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Incorporation of marble waste as sand in formulation of self-compacting concrete

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Abstract. Concrete is the most widely used building material all over the world, because of its many technical and economic qualities. This pressure on the concrete resource causes an intensive exploitation of the quarries of aggregates, which results in a exhaustion of these and environmental problems. That is why recycling and valorization of materials are considered as future solutions, to fill the deficit between production and consumption and to protect the environment. This study is part of the valorization process of local materials, which aims to reuse marble waste as fine aggregate (excess loads of marble waste exposed to bad weather conditions) available in the marble quarry of Fil-fila (Skikda, East of Algeria) in the manufacture of self-compacting concretes. It consists of introducing the marble waste as sand into the self-compacting concrete formulation, with variable percentages (25%, 50%, 75% and 100%) and to study the development of its properties both in fresh state (air content, density, slump flow, V-funnel, L-box and sieve stability) as well as the hardened one (compressive strength and flexural strength).

The results obtained showed us that marble wastes can be used as sand in the manufacture of self compacting concretes.

Keywords: self-compacting concrete; marble waste; sand; performance

1. Introduction

This study, which is part of the valorization of industrial wastes and industrial by-products, aims to reuse marble waste as sand comes from a metamorphic rock (with a high calcium carbonate content $CaCO_3$) (Topçu *et al*. 2009) in the manufacture of self-compacting concretes which are fluid concretes coming into place without vibration, guaranteeing resistant and durable structures.

Several researchers have studied the effect of the addition of marble waste in different forms on the behavior of cements, mortars and concretes.

The work carried out by Aruntas *et al.* (2010) studied the possibility of using marble powder in the manufacture of cement through the substitution of clinker by marble powder (2.5%, 5%, 7.5% and 10%). They concluded that the marble waste powder does not affect cement setting time, improves its compressive strength, and reduces manufacturing costs with an optimum substitution rate of 10%. Corinaldesi *et al.* (2010) has shown that the use of marble powder in the making of mortars gives them good cohesion and improves the mechanical strength with an optimal dosage equal to 10%. Hebhoub *et al.* (2014) have experimentally attempted to use the marble waste sand that comes from the Fil-fila quarry in the manufacture of the mortars. They concluded that this material provides cohesion, improves mechanical strength and reduces mortar shrinkage values with optimal substitution rate equal to 100%.

Several researchers studied the possibility of using marble waste in the manufacture of concrete. Hebhoub *et al.* (2011) have incorporated the aggregates of marble waste into the formulation of ordinary concrete, substitution rates were changed from 0% to 100%. They noted that marble aggregates improve mechanical strength and workability when the rate of substitution is between 25% and 75%. The publications (Binici *et al.* 2007, Rai *et al.* 2011, Patel *et al.* 2013, Ergun 2011, Anwar *et al*. 2014, Sounthararajan and Sivakumar 2013, Vardhan *et al*. 2015, Ali and Hashmi 2014), have studied the effect of adding marble waste powder on rheological and mechanical performance of ordinary concretes. They have agreed that this powder can be used as fillers in concrete fabrication. In another work, Binici *et al.* (2007) were interested by the effect of marble and granite powder on the durability of ordinary concretes, and they were demonstrated that marble and granite improve resistance against sulphate ions attacks and reduce the penetration depth of chloride ions by 70%. Djebien *et al.* (2015) explained the improvement of the properties of sand concrete, based on marble waste fines in the fresh and hardened states by the plasticizing capacity and the filling effect that these fines play. The publications (Sadek *et al*. 2016, Tennich *et al*. 2015, Gesoglu *et al*. 2012) have shown the possibility of using marble powder in combination with other wastes in the formulation of self-compacting concretes. They also showed that marble waste powder improves the physical, mechanical properties and durability of self-compacting concretes.

The possibility of valorization of marble waste is studied not only in the manufacture of cements, mortars and concrete but also in other fields. A dosage of 15% to 20%

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Table 1 Characteristics of ordinary aggregates

Characteristics	CA 4/8	CA 8/16	DS
Apparent density (g/cm^3)	1.53	1.53	1.603
Absolute density (g/cm^3)	2.61	2.64	2.63
Sand equivalent (%)	--	--	75.89
Fineness modulus	--	--	1.90
Fines content (%)	--	--	0.48
VBS	--	--	0.77
Los Angeles	26	26	--
Micro deval	14.80	14.80	--

