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Investigation on the use of crushed waste of ceramic tiles and clay brick as aggregate in dune sand based mortars

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Abstract

This present study aims to examine the possibility of using the dune sand which is abundant in Algeria in the manufacture of mortars having sufficient physical and mechanical performances to exploit them in different applications in the field of construction of buildings. The improvement of the mortars based on dune sand was made through the addition of crushed wastes of ceramic tiles and red clay brick. The formulation of mixtures is based on the substitution of dune sand with crushed wastes at different weight contents; 5, 10, 15, 20 and 25%. The W/C ratio is fixed at 0.7. The results obtained show that the incorporation of these additions improves the compactness, the mechanical strengths and the sulphate resistance, and enhancement the dynamic modulus of elasticity with 15% ratio of waste incorporation. Further to this, it was also observed that the inclusion of the used wastes with determined percentages can provide physical and mechanical performances exceed that given by the mortar made with alluvial sand, which demonstrate their effectiveness to the improvement of the various properties of the mortar.

Keywords: Dune sand, ceramic waste, clay brick waste, mortar, Mechanical strength, water absorption, dynamic modulus of elasticity, sulphate resistance.

1 Introduction

In Algeria, there is an abundant presence of noble aggregates. However, the excessive exploitation of these materials can cause long-term problems, especially on the environment.

The exploitation oriented towards to dune sand, clean and present in abundance. Its use could be related to its very high silica content. This sand is also of great economic interest, environmental and ecological. For these reasons which push to the valorization of dune sand.

The dune sand, which constitutes almost 60% of the Algerian territory, is characterized by its good cleanliness and high grain hardness [1-3]. These characteristics have encouraged researchers to further study this material in order to apply it to various fields of civil

engineering, such as road construction [4,5] and concrete and mortar manufacturing [6,7]. Due to the poor particle size distribution of dune sand [4,8], these researches were all focused on finding a way to correct the granular distribution of this sand, with the aim of reducing its porosity, and consequently improve the physical and mechanical characteristics of the mixtures based on this sand.
The waste materials aggregates can be used as well as in mortar and concrete. These waste materials play a very important role in solving present ecological problems. The waste of ceramic tiles and red-clay brick were produced during manufacturing industry, transportation and placing. The production of these wastes has seen a very significant increase in the world over the past few years. This increase was accompanied by an increase in interest in the valorization of these materials, for the purpose to use them as additives in the production of cement [9], or as active additions in the manufacturing of mortars and concretes [7,10,11]. Due to their pozzolanic activity reaction of clay brick powder in blended cement mortars contributes to the compressive strength of mortars and the microstructure of blended pastes became compact [12], the use of these wastes in the manufacture of cementitious mixtures can contribute to improving the physical and mechanical properties, reducing the cost, saving energy and protecting the environment [13]. Y.F. Silva et al [14] revealed that the addition of residue mortar composed of red clay bricks and cement mortar aggregate as cement substitute less than 37.5% can improve compressive strength and from 12.5% to 50% as cement substitute has good workability and self-compaction. Y. Ogawa et al [15] investigated in another study the cement hydration, compressive strength, shrinkage and carbonation properties of concrete made with porous ceramic waste coarse aggregate and 40% of fly ash. The results of this study showed that the porous ceramic waste and fly ash can be used to improve the compressive, drying shrinkage properties and carbonation resistance of concrete. With PCWA incorporation, cement hydration enhancement and fly ash reaction in steam-cured concrete. On the other hand, they can also be generated with other kinds of building materials. The residue of sintered clay brick and aerated concrete blocks generated to manufacture other kinds of building materials. Q. Liu [16] have shown that the use of 10% of recycled powder as cement replacement could be considered the best proportion to enhance the properties of mortar. However, Li et al. [17] demonstrated that mortar with ceramic polishing waste added as paste substitute can significantly enhance sulphate resistance, shrinkage and compressive strength resistance of mortar. Moreover, Pachta et al. [18] concluded that the usage of brick dust and crushed brick enhanced the layered as well as increased adhesion mortars performance and higher compressive strength and Huseien et al. [19] demonstrated the properties of self-compacting, alkali-activated concrete incorporating ceramic tile powder waste could substantially improve the low carbon by using high volume ceramic powder and concrete strength but have better workability performance resistances of concrete as well as, enhancement of concrete durability.
This study focused on the feasibility of correcting the dune sand particle size by the incorporation of crushed waste of ceramic tiles and red clay brick in the production of mortar. To evaluate the influence of waste addition on important physical and mechanical characteristics of modified mortars, the dune sand was replaced 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 the inclusion of these crushed wastes with determined percentages can provide physical and mechanical performances exceed that given by the control mortar, which demonstrates their effectiveness

to the improvement of the various properties of the mortar.

2. Materials

2.1. Cement

The cement used in this study is of ordinary Portland cement CEM I 42.5 class, conforming to the NF EN 197-1 standards [20]. It was manufactured by the Algerian cement company. 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 [21].

