Chapter

Introduction of Marble Waste Sand in the Composition of Mortar

Hebhoub Houria, Kherraf Leila, Abdelouahed Assia and Belachia Mouloud

Abstract

The aim of this research is to study the possibility of the valorization of sand marble waste in mortars as substitute in sand. To achieve this study, sand marble waste is used with weight ratios of 5, 10, 15 and 20% to formulate a mortar with sand marble waste and a control mortar with 0% of sand marble waste. The properties in the fresh state, the mechanical strength, absorption by immersion, and the weight loss as well as the shrinkage and acid attack of each mixture were carried out through the conducted experiments. The different results show that the introduction of recycled sand in the mortars gives good results and it can be used as aggregates.

Keywords: mortar, valorization, sand, waste, marble, substitution, performance, durability

1. Introduction

Aggregates production is mainly ensured by extraction in quarries. There are also two other resources that allow manufacturers to produce aggregates. Then, we can speak of recycled aggregates and artificial aggregates. Recycled materials can be represented an excellent source of aggregates, the use of these materials in concrete would help to the recovery of recycled materials, and also, the protection of natural resources.

This work aims to study the effect of partial substitution of ordinary sand (50% dune sand and 50% sea sand) by marble waste sand from the quarry of Filfila located in Skikda (East Algeria) with rates 5, 10, 15 and 20% on the properties of mortar.

Located 25 km by road, east of Skikda—Algeria, the Djebel Filfila marble deposit was exploited by the company ENAMARBRE from Roman antiquity, and may even be before. This deposit consists of outcrops of marble which can reach a length of 1100 m for a width which varies from 100 to 300 m. The exploitable part of the deposit is composed by a lenticular body which extends over 550 m in length occupying an area of 13 Ha. The maximum depth of the deposit is 180 m which shows that this deposit consisting of marble levels of different colors tends to develop in depth.

The marble of Filfila is made up of the following varieties: white, with gray, light gray, dark gray, banded in green shade, banded in brown shade. White marbles represent 44% of the whole.

The Filfila deposit is divided into two quarries:

- The first one is a quarry with white marble blocks and reseda green, the exploitation is carried out by horizontal sawing methods by cutting vertical and lateral sawing by a diamond wire with cooling in clear water. The waste from this quarry is the scraps and rubble having different geometric shapes (**Figure 1**) and declassified powder (powder subject to weathering), the waste rate is 56% of production. The waste from the processing plant is the fall of block sizes and the fall of tiles and marble powders, and the waste rate is 22 m^2/m^3.
- The second quarry is derived from Chatt, the exploitation is carried out by explosive. The waste from this quarry is (marble of different granular classes), downgraded powder (**Figure 2**), the waste rate is 19% of production.

The valorization of this waste in the manufacture of mortars and concretes remains in the current state of investigation. Several studies have been interested by the feasibility of partially replacing an ordinary aggregate with a marble aggregate,

Figure 1.
Waste from the block quarry.

Figure 2.
Downgraded powder from Chatt.

or partially replacing cement with marble fillers. Hebhoub and Belachia [1] studied the valorization of marble waste aggregates in the concrete composition with total and partial incorporation from 0 to 100%, they found an improvement of compressive and tensile strength as well the workability of the concrete. Binici et al. [2] examined the incorporation of marble coarse aggregates in concrete and they found that it tends to decrease its chloride penetration, reaching a 70% reduction compared to standard concrete at 28 days of immersion. Hasan and Ahan [3] found that, replacing standard sand by the marble dust, with percentages of 15–75%, leads to an increase of compressive and tensile strength from 20 to 26% and 10 to 15%, respectively. Aliabdo et al. [4] evaluated the possibility of reusing marble dust as a partial replacement of cement and sand in concrete; the results found indicate an improvement in the physical and mechanical properties of concrete. Djebien et al. [5] reused marble waste as sand in self-compacting concrete, they found that substitution of marble waste reduces density and air content, and ensures cohesion and resistance to segregation.

Gesog˘lu et al. [6] concluded that the incorporation of marble dust in concrete decreased chloride penetration. In particular, replacing 5% of marble dust, by cement weight, led to the highest decrease in chloride penetration. Corinaldesi et al. [7], studied also the effect of marble powder in concrete, concluding that, up to given ratios of replacement, concrete durability can be improved. Belaidi et al. [8] examined the effect of the substitution of marble powder on the properties of self-compacting concrete, in percentage different from 10 to 40% they have been shown an improvement on the workability of concrete with a negative effect on compressive strength. Aruntas et al. [9] studied the addition of marble dust in cement production, obtaining very similar results to the ones observed in our study. Chavhan and Bhole [10] produced concrete mixtures by replacing gravel with marble powder, the rate varied between 5 and 50% they found enhancement in compressive and tensile strength of samples with 50% of marble.

2. Used materials

2.1 Cement

Cement CEM I class 42.5 of the origin of the Ain kbira-Sétif cement plant (East of Algeria) with an absolute density of 3.22 g/cm^3 and a Blaine specific surface of 3000 cm^2/g. Physical properties; chemical and mineralogical composition of cement used in this work is presented in **Table 1**.

2.2 Sand

Three types of sand were used in this work, the first is sea sand, it is a nature rolled, class 0/2 of origin Larbi ben Mhidi-Skikda and the second one is a dune sand of nature rolled class 0/1 of origin Wadi Zhor-Skikda. We are used a mixture between the both with similar quantities (natural sand). The third sand is a marble waste sand from the Filfila quarry—Skikda class 0/2 (discarded powder exposed to the weather). The physical and chemical properties of different sands used are presented in **Table 2** and the particle size curves are given in **Figure 3**.