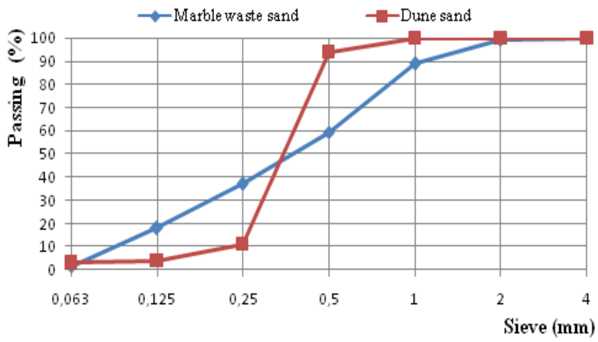

Fig. 1 Particles size distribution of sands

Table 2 Characteristics of marble waste sand

Characteristics	Marble waste sand
Apparent density (g/cm^3)	1.74
Absolute density (g/cm^3)	2.67
Sand equivalent	72.81
Fineness modulus	1.97
Fines content (%)	1.72
Absorption (%)	0.133
$CaCO_3$	98.67
CaO	55.29
Al_2O_3	0.14
Fe_2O_3	0.09
SiO_2	0.53
MgO	0.20
K_2O	0.01
Cl-	0.025
SO_3	0.04
Loss on ignition	43.40
Insoluble résidu	0.035

marble powder effectively improves the properties of bricks (Saboya *et al*. 2007). Akbult*et al*. (2007) demonstrated the possibility of using marble aggregates in bituminous concrete.

2. Materials characterization

The materials used for this study are:

- The cement used to formulate the various compositions of the self-compacting concrete is a cement CEM I of class 42.5 which comes from the Hdjar-soud plant (Skikda, East of Algeria).

- Crushed coarse aggregates CA of class 4/8 and 8/16 are used in this study. They have limestone nature from Ain Abid quarry, located in the East of Algeria.

- Siliceous dune sand DS of class 0/1 (rolled nature) comes from Oued Zhor région (Skikda-East of Algeria). The results of the characterization tests of the ordinary aggregates are presented in Table 1.

- Marble waste sand MS of class 0/2 of crushed nature, comes from the marble quarry of Fil-fila (Skikda-East of Algeria). The results of the characterization tests of this type of sand are given in Table 2.

- Polyfow SR5400 superplasticizer based on modified carboxylates. It is in the form of a light brown liquid of PH 5 with an absolute density of 1.07 g/cm^3.

Moreover, particles size distribution of both sands used is presented in (Fig. 1).

According to the characterization tests, it can be seen that:

-The density of marble waste sand is close to that of ordinary sand.

- The fineness modulus of both sands used indicate a majority of fine grains and high water demand (Dreux and Feasta 1996).

- The VBS value of dune sand is 0.77, which represents very small clay content.

-The distribution of particles size curve of both sands presents an average regularity of the granularity.

According to the results of the sand equivalent test, both sands are clean with a low percentage of fines, perfectly suited for quality concrete.

According to chemical analyzes, the marble waste sand has a $CaCO_3$ content equal to 98.67%. This is a sign that this type of aggregate has a good bonding with cement paste (Dreux and Feasta 1996).

3. Production of mixtures

In this study we substituted ordinary sand (dune sand) by marble waste sand in the formulation of self-compacting concrete with substitution rates (0%, 25%, 50%, 75% and 100%).

The formulation of the mixtures is carried out by the Japanese method. For all mixtures studied, the cement dosage, the water dosage and the superplasticizer dosage are kept constant at 545 kg/m^3, 218 l/m^3 and 9.90 l/m^3 respectively in order to study the effect of marble waste sand on the behavior of self-compacting concrete.

For these concretes we carried out measurements of air content, density, slump flow, V-funnel, L-box and sieve stability in the fresh state, and on hardened concrete, measurements of compressive strength on 16×32 Cm specimens and flexural strength on 7×7×28 Cm specimens.

The specimens were cured under water (specimens were immersed in water at 20°C±2 and 100% RH).

