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Research Paper

Use of crushed clay brick waste as dune sand granular corrector in mortar manufacturing

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ABSTRACT

The present study aims to investigate the possibility of using crushed clay brick waste as dune sand granular corrector in mortar manufacturing. The mixtures composition method is based on the progressive substitution of dune sand with crushed waste at different weight contents; 5, 10, 15, 20 and 25%. The effect of these recycled materials was studied in an experimental programme through several tests. The performance of these modified mortars was evaluated in terms of strength, workability, water absorption, and resistance to sulfuric acid attack. The results obtained show that the incorporation of the used waste has a significant influence on the behavior of the mortar, in the fresh state and the hardened state. Further to this, it has also been observed that its inclusion with certain percentages makes it possible to obtain performances comparable to those of the alluvial sand-based mortar, which demonstrates its effectiveness in improving the various properties of the mortar.

1 Introduction

Concrete and mortar manufacturing technology is related to several factors. The economic factor is considered important and inseparable from the imperative factors that a good concrete must present; such as mechanical strength and workability. And because aggregates make up the largest portion of concrete and mortar (over 75%), the use of suitable local materials as substitutes for conventional aggregates can vary the prices of the final products.

In Algeria, there is an abundance of good quality aggregates. However, excessive use of these materials can lead to long-term problems, especially on the environment. For these reasons, it would be advisable to use other substitute materials such as dune sands and construction waste to preserve these resources and avoid excessive pollution of the environment.

In areas where dune sand is abundant, this sand imposes itself for its hardness (siliceous nature), its cost of extraction

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which is very less, and its cleanliness. These features encouraged researchers to pursue the study of this material in order to apply it in the various fields of civil engineering, such as road construction [1,2] and concrete and mortar production [3,4,5]. Due to its poor particle size distribution [3,5], most of this research is aimed at finding a way to correct this inconvenience, with the aim of reducing the porosity of mixtures containing this sand, and consequently to improve its physical and mechanical characteristics.

The waste of red-clay brick was produced during manufacturing industry, transportation and placing. The production of this waste has seen a very significant increase in Algeria over the past few years. This increase was accompanied by an increase in interest in the valorization of this material, for the purpose to use it as additives in the production of cements [6,7], or as active additions in the manufacturing of mortars and concretes [8,9,10]. Due to their pozzolanic activity, the use of this waste in the manufacture of cementitious mixtures can contribute to improving the physical and mechanical properties, reducing the cost and limiting environmental pollution [11,12].

This study focused on the feasibility of correcting the dune sand particle size by the incorporation of Crushed red clay Brick Waste (noted by CBW) in the production of mortar. In order to assess the effect of this material on the characteristics of modified mortars at fresh and hardened state, the dune sand was substituted by several replacement ratios of waste. The performance of these modified mortars was compared with control mortar (made solely of alluvial sand, cement and water). The results obtained show that its inclusion with determined percentages can provide features comparable to those of the control mortar.

2 Materials

2.1 Cement

The cement used in this study is of ordinary Portland cement CEM I 42.5 grade, conforming to the NF EN 197-1 standards [13]. It has been manufactured by the cement company of Algeria. Its specific gravity is 3.11 g/cm^3 and its Blaine surface specific area is equal to 3118 cm^2/g. The potential mineralogical composition of the clinker (Table 1) is calculated according to the empirical formula of Bogue [14].

Table 1- Mineralogical composition of clinker (%)

C_3S	C_2S	C_3A	C_4AF
52.02	28.97	6.71	12.28

2.2 Various types of sands used

Table 2- Physical characteristics of the studied materials

Physical characteristics	AS	DS	CBW
Bulk density (g/cm^3)	1.61	1.46	1.19
Specific density (g/cm^3)	2.60	2.53	2.50
Porosity (%)	38.1	42.3	52.4
Compactness (%)	61.9	57.7	47.6
Water absorption (%)	0.87	2.15	5.61
Visual sand equivalent (%)	81	79	--
Sand equivalent with the piston (%)	80	75	--
Maximum size (mm)	5.00	0.63	2.50
Fineness modulus	2.36	0.86	--
Fine particles percentage (%)	-	-	37

In this work, the experiment was undertaken on two types of sand; a dune sand and an alluvial sand, designated respectively by (DS) and (AS). They come respectively from the regions of Zaafrane and Messaad (Djelfa, Algeria). The Details of their physical characteristics are summarized in Table 2.

The AS presents a good value of fineness modulus (2.36), however, the DS has a low value (0.86), which means that AS will give a judicious compromise between the workability and the resistance [15]. The sand equivalent test, which is carried out according to NF P 18-598 standard, has given values above the limit recommended for concrete and mortar. This allows their use in this investigation.

