Schmidt surface hardness index results (Fig. 12) and compressive strength calculated with combined formula between bounce index and ultra sound velocity (Fig. 13), show the same tendency observed with destructive test, despite of values; we always get the maximum resistance around 25% substitution of quarry sand as well as sand dune. So we can say that at this rate of ordinary sand replacement by the marble waste sand, we got the best performance.

### *4.8 Water absorption by immersion*

Absorption of water by immersion characterizes the open pores of the cement matrix at 28 days; the open porosity is due to the excess of water in the mixture which has not participated in the hydration of the cement nor absorbed by the aggregates, it also depends on the air trapped after vibration.

The curves in Fig. 14 show an unstable trend, as water absorption depends on pore size, distribution, and inter-connectivity (Aditya *et al.* 2015). The maximum absorption is achieved with the marble waste concrete; a result expected due to its workability in the fresh state (plastic concrete) due to its water absorption capacity, Gulden *et al.* (2015) found that the use of marble waste has positively affected water absorption.

### *4.9 Chloride penetration*

The lowest depth of penetration is obtained with the control concretes QSC 0% and DSC 0%, but it increased with the different substitution rates at 28 days (Fig. 15), whereas at 56 days (Fig. 16), the opposite effect is observed, which was observed by Gulden *et al.* (2016) due to the decrease in capillarity. Aditya *et al.* (2015) explained that water is the carrier of dissolved chloride ions, capillary in concrete, and that the addition of marble powder reduces these pathways. At 90 days of immersion (Fig. 17) penetration depth was more important at 50% substitution rate in QSC comparing it to DSC that the highest value was observed at 75% substitution rate but equal to both of control mixes.

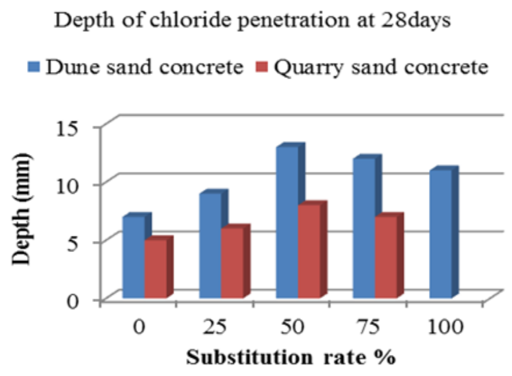


Fig. 15 Chloride penetration in sand concrete at 28 days

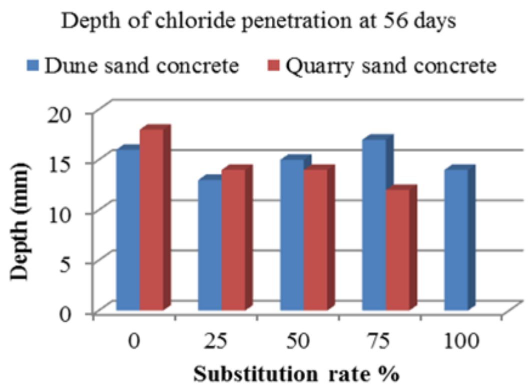


Fig. 16 Chloride penetration in sand concrete at 56 days

## 5. Conclusions

The study which is the subject of this article has reached the following conclusions:

- The characteristics of fresh sand concrete (air content and workability) have been improved with the partial substitution of ordinary sand with marble waste sand.
- The best compressive strength was obtained with a 25% substitution rate in quarry sand concrete; while the bending tensile strength was better with the control concrete, but a value close to 25% substitution was observed.
- Dune sand concrete is less resistant to traction and compression than quarry sand concrete, even with substitution.
- The partial substitution of 25% gave a better propagation of the sound as well as a better hardness of surface.
- The same tendency of improvement in compressive resistance was obtained with Schmidt hardness test and the values calculated with combined formula Schmidt hardness test and ultrasonic velocity; these results confirm that 25% of replacement of quarry sand gives the best compressive strength obtained by destructive and no destructive tests.
- The partial substitution has negatively influenced the penetration of chloride, as well as the absorption of water, so our mixtures are less vulnerable to external environments.

More durability parameters will be studied in future researches.

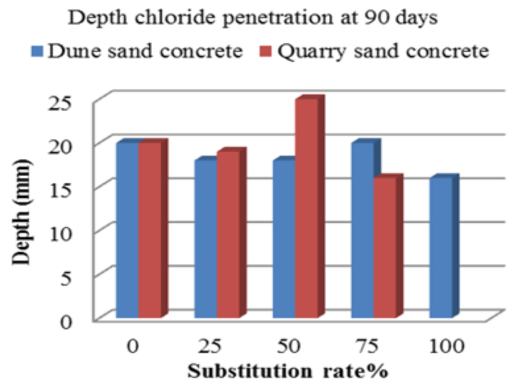


Fig. 17 Chloride penetration in sand concrete at 90 days

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