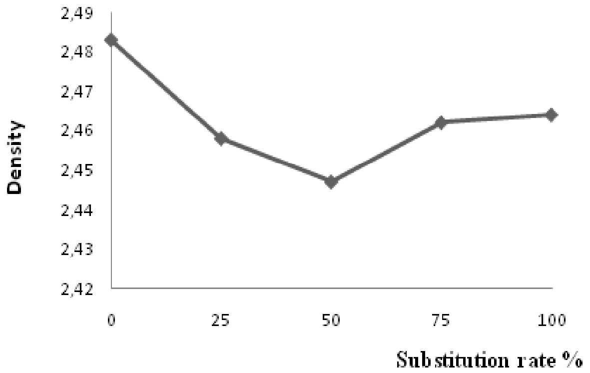

Fig. 2 Influence of substitution rate on density of self-compacting concrete

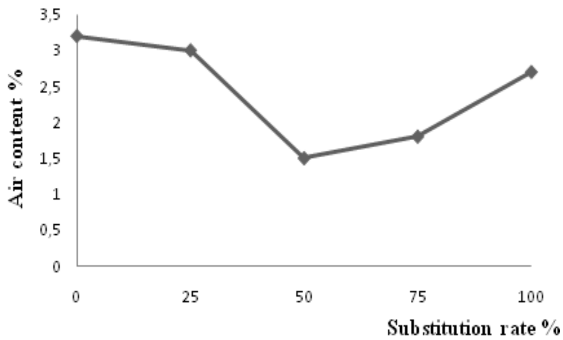

Fig. 3 Influence of substitution rate on air content of self-compacting concrete

4. Results and discussions

4.1 Density

The substitution of dune sand by marble waste sand decreases the density of the self-compacting concrete until 50% of substitution where the effect is reversed but the density values are still lower than those of concrete based on dune sand (Fig. 2). This trend can be explained by the shape and nature of sand dune which is finer than marble waste sand and which penetrates easily into the porosity of coarse aggregate and makes the concrete denser (De larrard 1999).

4.2 Air content

Fig. 3 shows the variation of the air content as a function of the substitution rate of dune sand by the marble waste sand. It is noted that the introduction of the marble waste sand into the self-compacting concrete composition decreases the air content with an optimal content equal to 1.5% which corresponds to a substitution rate equal to 50%. This decrease can be explained by the plasticizing capacity of marble waste sand which ensures the laying between the components by decreasing the volume of air (Corinaldesi *et al.* 2010, Djebien *et al*. 2015).

4.3 Slump flow

It is noted that the spreading values remain almost insensitive if the substitution rate does not exceed 50%. Beyond this percentage, the spreading value starts to decrease but remains acceptable. This decrease is due to the angular shape of the grains of the marble waste sand which is characterized by high friction and which decreases spreading values of self-compacting concrete. (Hebhoub *et al.* 2011).

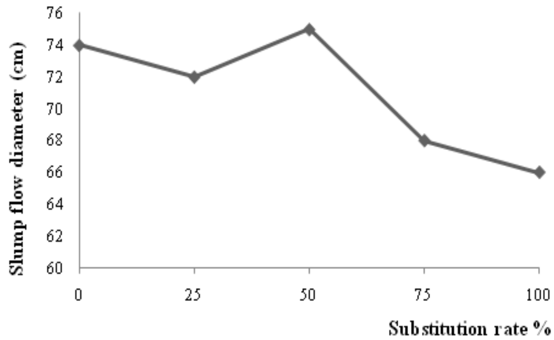

Fig. 4 Influence of substitution rate on slump flow values of self-compacting concrete

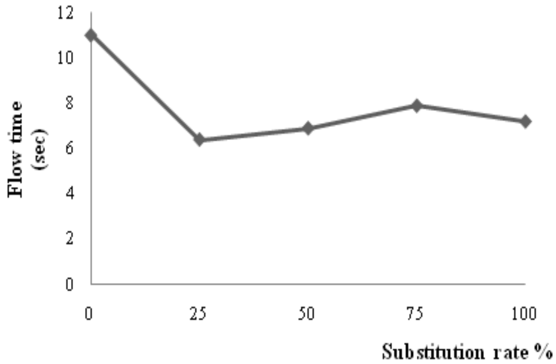

Fig. 5 Influence of substitution rate on V-funnel values of self-compacting concrete

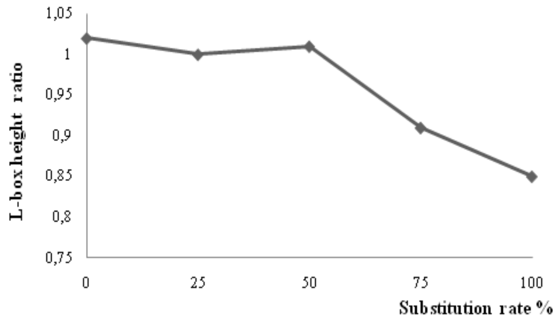

Fig. 6 Influence of substitution rate on L-box height ratio of self-compacting concrete

4.4 V- funnel

Fig. 5 shows the variation of the flow time as a function of the marble waste sand dosage. It is noted that concretes containing the marble waste sand in their composition require less flow time compared to ordinary concrete based on dune sand. This is always explained by the plasticizing capacity of the marble waste sand (Corinaldesi *et al*. 2010, Djebien *et al*. 2015).