The DS sand presents a continuous particle size distribution ranging from 0 to 0.63 mm (Fig. 1). It can clearly be seen that 90% of the dune sand grains are lower than 0.3 mm. This sand can be classified from a granular viewpoint as fine sand [16]. The grading is very tight; nearly 90% of the grains have a dimension ranging between 0.1 mm and 0.5 mm; its use alone cannot give a sufficient compactness, and thus insufficient performance. This confirms that the use of a granular corrector is certainly necessary [3].

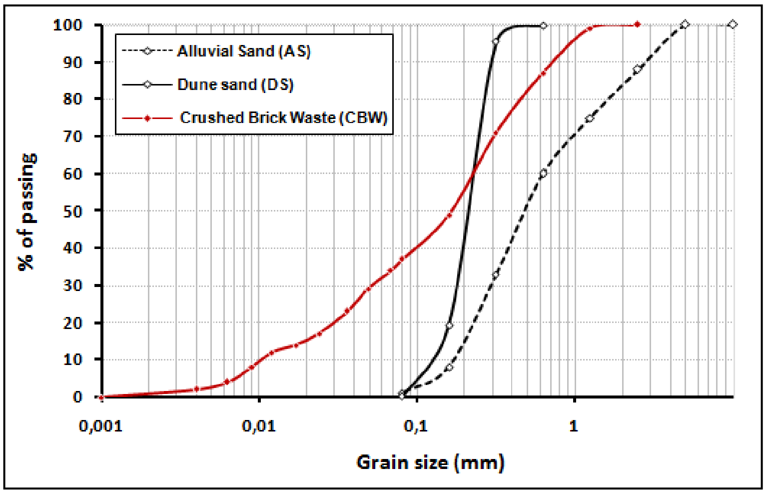

Fig. 1- Particle size distribution of the materials used

The alluvial sand (AS) which is used to make the control mortar, presents a continuous particle size distribution ranging from 0 to 5 mm. Less than 20% of the elements are greater than 2 mm, and more than 50% of the elements greater than 80 µm are between 0.2 and 2 mm. According to its grain size, the AS is a medium sand [16].

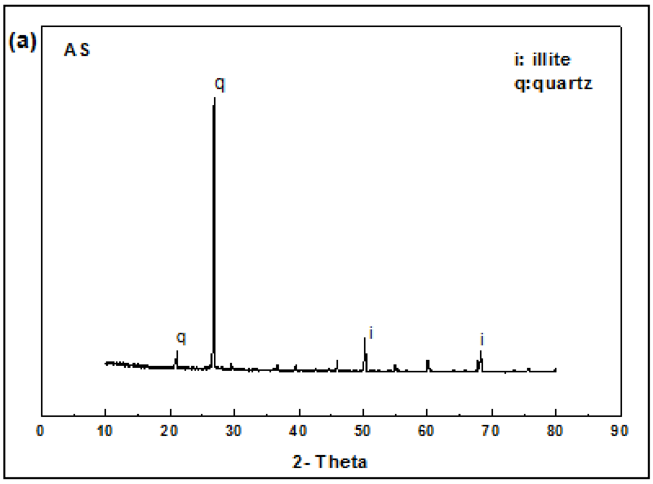

Fig. 2.a- X-ray diffraction patterns of sand AS

In this investigation, the X-ray diffraction was conducted with the random powder method for the bulk sample. The results obtained performed by XRD analysis of studied sands demonstrates the essentially siliceous nature of DS and AS (Fig. 2.a and 2.b). The contents of the essential harmful substances lie within the tolerable limits recommended by AFNOR standard FD P 18-011 [17].