2.3 Water

Potable water was used in all the mixes and curing of the specimens. (temperature was between 20 $\pm$ 2°C).

Designation	Results (%)
Density (g/cm^3)	3.07
Specific surface Blaine (cm^2/g)	3700
CaO	65.85
Al_2O_3	4.13
Fe_2O_3	4.16
SiO_2	21.31
MgO	1.34
Na_2O	0.16
K_2O	0.25
Cl	0.003
SO_3	2.13
Free CaO	0.5
MS	2.43
MAF	0.88
C3S	72.25
C2S	8.83
C3A	3.14
C4Af	14.7

Table 1.
Physical properties and chemical and mineralogical composition of the cement.

Designation	Sea sand	Dune sand	Marble waste sand
Physical properties			
Apparent density (g/cm^3)	1.606	1.850	1.50
Absolute density (g/cm^3)	2.570	2.60	2.700
Value of blue methylene (%)	0.25	0.7	0.35
Sand equivalent (%)	81	84	67.11
Absorption	1.10	1.15	2.30
Fineness modulus (%)	2.83	1.88	1.65
Fines content (%)	1	2.5	6
Chemical composition			
$CaCO_3$	—	—	98.67
CaO	4.01	0.80	55.29
Al_2O_3	0.76	2.36	0.14
Fe_2O_3	1.17	1.15	0.09
SiO_2	87.32	94.09	0.53
MgO	0.15	0.14	0.2
Na_2O	0.090	0.20	0.00
K_2O	0.200	0.58	0.01
Cl^-	0.00	0.00	0.025

Designation	Sea sand	Dune sand	Marble waste sand
SO_3	0.01	0.01	0.04
PF	—	—	43.40
Insoluble residue	—	—	0.035

Table 2.
Physical and chemical properties of different sands.

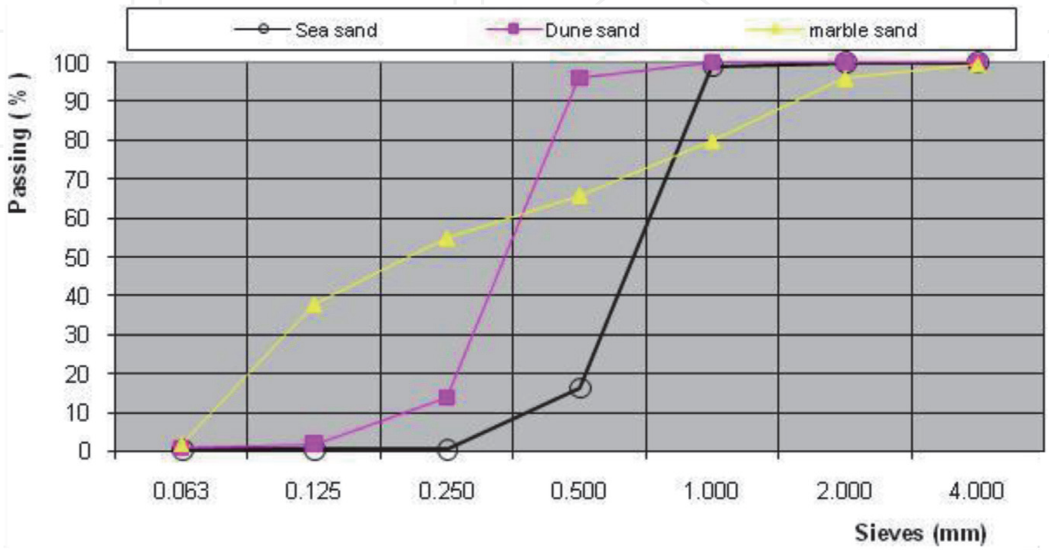

Figure 3.
Granulometric curves of the various sands.

From the results obtained we can draw the following observations:

- The absolute density of marble waste sand is higher than that of natural sand.
- Marble waste sand is less clean than natural sand.
- The marble waste sand has the highest percentage of fine clayey.
- The absorption coefficient of marble waste sand is stronger than that of natural sand.
- Marble waste sand is rich in calcium carbonate while the essential component of natural sand is silica.

3. Experimental program

The objective of this work is to study the effect of partial substitution of natural sand (50% dune sand and 50% sea sand) by a marble waste sand with rates 5, 10, 15 and 20% on the characteristics of mortars.

Reference mortar (control mortar) was prepared (0% marble waste sand) according to standard EN 196–1, with a quantity of water adjusted in order to obtain a reference consistency, the fixed parameters are cement and water dosage. The different mixes were prepared by replacing four percentages of natural sand with the same mass percentages of marble waste sand. This makes a total of five different mixes, including a control mortar. $4 \times 4 \times 16$ cm^3 prismatic test pieces were made to determine the performance of hardened mortars as well as $5 \times 5 \times 5$ cm^3 test

Figure 4.
Prismatic test pieces (4 × 4 × 16).

Figure 5.
Cubic test pieces (5 × 5 × 5).

pieces for acid attack tests **Figures 4** and **5**. Specimens produced from fresh mortar were demolded after 24 h and were then cured in water at 20 ± 2°C until the date of the test. All tests are realized in the same conditions (laboratory conditions).

The different compositions of the mixtures for the five formulations are given in **Table 3**.