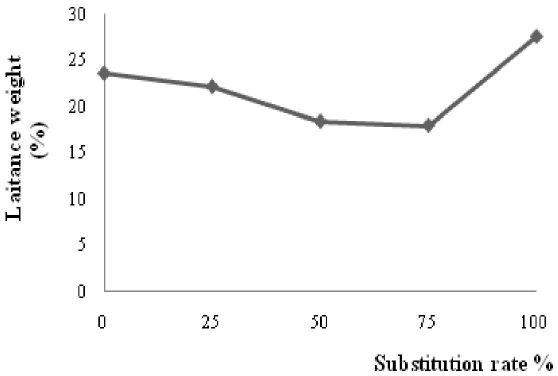

Fig. 7 Influence of substitution rate on segregation resistance of self-compacting concrete

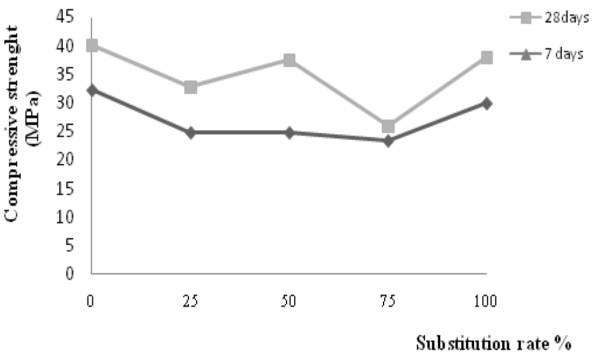

Fig. 8 Influence of substitution rate on compressive strength of self-compacting concrete

4.5 L-box

According to Fig. 6, it can be seen that the filling capacity of self-compacting concrete in confined medium decreases when the substitution rate exceeds 50%, where the L-box ratio decreases by 18.66% of its initial value. This is always due to the high friction between the sand grains of marble waste which have an angular shape and which causes a difficult movement (Hebhoub *et al.* 2010, Barron and Ollivier 1999).

4.6 Sieve stability

Fig. 7 shows the variation in the weight of laitance (represents the segregation resistance of self-compacting concrete) as a function of the substitution rate. It is noted that the highest laitance weight obtained corresponds to a substitution rate equal to 100% (concrete based on marble waste sand). This confirms the plasticizing capacity and the cohesion that the marble sand gives to the self-compacting concrete and which allows it to avoid the separation between its different components.

4.7 Compressive strength

Fig. 8 shows the evolution of the mechanical resistance at 7 and 28 days as a function of the substitution rate of marble waste sand.

It is noted that the addition of the marble waste sand into the self-compacting concrete composition reduces the compressive strength, especially for a substitution rate of 100% which corresponds to a decrease of resistance equal to 7.15% at 7 days and 5.23% at 28 days.

It is also noted that in spite of this decrease, the values of the compressive strength of the self-compacting concrete based on waste marble sand remain very acceptable.

This decrease of compressive strength can be explained by the fineness of the dune sand which is finer than that of marble waste sand. Therefore, it has the greatest ability to penetrate in the porosity of the coarse aggregates and decrease the voids volume (Djebien *et al.* 2015).

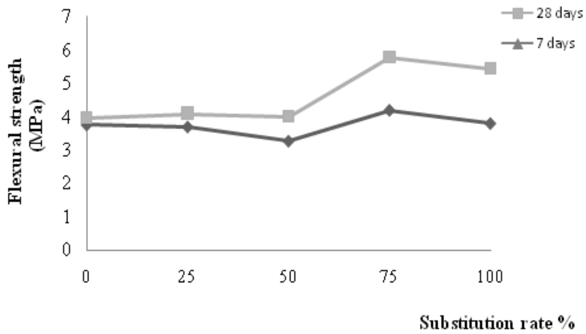

Fig. 9 Influence of substitution rate on flexural strength of self-compacting concrete

4.8 Flexural strength

From Fig. 9, it is noted that there is a slight increase in flexural strength when the substitution rate increases. We can say that the addition of recycled sand leads to increase the cohesion, and the presence of carbonate in marble waste sand gives a good bonding, matrix/granulate (Hebhoub *et al.* 2011).

5. Conclusions

This study, which is a part of valorization using local materials in Skikda city, aims to reuse marble waste in the field of civil engineering and more precisely in the manufacture of self-compacting concrete. The results obtained allowed us to advance the following results:

• The introduction of marble waste sand into the self-compacting concrete makes it less dense and decreases the value of the air content.

• Marble waste sand gives plasticizing capacity to self-compacting concrete which ensures cohesion and resistance to segregation.

• Marble waste sand decreases the ability of self-compacting concrete to flow, especially in confined environments.

• Self-compacting concretes based on marble waste sand have lower compressive strengths compared to those based on dune sand.

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