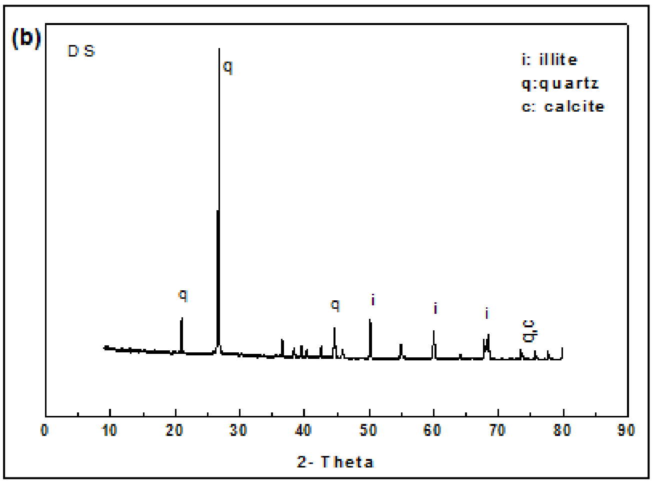

Fig. 2.b- X-ray diffraction patterns of sand DS

2.3 Crushed brick waste (CBW)

The crushed clay brick waste (CBW) was used as a granular corrector in order to improve the physical and mechanical properties of dune sand mortar. Its production was made in laboratory by crushing followed by grinding using a ball mill. Its particle size distribution which is shown in Fig. 1, has been determined by sieving method according to NF P94-056 [18] for the fraction higher than 0.080 mm, and by sedimentation method according to NF P94-056 [19] for the fine fraction (smaller than 0.080 mm). The CBW presents a continuous particle size distribution ranging from 0 to 2.5 mm. The used addition presents relatively lower bulk density and higher water absorption compared to AS and DS aggregates, as can be seen in Table 2. The higher water absorption of crushed waste aggregates is due to the higher porosity of the original waste. The XRD analysis mentioned in Fig. 2.c shows that the CBW is comprised of mainly crystalline phase of illite.

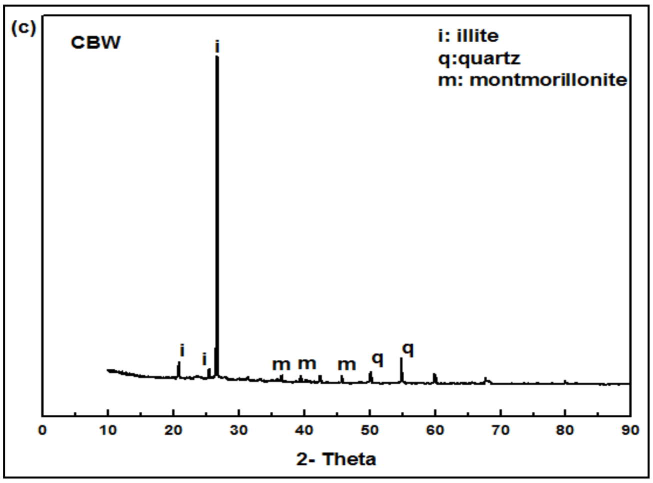

Fig. 2.c- X-ray diffraction patterns of CBW

3 Mortar Mixture proportions and sample preparation

The formulation method used to prepare the mortar mixtures was the same as that used to make the normal mortar, according to the NF EN 196-1 Standard [20]. The crushed brick waste (CBW) was used as a partial substitute of dune sand. In order to study the effect of the waste incorporation on mortar characteristics, the percentages used were 5, 10, 15, 20 and 25% by weight of dune sand. A fixed water-cement ratio of 0.70 was utilized for all mixes. Cement-aggregate ratio was 1:3.

A reference mix (control mortar) using cement and alluvial sand was prepared, in order to compare it with the CBW mortars. Details of the proportions of mixtures are given in Table 3.

Table 3- Ponderal composition of designed mortars

Symbol of mortar	Mix proportions	Cement (g)	DS (g)	AS (g)	CBW (g)	W/C
MA0 (control mortar)	100% AS	450	-	1350	0	0.7
MD0	100% DS + 0% CBW	450	1350	-	0	0.7
MB5	95% DS + 5% CBW	450	1282.5	-	67.5	0.7
MB10	90% DS + 10% CBW	450	1215	-	135	0.7
MB15	85% DS + 15% CBW	450	1147.5	-	202.5	0.7
MB20	80% DS + 20% CBW	450	1080	-	270	0.7
MB25	75% DS + 25% CBW	450	1012.5	-	337.5	0.7

Upon completion of mixing, the fresh mortar was placed into the molds of dimensions 4×4×16 cm^3; they were then clamped onto a vibrating table for 20 s. During the first 24 h, the samples were stored in the normal laboratory environment. After 24 h, these samples were demoulded, and they were then immersed in drinking water at laboratory temperature (23 ± 2 C°), until testing.

4 Testing details

4.1 Tests on fresh mortars

The workability of fresh mortars was investigated using LCPC maniabilimeter according to the NF P18-452 standard [21]. The test consists of measuring the time necessary for mortar to flow under the effect of specific vibration until it reaches a reference line. This time will be all the shorter as the mortar will be more fluid. The bulk density of fresh mortars was measured according to the standard NF EN 1015-6 [22].

4.2 Tests on hardened mortars

Mechanical testing of the prepared samples was carried out using an electromechanical universal press TE 300 kN, in accordance with the NF EN 196-1 standard [20]. Mechanical properties were performed on mortar samples of dimensions 4×4×16 cm^3 at different curing times 7, 28 and 90 days. The flexural strength was measured using a three point bending test. The distance between supporting pins is 100 mm. The half-specimens resulting from bending test were then subjected to compression on a 4×4 cm^2 test section. The dry bulk density and water absorption of hardened mortars were performed in accordance with the standard NF EN 1015-10 [23] and NF EN 1015-18 [24] respectively.