Table 1: Mineralogical composition of clinker (%)

C_3S	C_2S	C_3A	C_4AF
52.02	28.97	6.71	12.28

2. 2. Studied sands

In this work, the experiment was undertaken on two types of sand; dune sand noted by DS and alluvial sand designed by AS (Fig. 1). The dune and alluvial sand comes from the southern region of Algeria.

Figure. 1. Used materials

The different results of the physical characteristics of the sands studied are summarized in Table 2. The AS presents a good value of the fineness modulus (2.36), but the DS has a low value (0.86), which means that the AS provides a reasonable compromise between the workability and the resistance [22].

Table 2: Physical characteristics of the studied materials

Physical characteristics	AS	DS	CW	BW
Bulk density (g/cm^3)	1.61	1.46	1.02	1.19
Specific density (g/cm^3)	2.60	2.53	2.43	2.50
Porosity (%)	38	43	58	52
Compactness (%)	62	57	42	48
Water absorption (%)	0.87	2.15	12.73	5.61
Visual sand equivalent (%)	81	79	--	--
Sand equivalent with the piston (%)	80	75	--	--
Maximum size (mm)	5.00	0.63	2.50	2.50
Fineness modulus	2.36	0.86	--	--
Fine particles percentage (%)			47	37

The sand equivalent test carried out in accordance with the NF P 18-598 standard, set values above the recommended limits for concrete and mortar. This allows us to use AS and DS in our investigation.

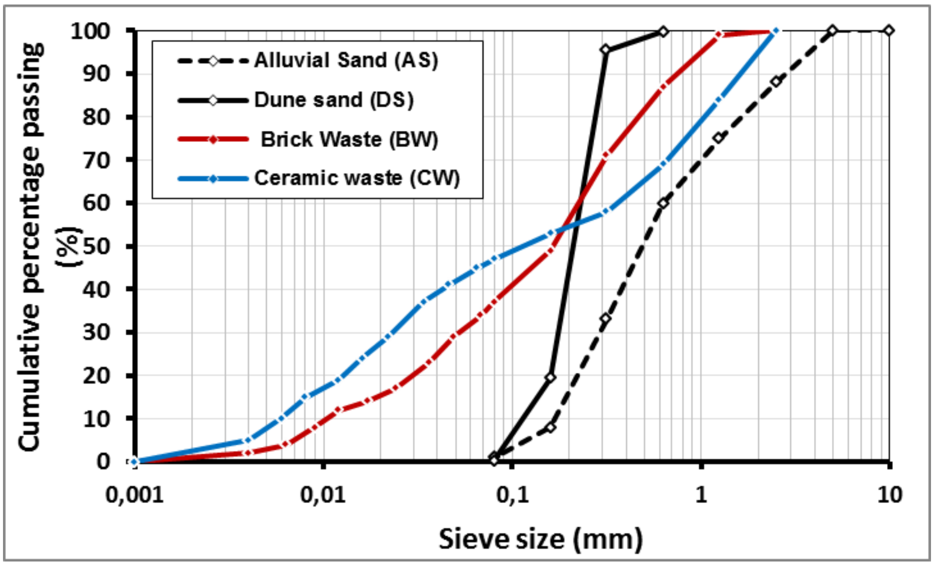
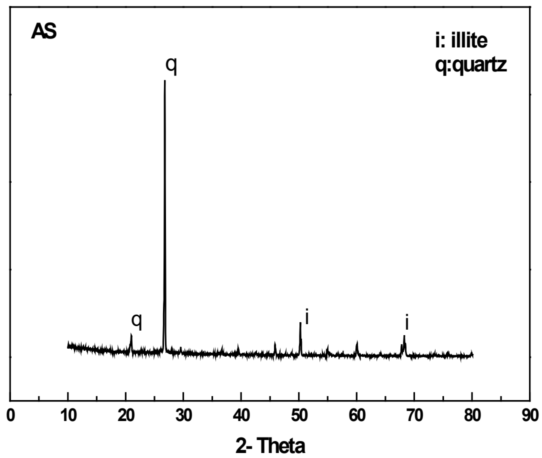


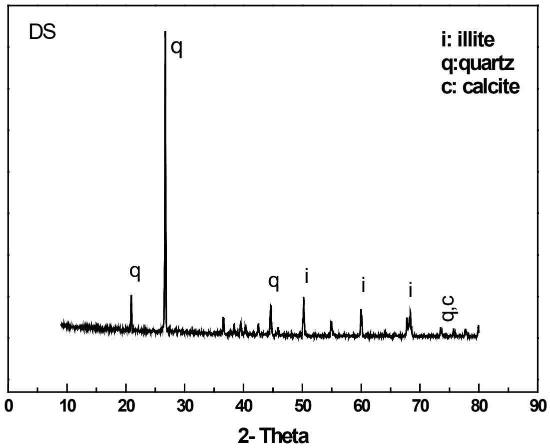
Figure. 2. Particle size distribution of the materials used

The dune sand (DS) presents a continuous distribution of particle sizes from 0 to 0.63 mm (Fig.2). It can be clearly seen that 90% of the sand grains in the dunes are below 0.3 mm. From a granular point of view, this sand can be classified as fine sand [23]. The grading is very tight; almost 90 % of the grains have dimensions ranging from 0.1 mm to 0.5 mm. The sand alone could not have sufficient compactness and therefore not have sufficient mechanical strength (compressive and tensile strength). It should be noted that the sand considered must therefore be granularly corrected [1].