Notation	Dune sand (g)	Sea sand (g)	Marble waste sand (g)	Cement (g)	Water (ml)
CM (0%)	675	675	0	450	252
M (5%)	641.25	641.25	67.5	450	252
M (10%)	607.5	607.5	135	450	252
M (15%)	573.75	573.75	202.5	450	252
M (20%)	540	540	270	450	252

Table 3.
Compositions of mixtures.

4. Tests performed

The tests carried out on the different formulations are:

- Consistency, measured by the mini slump test in accordance with standard NF EN 1015-3.
- Density in the fresh state according to standard NF EN 1015-6.
- Air content determined according to standard NF P 18-353.
- Flexural tensile and compressive strength at the age of 2, 7, 28 and 90 days, measured on $4 \times 4 \times 16$ cm^3 prismatic specimens preserved in water in accordance with standard EN196-1.
- Shrinkage and mass loss on specimens $4 \times 4 \times 16$ cm^3 according to NF P 18-433.
- Absorption by immersion measured by Neville, 2000.
- Acid attack measured on cubic specimens of size $5 \times 5 \times 5$ cm^3 according to ASTM C-267-96 standard.

5. Results and discussion

5.1 Consistency of mortars

The slump of various mortars is evaluated according to the standard NF EN 1015-3. The test is mentioned in the **Figure 6**.

The results of consistency of different mortars are shown in **Figure 7**.

The figure shows that the increase in marble waste sand rate in the mortars increases slightly the consistency of the mortar. The maximum value is recorded by the mortar with 15%, with an increase of around 20% compared to that of the control mortar. This trend can be explained by the amount of fines present in the marble waste sand which enter the pores and thus release the trapped water, which results in better consistency.

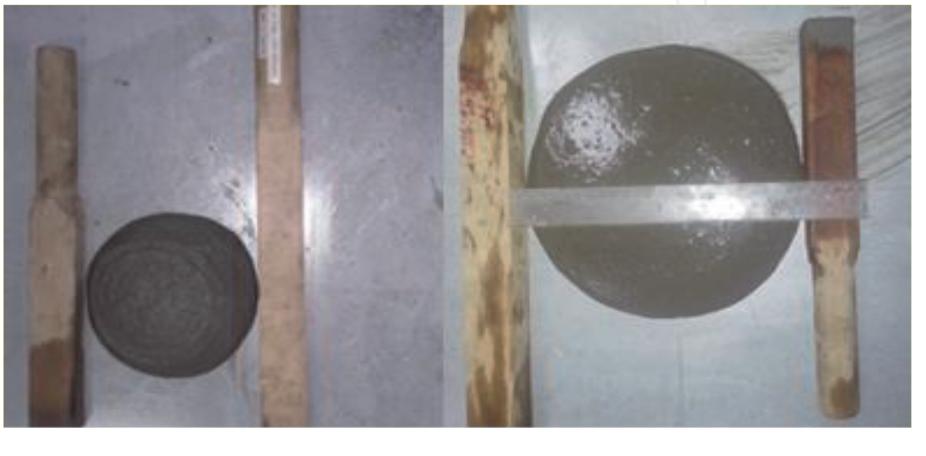

Figure 6.
Consistency of mortar.

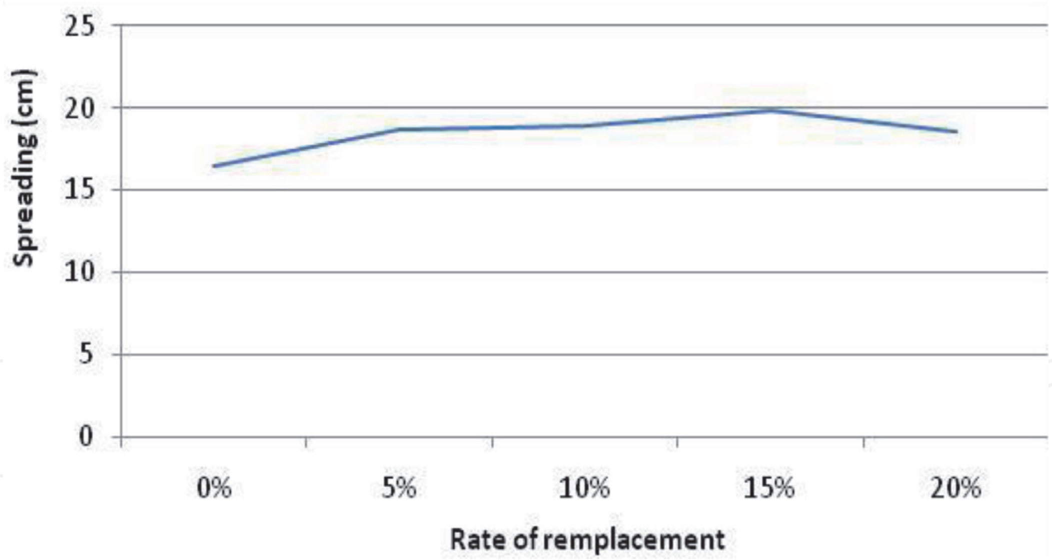

Figure 7.
Variation of consistency versus substitution rate.

5.2 Density of mortars

The density of various mortars is evaluated according to the standard NF EN 1015-6. The results of the density of mortars are shown in **Figure 8**.