The sulfuric acid immersion test was determined on mortar samples of dimensions 4×4×16 cm^3, in accordance with the standard ASTM C267 [25], using the 5% sulfuric acid solution (H_2SO_4). The mortar samples were conserved in water until the age of 28 days, at laboratory temperature (23 ± 2 C°). The samples were then immersed in the sulfuric solution. The masse loss of the mortar samples was monitored at 15, 30, 45, 60, 75 and 90 days after immersion, and the sulfuric acid solution was renewed every 2 weeks.

The sulfuric acid resistance is evaluated by the cumulative percentage of mass loss (CPLM), which is given by the following formula:

$$CPLM\left(\%\right)=\frac{M_t-M_0}{M_0} \quad (1)$$

Where; M_t is the mass of the sample at time t, and M_0 is the initial sample mass before immersion in sulfuric acid solution.

5 Test results and discussion

5.1 Workability of mixtures

The curve of Fig. 3 represents the evolution of the flow time (workability) according to the quantity of CBW. It was noted that, for a fixed water-cement ratio (W/C = 0.7), the mixture with dune sand (MD0) presents low workability (16 seconds) in comparison with the control mortar (2 seconds); this is mainly due to the particle size of dune sand which is very fine compared with that of alluvial sand (fine sands require more water).

It was also noted that the progressive substitution of dune sand by CBW with percentages of less than 15%, has a significant negative influence on the workability. This may be explained by the increasing in the specific surface area of the fine particles in mixtures after adding crushed waste, thereby increasing the water requirement to wetting the fine waste aggregates [26]. However, beyond 15%, the incorporation of CBW has a positive influence on this characteristic. This improvement in workability can be related to the waste fine fraction which filling the voids and releasing the trapped water which consequently improves the consistency of the mortar mixtures [27].

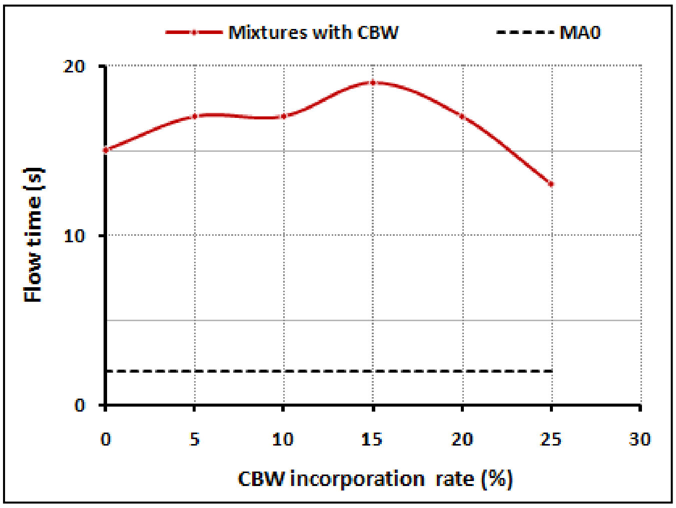

Fig. 3- Variation of workability as a function of the substitution rate

5.2 Dry bulk density of fresh mortars

Fig. 4 displays bulk density results of fresh mixtures as a function of crushed waste amounts.

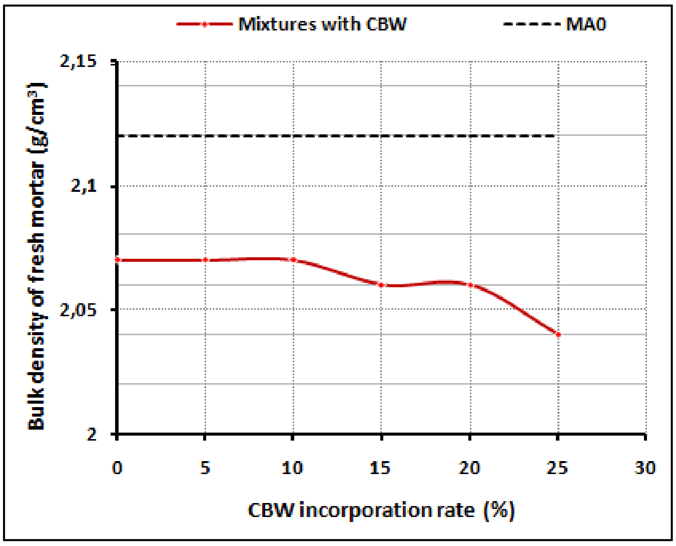

Fig. 4- Effect of the inclusion of the CBW on bulk density of fresh mortar

It should be noted that, for a constant quantity of water, the bulk density of dune sand mortar (MD0) is lower than that of control mortar (MA0). The reason of this difference is mainly attributed to the bulk density of DS sand, which is lower than that of SA sand. Furthermore, the bulk density generally decreases according to the incorporation rate; this appears to be due essentially to the lower bulk density of the used waste (1.19 g/cm^3) as compared with SD sand (1.46 g/cm^3). This observation was already reported by several authors [10, 28, 29].