In this investigation, the X-ray diffraction was performed using a random powder method for the bulk sample. The results obtained by the XRD analysis of the sands studied to demonstrate the essentially siliceous nature of DS and AS (Fig. 3.a and 3.b).
The contents of the essential harmful substances (Table 3) are within the tolerable limits recommended by AFNOR standard FD P 18-011[24]. This enables us to use ordinary Portland cement as a binder.



(a)

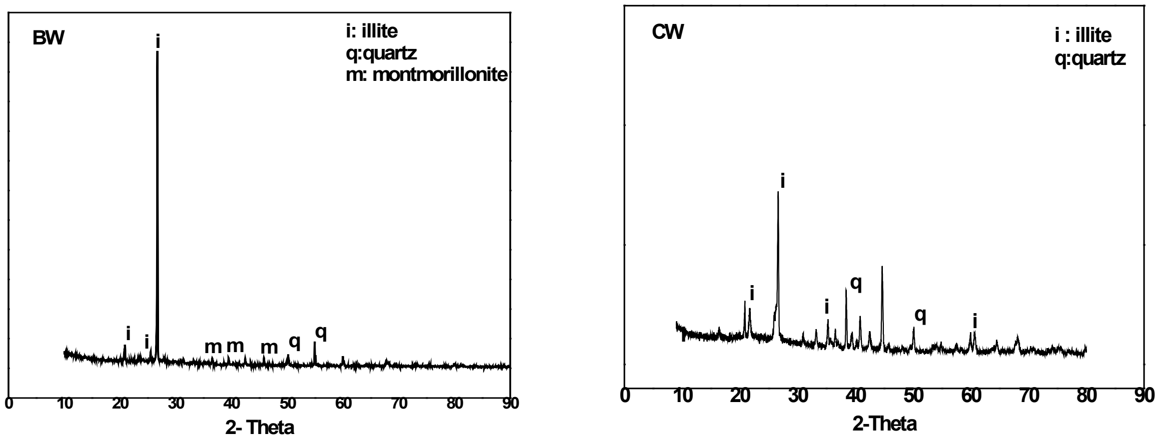


(b)

Figure. 3: X-ray diffraction patterns of sands: (a) Alluvial and (b) dune

2. 3. Additions

In our study, two additions from two different origins were chosen. The additions used in the experiments are; crushed ceramic tile waste and crushed Red-clay brick waste noted respectively by CW and BW (Fig. 1). The reduction of the particle size of the CW and BW was made in the laboratory by crushing and grinding using a ball mill. It should be noted that for the same grinding time, the ceramic waste offers more resistance during the crushing operation. The particle size distribution of studied additions which is shown in Fig. 2, has been determined by sieving method according to NF P94-056 [25] for the fraction higher than 0.080 mm, and by sedimentation method according to NF P94-056 [26] for the fine fraction (smaller than 0.080 mm). The CW and BW present a continuous particle size distribution ranging from 0 to 2.5 mm. The percentage of fine particles is respectively, 47% and 37%. The additions used have a 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 wastes aggregates is due to the higher porosity of the original wastes.



(d) (c)

Figure. 3. X-ray diffraction patterns of additions; (c) CW and (d) BW

The XRD analysis mentioned in Fig. 3.c and 3.d shows that CW and BW are comprised of mainly crystalline phase of illite. The chemical analysis shows that these additions contain almost no harmful elements (Table 3).

Table 3: Contents of the essential harmful substances

Essential harmful substances	AS	DS	CW	BW
Sulphates (%)	traces	traces	traces	traces
Chlorides (%)	0.16	0.82	traces	traces

3. Mix proportions and sample preparation

The mix proportion used to prepare the mortars was the same as used to make the normal mortar, according to the NF EN 196-1 Standard [27]. The additions CW and BW were used as dune sand replacement. To study the effect of the waste incorporation on mortar characteristics, the percentages used were 0%, 5%, 10%, 15%, 20% and 25% by weight of dune sand. A fixed water-cement ratio of 0.70 was used for all mixtures. Cement-aggregate ratio was 1:3. A reference mixture (control mortar) using cement and alluvial sand was prepared to be compared with the CW and BW mortars. Twelve (12) mixtures are to be studied in this investigation. Details of the proportions of mixtures are given in Table 4.