The results show an increase in the density of all mortars. This growth is clearer with the increase in the rate of marble waste sand. The density values increase from 2.168 kg/m^3 for the reference mortar to 2.175, 2.192, 2.201, and 2.186 kg/m^3 for the mortars containing 5, 10, 15 and 20%. The increase in the density of the mortar to 15% of marble waste sand is around 1.52%. It is mainly due to the higher density of marble waste sand, which is higher than that of natural sand (dune sand and sea sand), and also to the retention of water by the grains of marble waste during the mixing.

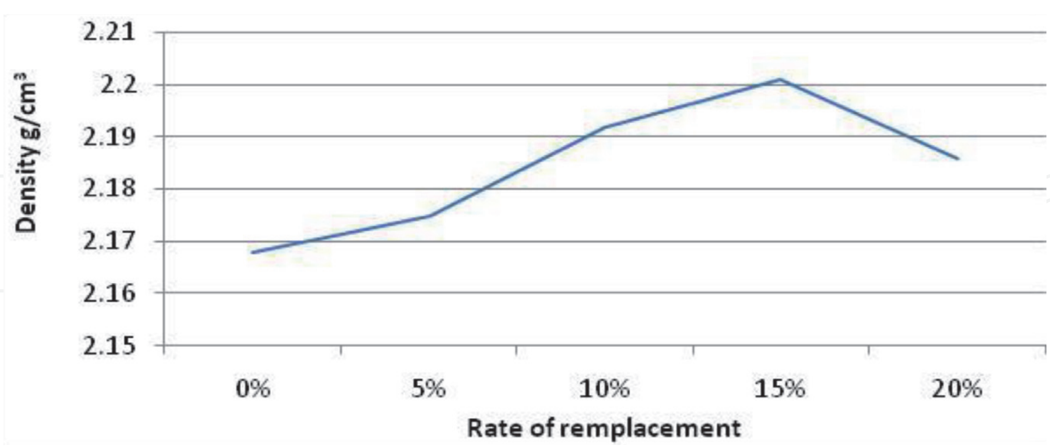

Figure 8.
Variation of density versus substitution rate.

5.3 Air content

The introduction of marble waste sand (**Figure 9**) leads to a decrease in the air content regardless of the substitution rate. The volume of occluded air decreases slightly from 7.4% for the reference mortar to 4.8% for the mortar incorporating 15% of marble waste sand. The significant reduction in the volume of air entrained in composite mortars of marble waste sand is related to the increase in the

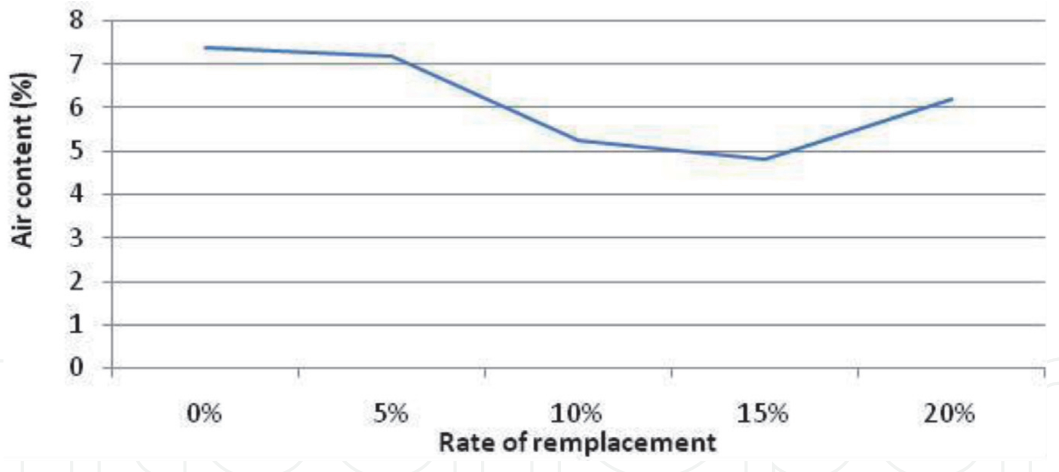

Figure 9.
Change in air content as a function of the substitution rate.

compactness of the mixtures following the substitution of natural sand by marble waste sand [11].

5.4 Compressive and flexural tensile strength of mortars

After 2, 7, 28 and 90 days of water curing, the 4 × 4 × 16 cm^3 samples were used for compressive and flexural tensile strength tests. The results are shown in **Figures 10** and **11**, respectively.

At early ages (2 and 7 days), and through **Figure 10**, the compressive strengths of mortars based on marble waste sand presented higher strength than that of control mortar, except for mortar with 5%. The best gain of compressive strength is of the order of 13.65 and 35.2%, it is recorded in the mixture of (20%) on the two deadlines respectively. These improvements in both levels can be explained by the presence of calcium carbonate [12, 13], which favor the creation of nucleation sites and hence the formation of calcium carbo-aluminates.

The compressive strength of specimens with marble waste sand at rates above 5% are better than that of the control mortar and the best gain is noted in the mixture of (20%) substitution rates. In fact, above 5% of the substitution rate of marble waste sand, all mortar compressive strengths are increasing, due to the increased compactness of mortars with less occluded air and constant W/C ratio [14].