5.3 Dry bulk density of hardened mortars

The evolution of dry bulk density of hardened mortars with additions percentage is shown in Fig. 5. It was observed that by increasing of the replacement rate of the crushing waste, the bulk density of the mortars in their hardened state increased until a certain optimum (15% of CBW) and then decreased. The increase in bulk density is linked to the decrease of voids volume within the mortars due to the addition of the fine particles of CBW [11]. At 15% CBW, the bulk density reaches maximum value 1.9 g/cm^3; this value correspond to optimal filling of the spaces between grains of dune sand (maximum compactness) [30]. The decrease in bulk density for percentages greater than 15% is ascribed to the waste fine particles which begin to occupy the place of the dune sand grains [27], which increased the overall volume (for the same mass, the volume of the crushed waste is greater than that of dune sand), and consequently, decreased the bulk density of the modified mortars. Thus, the dune sand correction with the CBW does not allow the modified mortars to reach the apparent density value of the control mortar (MA0).

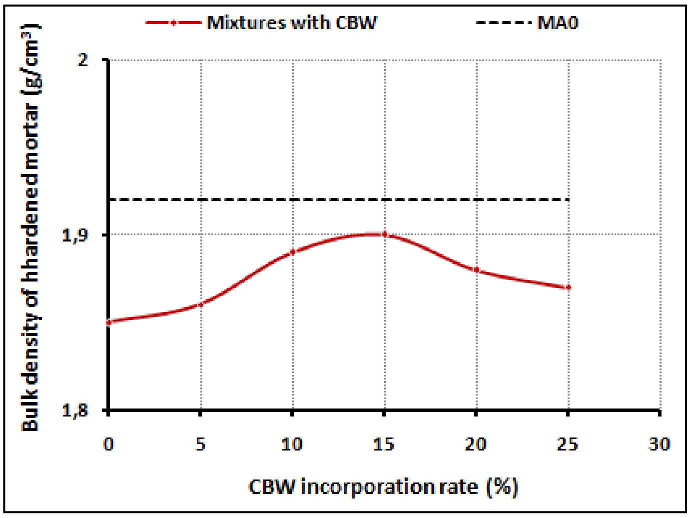

Fig. 5- Effect of CBW incorporation rate on bulk density of hardened mortar

5.4 Compressive strength

The evolution of the compressive strength according to the waste content and time is given in Fig. 6.a and 6.b. Many remarks can be formulated about these results;

At 7 days, the inclusion of CBW leads to lower compressive strengths than that of mortar without addition (MD0). The maximum resistance loss was observed at 25% of CBW; it is about 52.7%. This results show that, at this age, the use of CBW has significantly delayed cement hydration (chemical effect).

At 28 days, it was observed that the compressive strength increased up to a certain optimum (15% of CBW) and then decreased with increasing amounts of CBW (evolution similar to that of compactness). Furthermore, it was noted that the correction of dune sand with CBW Does not contribute to obtain 28-days compressive strength higher than that of mortar without addition (MD0), but there is a decrease in the strength loss rate compared with that at 7 days; for 15, 20 and 25% of CBW, it was observed a strength loss of 8.2, 6.8 and 19.2% at 28 days versus 13.4, 22 and 52.7% at 7 days respectively.