Table 4: Ponderal composition of designed mortars

Symbol of mortar	Mix proportions	Cement (g)	DS (g)	AS (g)	CW (g)	BW (g)	W/C
MA0 (control mortar)	100% AS	450	-	1350	-	0	0.7
MD0	100% DS + 0% CW	450	1350	-	-	0	0.7
MC5	95% DS + 5% CW	450	1282.5	-	67.5	-	0.7
MC10	90% DS + 10% CW	450	1215	-	135	-	0.7
MC15	85% DS + 15% CW	450	1147.5	-	202.5	-	0.7
MC20	80% DS + 20% CW	450	1080	-	270	-	0.7
MC25	75% DS + 25% CW	450	1012.5	-	337.5	-	0.7
MB5	95% DS + 5% BW	450	1282.5	-	-	67.5	0.7
MB10	90% DS + 10% BW	450	1215	-	-	135	0.7
MB15	85% DS + 15% BW	450	1147.5	-	-	202.5	0.7
MB20	80% DS + 20% BW	450	1080	-	-	270	0.7
MB25	75% DS + 25% BW	450	1012.5	-	-	337.5	0.7

Upon completion of the mixing process, the fresh mortar was placed in molds of dimensions (40×40×160) mm^3, which were then clamped onto a vibrating table for 20s. During the first 24 hours, 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 the NF P18-452 LCPC workabilymeter [28]. The test consists of measuring the time necessary for the flow of mortar under the effect of the specified vibration until the reference line is reached. This time is going to be all the shorter as the mortar will be more fluid. The bulk density of fresh mortars was determined in accordance with NF EN 1015-6[29].

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 [27]. 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 [30] and NF EN 1015-18 [31] respectively.
The methods used in most of the tests complied with European standards, rendering mortars may be classified according to the Dynamic modulus of elasticity categories (determined in accordance to EN 14146 [32]) Three prisms (40x40x160) mm^3 per mortar presented in figures 10.a and 10.b. respectively, measure the velocity of ultra-sonic waves according to Fe Pa 43 (2010) [33].
The sulfuric acid immersion test was determined on mortar samples of dimensions 40×40×160 mm^3, in accordance with the standard ASTM C267 [34], using the Vol 5% 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 (%) = $((M_t - M_0)/M0)$ x100%
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 curves of Fig.4 show the evolution of the flow time (workability) according to the quantity of crushed waste added. We notice that for a fixed water-cement ratio (W/C = 0.7), the dune sand mixture (MD_0) presents low workability (16 seconds) compared to the control mortar (2 seconds), this is mainly due to the size of sand dunes, which is very fine compared to alluvial sand (fine sands require more water).
It was also noted that the progressive substitution of dune sand by CW and BW addition with percentages of less than 15%, has a significant negative influence on the workability. This may be explained by the increase in the specific surface area of the fine particles in mixtures after adding crushed wastes, thereby increasing the water requirement to wetting the fine waste aggregates [35]. However, beyond 15% of CW and BW addition, the dune sand replacements by used additions have a positive influence on the workability of the fresh mortars. This improvement in workability may be related to the fine fraction of the additions filling the voids and releasing the trapped water, which therefore improves the consistency of the mortar [36].

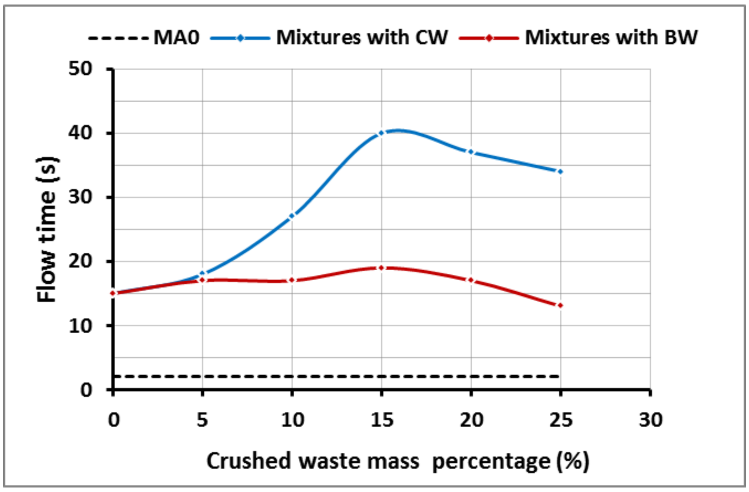


Figure. 4. Evolution of workability as a function of the substitution rate

In the curves shown in Fig. 4, it can also be observed that, beyond 5 % crushed waste replacement, the effect of the type of waste on workability becomes very significant; the mixes containing BW exhibit good to very good workability (13 to 19 seconds), however, it is medium to low (27 to 40 seconds) for those based on CW. This can be explained by the distinct fine particles percentage and water absorption for each addition (Table 2).

5.2. Dry bulk density of fresh mortars

Fig. 5 displays bulk density results of fresh mixtures as a function of crushed wastes amounts. It should be noted that, for a constant W/C ratio, the bulk density of mortar containing dune sand is lower than that of control mortar. The reason for this difference is mainly attributed to the bulk density of dune sand that is lower than that of alluvial sand by 10%. Furthermore, the bulk density generally decreases according to the percentage of incorporated additions. This appears to be due essentially to the lower bulk density of CW and BW (1.02 g/cm^3 and 1.19 g/cm^3 respectively) as compared with dune sand. This observation was already reported by several authors [11, 37, 38].