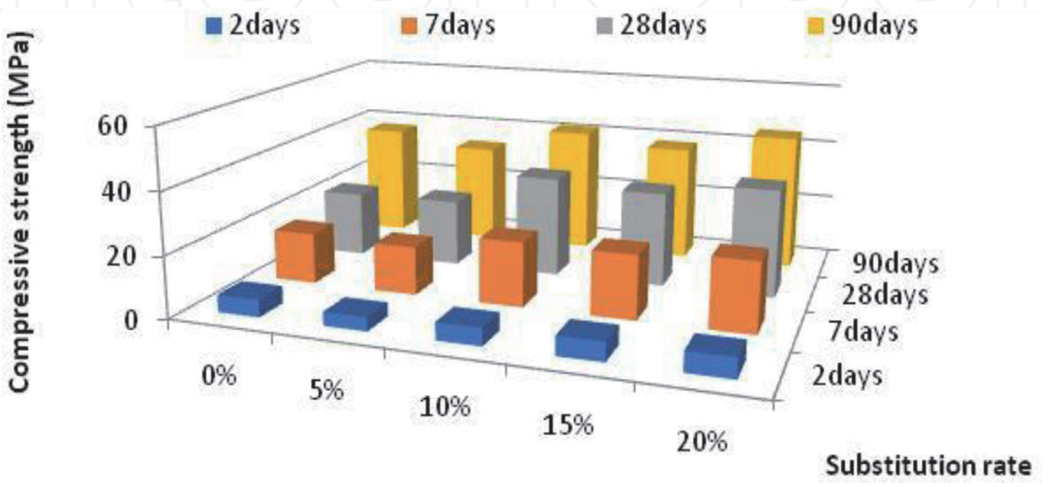

Figure 10.
Effect of the substitution rate on the compressive strength.

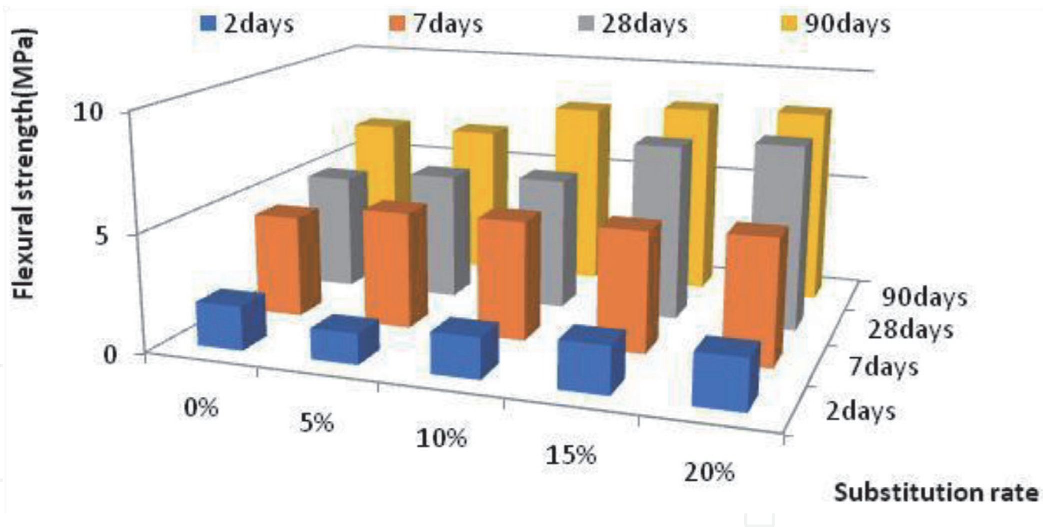

Figure 11.
Effect of the substitution rate on the flexural tensile strength.

Generally, we note that the flexural tensile strengths of the mortars with marble waste sand, at all the ages (7, 28 and 90 days) are better than that of control mortar. The most significant value is achieved with the 20% mixture of marble waste sand, which presents a gains of 13.29, 22, 58 and 28% compared to the control mortar on the ages 2, 7, 28 and 90 days respectively. Two factors can explain these notations. Mortars based on marble waste sand contain quantities of fine particles, which favor granular stacking during mixing and thus causes an increase in flexural strength. However, the marble waste sand is characterized by more acute and porous grains, so that the bond with the cement paste of the mixture is better [7].

5.5 Absorption by immersion

The absorption of water by immersion is a property related to the durability of mortar, it allows estimating the volume of open pores of specimens by the penetration of water through the structure of these pores.

When the ratio of replacement of marble waste sand in mortar increased (**Figure 12**), there was an increase in water absorption, especially for the 20% of

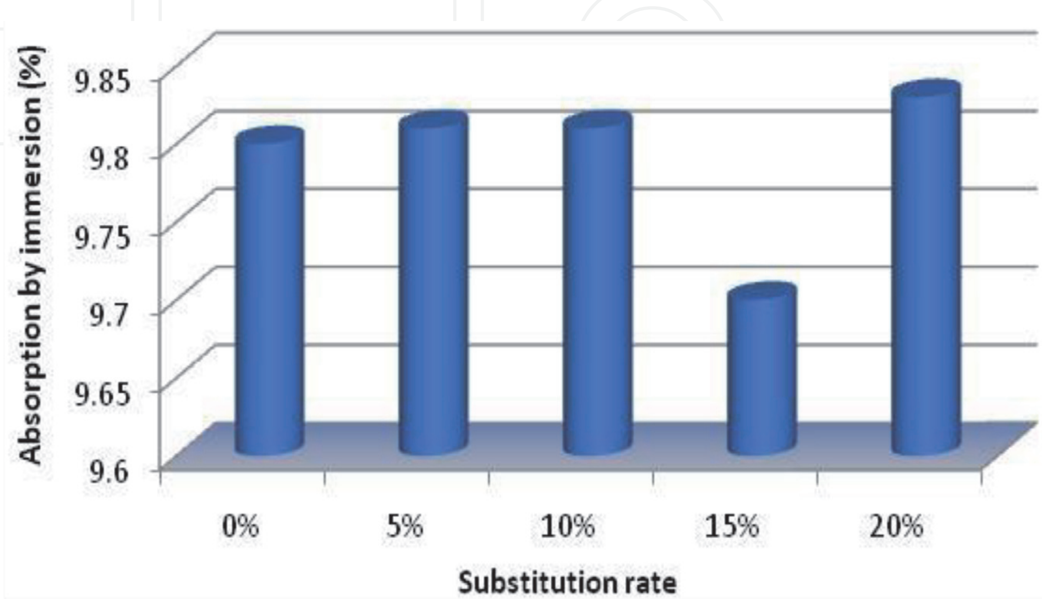

Figure 12.
Absorption of water by immersion as a function of substitution rate.