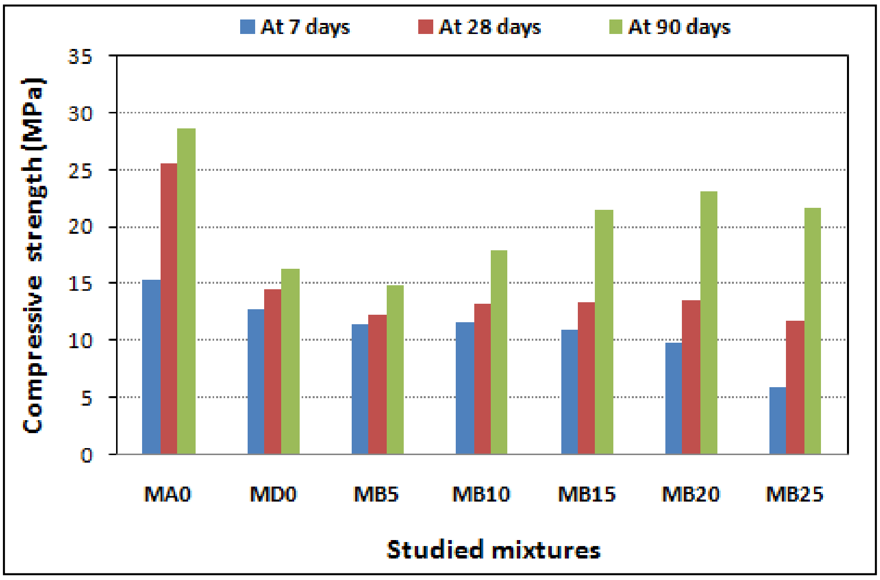

Fig. 6.a- Influence of the incorporation of CBW on compressive strength

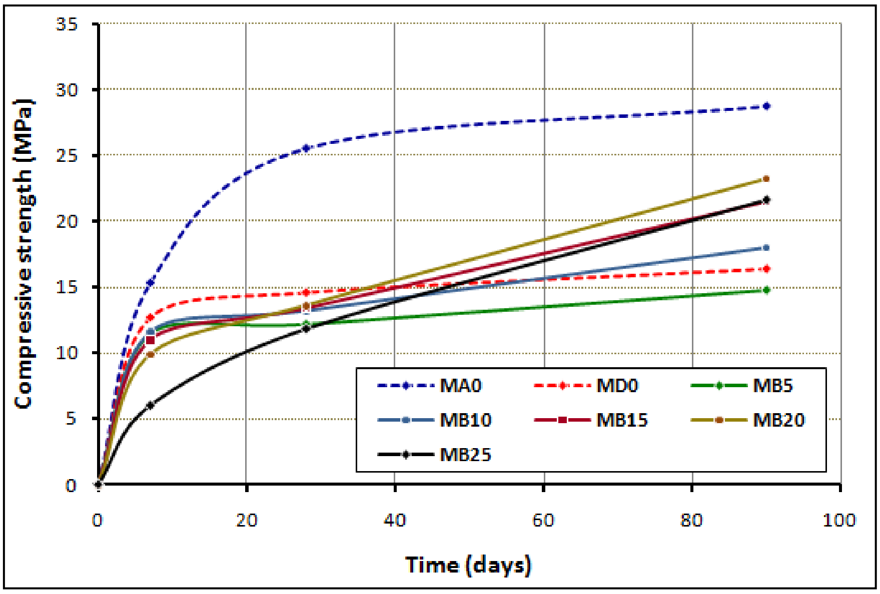

Fig. 6.b- Variation of compressive strength over time

At 90 days, it was noted that the increase in CBW, causing the same evolution of the compressive strength at 28 days, but with an optimum corresponds to 20% of CBW; which shows that the use of this addition is less effective for percentages greater than 20%, and its incorporation becomes effective only from 10%. The compressive strength gain is of the order of 10, 30, 40 and 30% for 10, 15, 20 and 25% of CBW respectively. This improvement makes it possible to reach more than 80% of the resistance of the control mortar (MA0) at 90 days. These results clearly indicate the effectiveness of the CBW in improving this characteristic.

Finally, it is found that the rate of increase in compressive strength from 28 to 90 days for mortars without additions (MA0 and MD0) is about 12%, whereas, it is 36, 60, 71 and 83% for 10, 15, 20 and 25% of CBW respectively (Figure 6.b); this can be attributed to the pozzolanic activity which becomes important after 28 days.

5.5 Flexural strength

The results of the test are shown graphically in Fig. 7.a and 7.b. From these results, it can be seen that the flexural strength values for 10, 15 and 20% CBW were higher than that the mortar without addition (MD0) at all ages. The inclusion of CBW with incorporation rate of 15%, makes it possible to achieve a flexural strength at 90 days equivalent to that of the control mortar (MA0). This result proved the effectiveness of the used crushed waste.