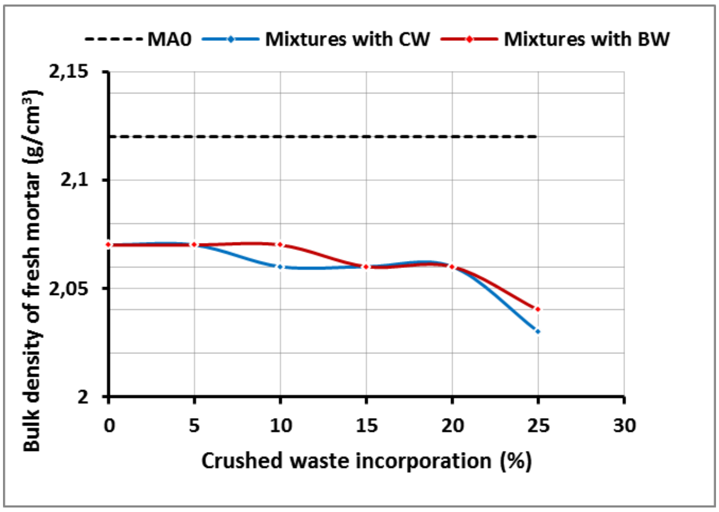


Figure. 5. Evolution of the bulk density of fresh mortar according to the incorporation rate

5.3. Dry bulk density of hardened mortars

The evolution of dry bulk density of hardened mortars with additions percentage is shown in Fig. 6. It was observed that, for a fixed water quantity the dry bulk density of mixture based on dune sand (MD_0) is lower than that of the mixture based on alluvial sand (control mortar). This is principally caused by the distinct porosity (Table 2) for each sand (the DS contains a higher void volume).

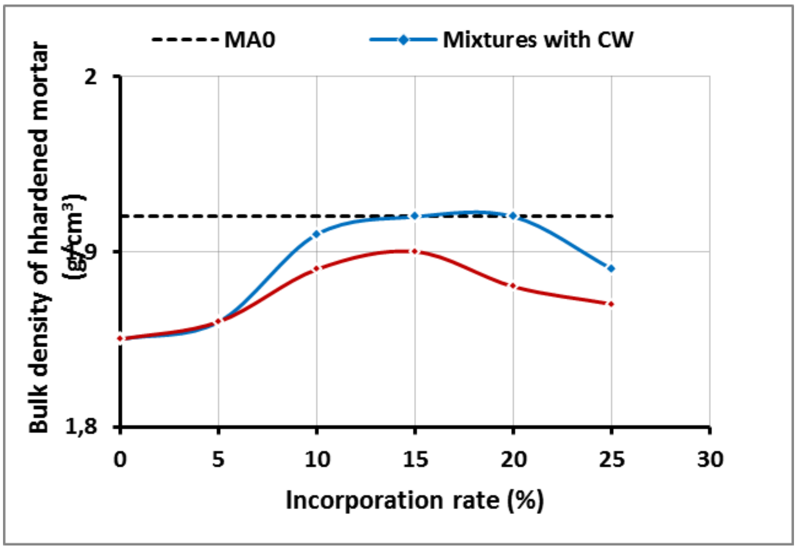


Figure.6. Evolution in bulk density of hardened mortar versus addition rate

It was also observed that, by increasing the replacement rate of the crushing wastes, the bulk density of the hardened mortars increased until a certain optimum and then decreased (Fig. 6). The increase in bulk density for replacement rates from 5% to 15% is linked to the decrease of voids volume within the mortars due to the addition of the fine particles [11]; which explains the effectiveness of the used granular correctors (CW and BW) to improve the compactness of the mixtures. A replacement rate equal to 15%, the bulk density of the modified mortars reaches maximum values of 1.92g/cm^3 and 1.9g/cm^3 for CW and BW respectively; these values correspond to the optimal filling of the spaces between grains of dune sand [39]. The decrease in bulk density for incorporation percentages beyond 15% and 20% of BW and CW respectively is ascribed to the fine particles which begin to occupy the place of the dune sand grains [36], which increased the overall volume (for the same mass, the volume of the crushed waste is greater than that of dune sand), and consequently, The apparent density of modified mortars decreased.
From Fig. 6, it may also be noted that beyond 5 % of addition replacement the effect of the type of waste on the bulk density becomes very significant; at the same replacement level, the incorporation of CW in the mortars results in a higher bulk density compared to that of mortars containing BW; Due to the higher percentage of fine particles and water absorption capacity of CW compared with BW (Table 2), at fixed W/C ratio, the amount of the water in excess in mortars containing CW is lower than that mortars containing BW, which gives after evaporation a smaller voids volume, and consequently greater compactness.
Finally, it should be noted that the dune sand correction with 15 to 20 per cent CW makes it

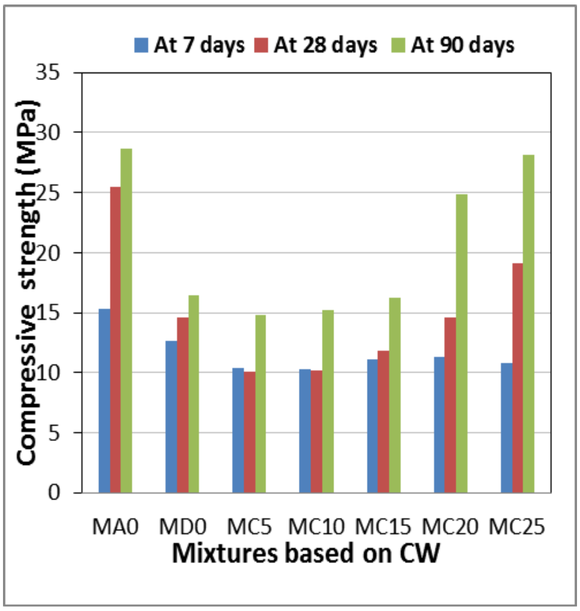
possible to obtain a bulk density equal to that of the control mortar (MA_0).