replacement, due to the height porosity of specimens with marble waste sand. Also, it can be assumed that that the matrix-sand interface of marble waste often gathers pores thus increasing porosity.

5.6 Weight loss

The results of the mass loss of the various mortars are presented in **Figure 13**.

From the **Figure 13**, it is clear that the weight loss of mortars is influenced by the incorporation of marble waste sand. The values obtained are generally high compared to the control mortar. The optimum value is found in the 15% marble waste sand mortar. This is due to the departure of the water initially retained by the grains of the marble sand.

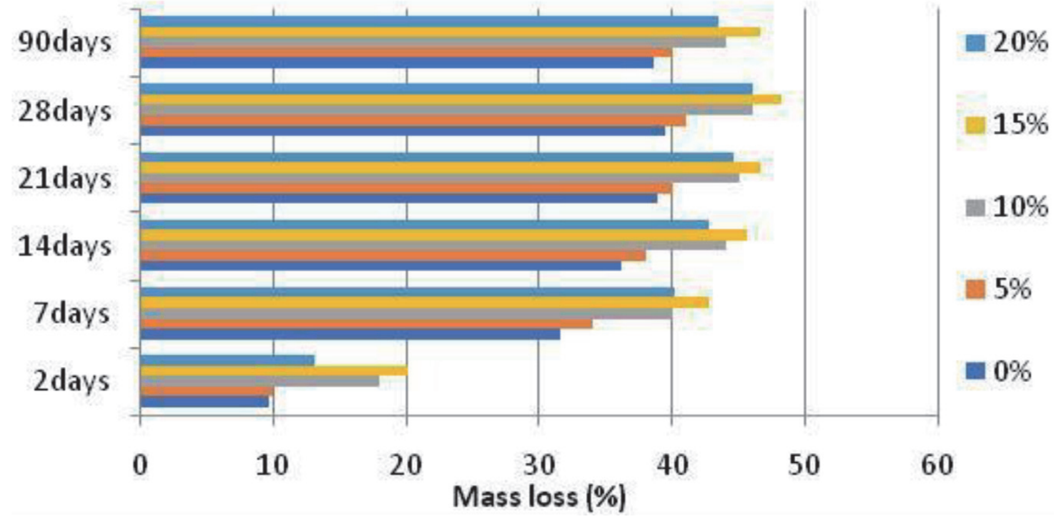

Figure 13.
Weight loss of different mortars.

5.7 Shrinkage

The shrinkage test is carried out according to standard NF P 18-433, test is mentioned in **Figure 14**.

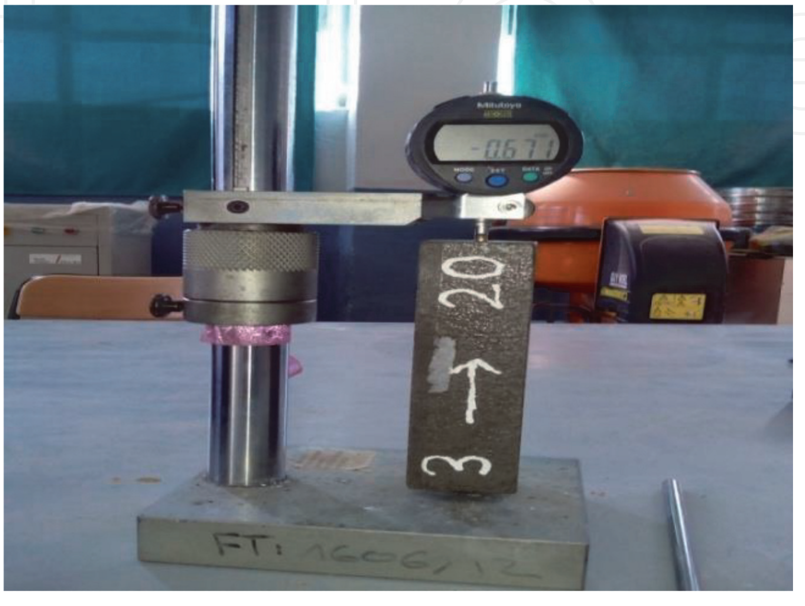

Figure 14.
Shrinkage measurement on prismatic test piece.

Shrinkage results of various mortars are presented in **Figure 15**.

Figure 15 shows that the incorporation of marble waste sand has a considerable impact on the shrinkage of mortars stored in the laboratory room with a relative humidity of 80%. The mean values recorded are higher than that displayed for the control mortar, except for the mortar of 5% marble waste sand from 2 days until 21 days, where the mortar has a similar shrinkage to the mortar witness.

The highest value is found in the mortar with 20% marble waste sand on all ages. These expected shrinkage values are due to the evaporation of the free water contained in the test specimens.