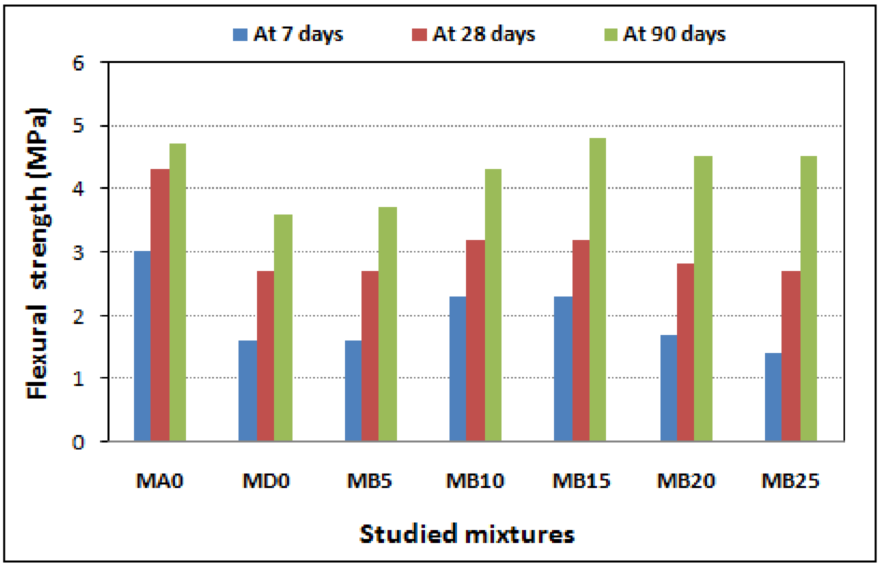

Fig. 7.a- Influence of the incorporation of CBW on flexural strength

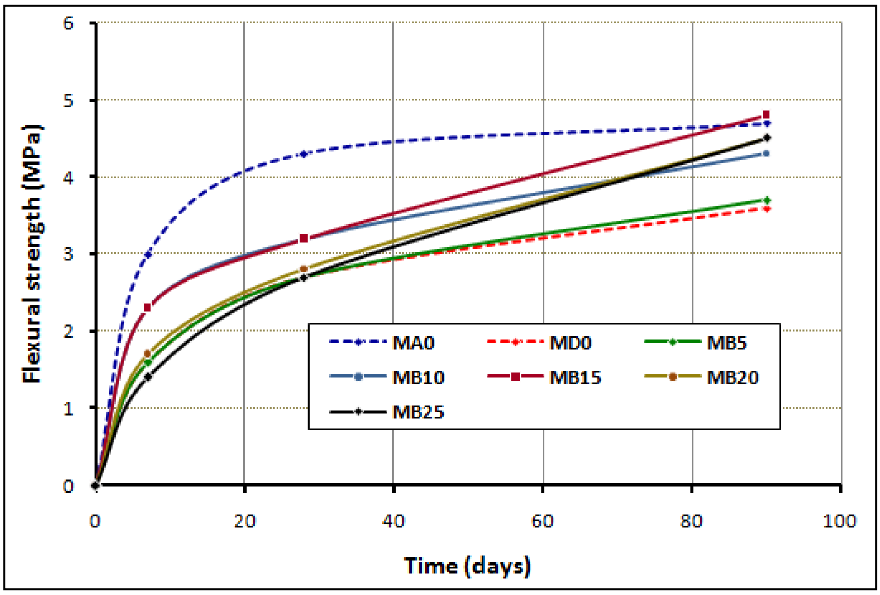

Fig. 7.b- Variation of flexural strength over time

5.6 Water absorption of hardened mortars

The results of water absorption of the mortar mixes are shown in Fig. 8. Initially, It was observed that, the water absorption decreases until a minimum value corresponding to an incorporation rate equal to 15%, then it increases with the increase of CBW amount. The decrease in the water absorption is mainly due to the filling effect of CBW. The increase of this characteristic can be related to the increase of the quantity of free water in the mixtures after the filling of the voids. The value of water absorption at 15% CBW indicates that the MB15 mixture is the least porous; this confirms the results of the other tests (workability, density, mechanical strength).

Finally, it can be seen that the granulométric correction of the studied dune sand by the use of CBW, does not make it possible to obtain water absorption coefficients lower than that of the control mortar (MA0). This is mainly due to the good particle size distribution of the sand SA.