5.4. Compressive strength

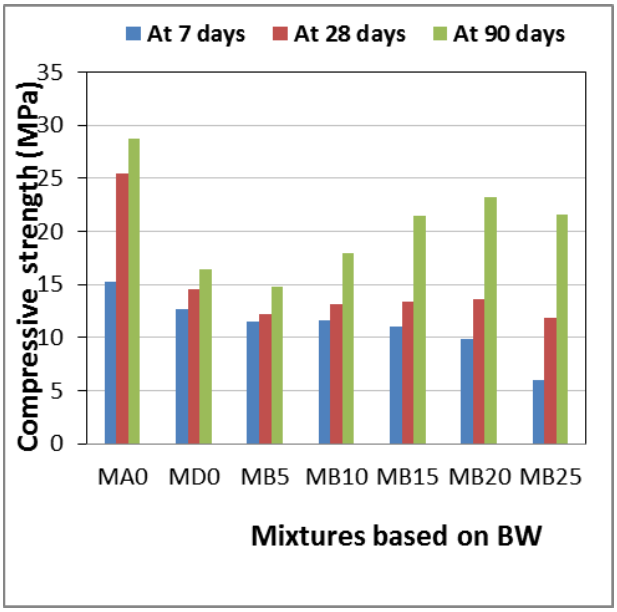
The development of compressive strength with additions content and with time is given in figures 7.a and 7.b. A number of comments on these results may be made;

At 7 days, the incorporation of CW and BW as partial replacements of dune sand leads to lower compressive strengths than that of a mortar without addition (MD_0). As seen in Fig. 7.a and Fig.7.b, the use of 25% CW and BW induces a loss in compressive strength of 15% and 52.7% respectively. These results show that, at this age, the use of the studied additions has significantly delayed cement hydration (chemical effect) and consequently decreased the compressive strength of mortars.

The increase in CW content at 28 days leads to a continuous increase in compressive strength.



(a)



(b)

Figure. 7. Influence of the incorporation of CW (a) and BW (b) on compressive strength

This shows that the chemical effect of CW on the evolution of compressive strength, due to its possible pozzolanic reactivity, is most dominant, as its filling effect normally leads to compressive strength. To a maximum strength between 15% and 20% of CW (the percentages for which the compactness is maximum (Fig.6)). We can also add that the compressive strength does not reach that of the mortar without addition (MD_0) that as from 20% CW and the incorporation of 25% CW induces a gain in compressive strength of 30.8%. On the other hand, it is also observed that the compressive strength increased up to a certain optimum (15% of BW) and then decreased with increasing amounts of BW (evolution similar to that of compactness). Furthermore, it is noted that the correction of dune sand with BW does not participate in the giving of strengths at 28 days higher than that of a mortar without addition (MD_0), but there is a decrease in the strength loss rate compared with 7 days; for 15%, 20%

and 25% of BW, it is 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.

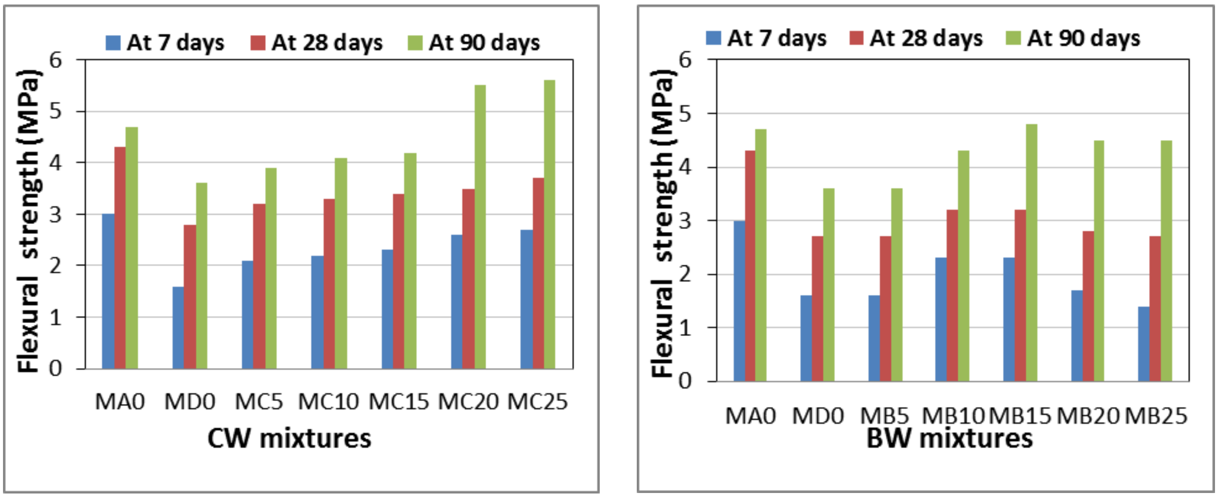
At 90 days, the same observation may be noted concerning the evolution of the compressive strength as a function of the percentage of CW, Which remains an increasing function. We also note that the use of CW as a dune sand substitute is only 20 per cent effective for CW. The strength gain rate is 50 per cent and 70 per cent respectively for 20 per cent and 25 per cent for CW. The strength gain rate is of the order of 50% and 70% for 20% and 25% of CW respectively. On the other hand, it is also observed that the increase in BW, causing the same evolution of the compressive strength at 28 days, but with an optimum corresponds to 20% of BW; 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 strength gain rate is of the order of 10%, 30%, 40% and 30% for 10%, 15%, 20% and 25% of BW respectively.