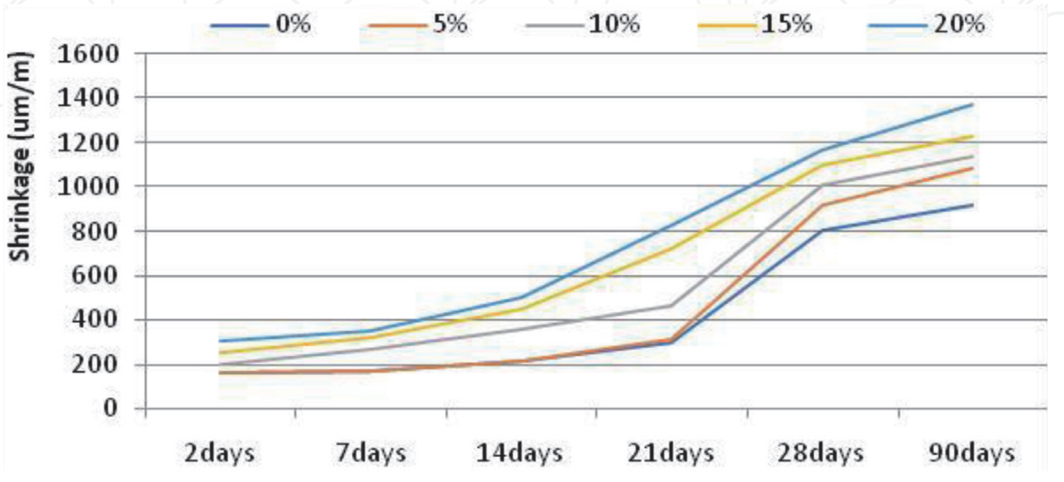

Figure 15.
Shrinkage results of various mortars.

5.8 Acid attack

After 28 days of water curing, the $5 \times 5 \times 5\ cm^3$ specimens were immersed in two solutions, HCl and H_2SO_4 acid with the same concentration 5% (**Figure 16**). The aggressive solutions were renewed every 14 days. After 1, 7, 14, 21, 28, 56 and 90 days, they were used to estimate the weight loss according to the standard ASTMC267-96.

Results of the weight changes for the different mortars preserved in HCl and H_2SO_4 solution are presented in **Figures 17** and **18**.

The curves, presented by **Figure 17**, show the weight loss in % measured at the end of each aging of mortars stored in HCl solution (after 28 days of cure in water).

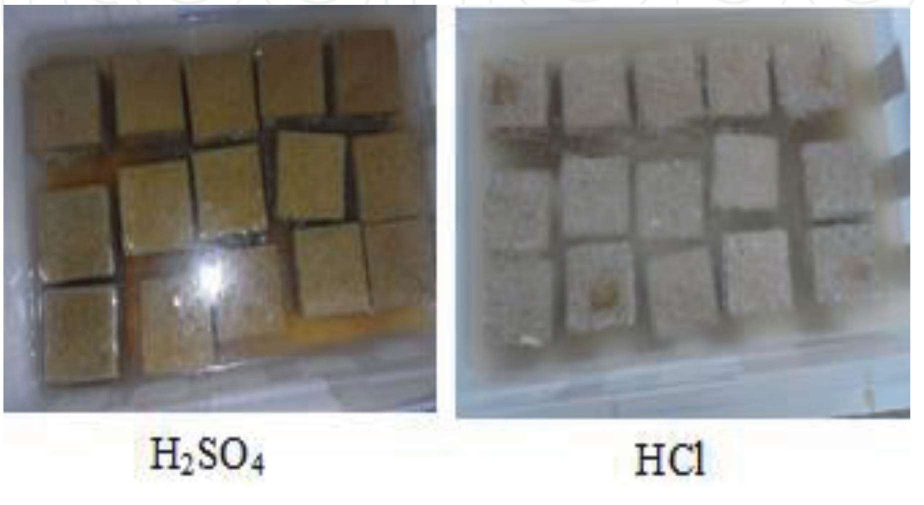

Figure 16.
Specimens immersed in acid solution.

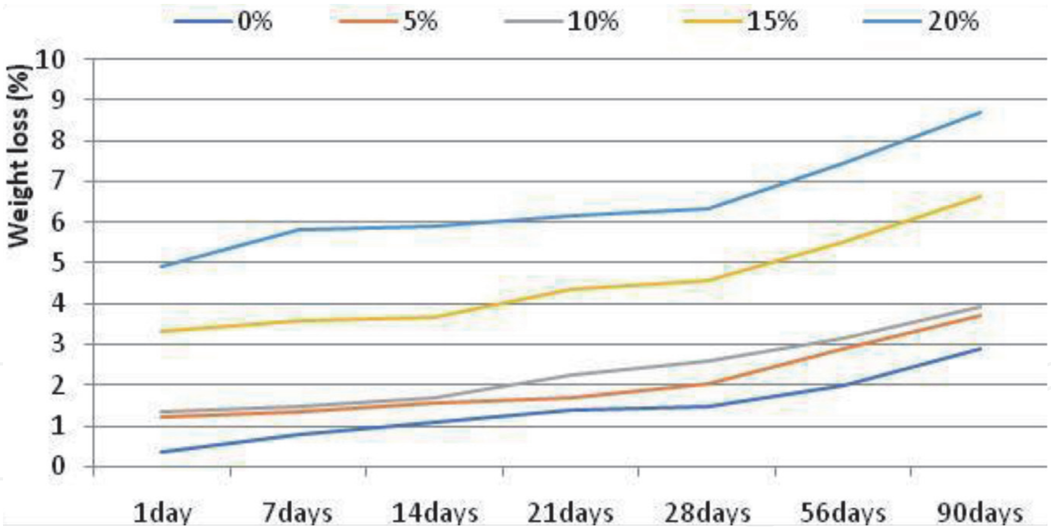

Figure 17.
Weight loss of specimens after 1–7–14–21–28–56–90 days of immersion in 5% HCl.