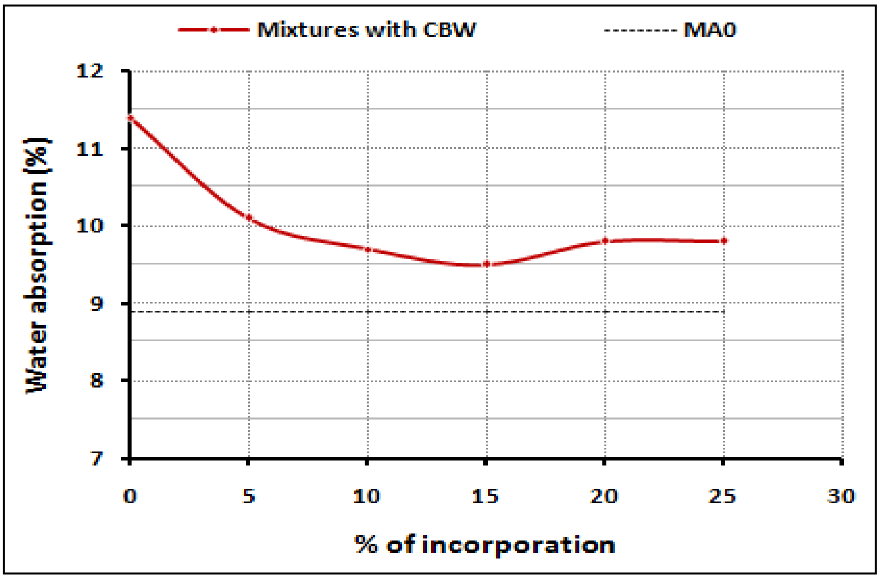

Fig. 8- Effect of CBW amount on water absorption

5.7 Resistance to sulfuric acid attack

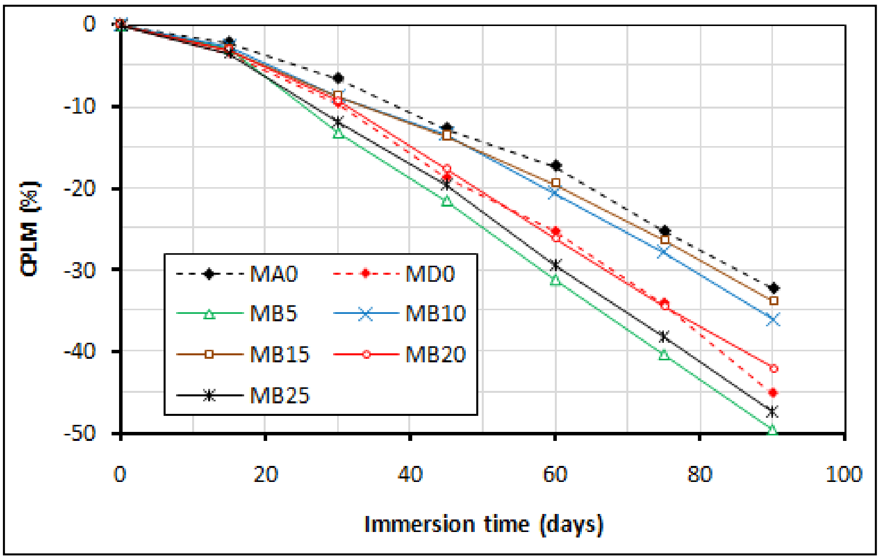

Fig. 9- Mass loss of mortar samples made with CBW due to immersion in sulfuric acid solution

The mass loss is commonly used as acceptable indicator to evaluate the deterioration of mortars and concretes under acid attack [31,32].

Fig. 9 represent the mass loss (negative means mass loss) of specimens exposed to sulfuric acid up to 90 days. From these results, it can be observed that the mass is gradually decreased with the increase in exposure time for all studied mortars. This deterioration of mortar structure is mainly caused by the reaction between calcium hydroxide ($Ca(OH)_2$) presented in cement and the sulfuric acid, which can induce tensile stress, resulting in cracking and scaling of mortar [33].

Concerning the effect of the incorporation of CBW, as illustrated in Fig. 9, the amelioration of the resistance to sulfuric acid attack is only possible for incorporation rates of 10% and 15%. These gains are not sufficient to achieve the results obtained by the control mortar. After 90 days of immersion in sulfuric acid solution, the correction of SD with 15 % CBW contributes to reducing the deterioration of mortar structure by 25%. Visually, the Fig. 10 reflects the deterioration of mortar samples in sulfate environment, particularly for the mortar with 5% of CBW.

Fig. 10- Deterioration of CBW samples after 90 days of immersion in 5% H_2SO_4 solution

6 Conclusion

This study was conducted to assess the possibility of utilizing crashing waste of red clay brick waste (CBW) as a partial replacement of dune sand and of valorizing them in mortar manufacturing. Based on the results of the experiment conducted in this investigation, the following main conclusions could be pinched:

The amount of crushed brick waste has a significant effect on the properties of dune sand mortar in the fresh state and the hardened state. The progressive substitution of dune sand by crushed waste addition with percentages of less than 15%, has a significant negative influence on the workability, however, beyond 15%, it has a positive effect. The mixes containing CBW exhibit good to very good workability. The maximum value of the bulk density of the hardened mortar which corresponds to optimal filling of the voids between grains of dune sand (maximum compactness) is obtained for CBW content of 15%.

The use of the crushed clay brick waste as a partial replacement of dune sand can give very significant improvement in compressive strength at 90 days (about 40%). This improvement makes it possible to reach more than 80% of the resistance of the control mortar at 90 days. The effect of this crushed waste on the evolution of compressive strength with time is very significant, especially after 28 days; this is mainly attributed to the pozzolanic activity which becomes important in this period. Also, the inclusion of CBW with incorporation rate of 15% makes it possible to achieve a flexural strength at 90 days equivalent to that of the control mortar, and leads to significant improvements in resistance to sulfuric acid attack.

In the perspective and to better control the behavior of dune sand mortars treated with crushed brick waste, it is hoped that other characteristics such as shrinkage, permeability, thermogravimetric analysis (TGA) and differential thermal analysis (DTA) can be studied in future work. The limitation of this study is that this research covers only the case of the dune sand of the region of Djelfa (Algeria). The same investigation for other dune sand types is required.

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