The incorporation of CW and BW can give maximum improvements in compressive strength at 90 days of the order of 70% and 40% for 25% CW and 20% BW respectively. These improvements make it possible to reach compressive strength close to that of the control mortar (MA_0) in the case of CW and to attain 81% of its strength in the case of BW. These results clearly indicate the effectiveness of the CW and BW in improving the compressive strength of the dune sand-based mortars.

Finally, it is found that the effect of the addition of CW and BW on the evolution of compressive strength as a function of time is very significant, especially after 28 days. Where it is observed that the proportion of the increase in compressive strength for mortars without incorporation is from 28 days to 90 days. for mortars without incorporation (MA_0 and MD_0) is approximately 12%, whereas, it is 70% and 47% for 20% and 25% of CW respectively, and 36%, 60%, 71% and 83% for 10%, 15%, 20% and 25% of BW respectively; This can be attributed to the pozzolanic activity that is becoming more important after 28 days.

5.5 Flexural strength

The flexural strength results of mortars mixes made with and without CW and BW were given in Fig. 8.a and Fig. 8.b. From these results, it can be seen that the flexural strength of CW mortars, were higher than the mortar without addition (MD_0) at all ages. It is evident from Fig 8a that this characteristic increases continuously until reaching its maximum value at 25% CW, with the rate of increase of strength about 69%, 32% and 56% at 7 days, 28 days and 90 days respectively. It can be seen also that the flexural strength of BW mortar mixes with 10%, 15% and 20% replacement were higher than the mortar without addition at all ages. Maximum strength at all ages occurred at 15% CW replacement, with the rate of increase of strength about 44%, 19% and 33% at 7 days, 28 days and 90 days respectively.



(a) (b)

Figure. 8. Influence of the incorporation of CW (a) and BW (b) on flexural strength

The inclusion of CW and BW as a partial replacement of dune sand makes it possible to achieve flexural strengths at 90 days higher than that of the control mortar (MA_0); the 90-days strengths at 20% and 25% of CW and 15% of BW exceed that of the control mortar by 17%, 19% and 2%, respectively. These values vividly demonstrate the effectiveness of the additions used to improve the flexural strength of dune sand mortars. These results may be explained, by a higher compactness of the hardened mortar (filler effect) and a potential pozzolanic effect of this construction and demolition waste.

5.6. Water absorption of hardened mortars

The results of water absorption of the mortar mixes are shown in Fig. 9. It was observed that, by increasing the rate of incorporation of CW and BW, the water absorption coefficient of the mortars decreased to 15% and then increased. The decrease in water absorption is mainly due to the filling effect of CW and BW. The increase of this characteristic may be related to the increase of the quantity of free water in the mixtures after the filling of the voids. The mortars with 15% CW and BW (MC_{15} is MB_{15}) are those that exhibit the lowest workability for each type of addition (Fig. 4). The amount of free water in the mixtures is thus reduced for these mortars, which decreased the volume of voids and therefore the water absorption coefficient (Fig. 9). This means that the porosity at 15% CW and BW is the lowest (the compactness is the highest), which confirms the results of the other tests (workability, bulk density of hardened mortars, compressive and flexural strength).