It can be observed that all specimens had a weight loss, through the reaction between the calcium hydroxide Ca(OH)2 and the chlorine, the reaction was expressed in Eq. (1).

$$Ca(OH)2 + 2HC \rightarrow CaCl_2 + 2H_2O \tag{1}$$

Calcium chloride ($CaCl_2$) causes dissolution of cement, the production of $CaCl_2$ salt increases the porosity because it is very soluble in water.

It can be also noted that in all ages the loss weight increased proportionally with marble waste sand substitution, and the control mortar presented the lowest weight loss at all ages. It can be concluded that a high calcium carbonate ($CaCO_3$) content in marble waste sand increases the capacity of mortars to react with aggressions according the reaction Eq. (2)

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2 \tag{2}$$

A sudden loss of weight was noticed during 1–90 days (**Figure 18**). It can be also noted that in early age all weight loss is close, the highest value of weight loss

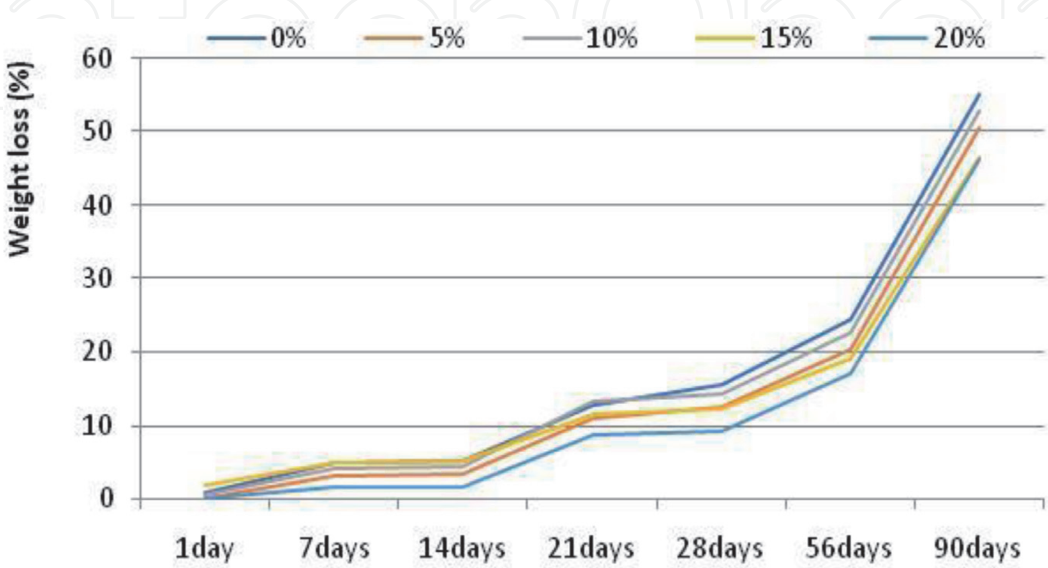

Figure 18.
Weight loss of specimens after 1–7–14–21–28–56–90 days of immersion in 5% H_2SO_4.

corresponds to control mortar, when the mortars are attacked by sulfuric acid H_2SO_4, they react with the Portlandite Ca(OH)2 resulting from the hydration of the cement [15], which causes the of gypsum. The process is described by the following chemical reaction:

$$Ca(OH)2 + H_2SO_4 \rightarrow CaSO_4.2H_2O \quad (3)$$

The low percentage of alumina Al_2O_3 in marble waste sand decreases the formation of C3A, which reacts with gypsum to produce ettringite (Eq. 4), that is why the increase in marble waste sand percentage decreases the weight loss of mortars.

$$3CaSO_4 + 3CaO.Al_2O_3.6H_2O + 26H_2O \rightarrow 3CaO.\ Al_2O_3.\ 3CaSO_4.32H_2O \quad (4)$$

6. Conclusions

After the comparative study between mortars based on natural sand and marble waste sand, we can draw the following conclusions:

- The optimal density is observed for the mortar based on 15% of marble waste sand, due to the actual density and the water retention by the grains of marble waste.

- The best consistency is given by the mortars based on 15% of marble waste sand, the presence of fines promotes the slump of the mortars.

- The mortar with 15% marble waste sand registers the low volume of air content, which is explained by a better compactness.

- Compressive and flexural strength, in all ages, of mortars based on marble waste sand are better than those of mortars based on natural sand. The mortar with 20% of marble waste sand is the most effective.

- The absorption of water of mortars containing marble waste sand is high compared to that of the control mortar. This is caused by the large volume proportion of the capillary pores.

- The mortars with the marble waste sand approved a greater shrinkage than that of the control mortar, following the evaporation of the free water existing in the test specimens.

- Concerning acid attack, and in HCl solution, the mortar with marble waste sand had a bad resistance to aggression due the high amount of $CaCO_3$ in marble. On the other hand, marble sand enhances resistance to H_2SO_4.

In light of the analysis, the conclusion of this study is that the introduction of marble waste sand was beneficial to some properties and durability of mortars.

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