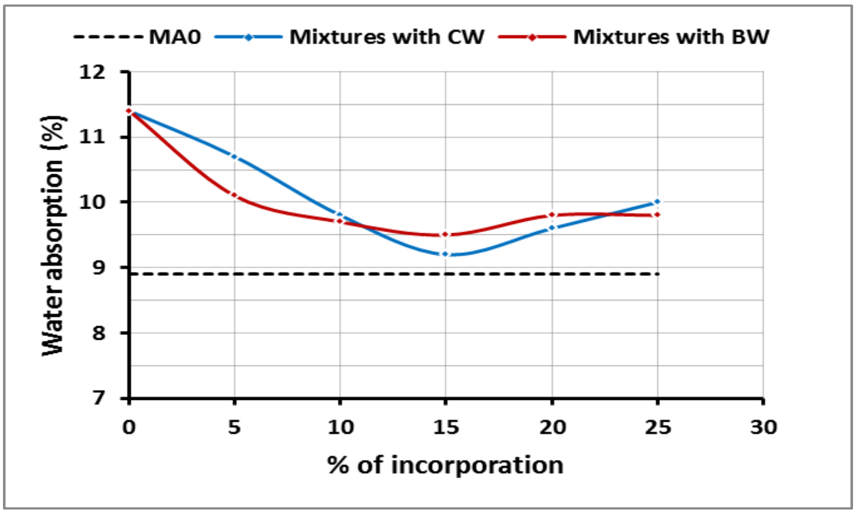


Figure. 9. Effect of addition amount on water absorption

Finally, it can be seen that the correction of studied dune sand granulometry by the use of CW and BW does not make it possible to obtain water absorption coefficients lower than that of the control mortar (MA_0). This is mainly due to the good particle size distribution of the alluvial sand.

5.7. Dynamic modulus of elasticity of hardened mortar

The results of the dynamic modulus of elasticity test are presented in Fig. 10.a. The dynamic modulus of elasticity, considered of the materials waste used, increased with the type of waste incorporation (ceramic tile and crushed red-clay brick). This is due to the fine particles that occupy the voids between sand aggregates. Thus, mortars become more compact, the irregularity shape of waste materials provides a higher bond between waste aggregates and the cement paste and as a consequence, the modulus of elasticity increased. The dune sand mortar with 15% rate incorporation of ceramic tile and red clay brick had a modulus of elasticity 28%, 10% and 24%, 0.6% higher than that of the references mortars (MD_0, MA_0). This denotes higher compactness of the modified dune sand mortar (15%) when compared with a reference mortar and as well consistent with higher lower water absorption and mechanical strength.

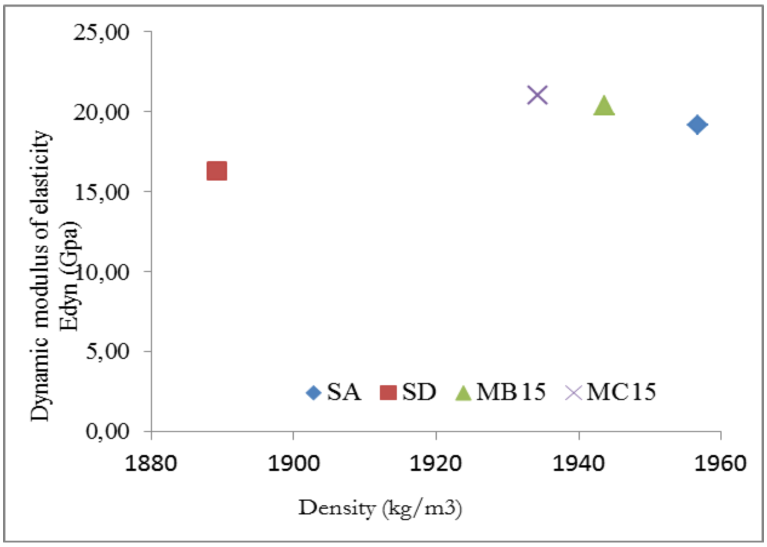


Figure. 10.a. Dynamic modulus of elasticity of mortar tested

5.8. Ultra-sound of hardened mortar

The effect of adding aggregates waste (CW, BW) on these tests of a dune sand mortar has been presented on Fig.10.b, an increase in ultra-sound pulse velocity in the modified dune sand mortars with incorporation of ceramic tile and red clay brick waste. This result of agreeing with the modulus of elasticity test. These experimental strengthen the concept that the incorporation of ceramic tile and crushed red-clay brick wastes produced a dune sand mortar with a lower volume of pores, which higher mechanical resistance, and lower water absorption.

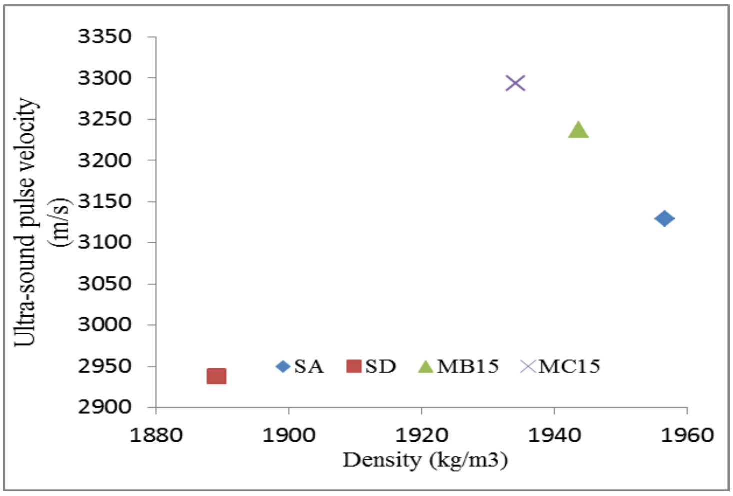


Figure. 10.b. Ultra-sound pulse velocity of the mortar tested

5.9. Resistance to sulfuric acid attack

The mass loss is commonly used as an acceptable indicator to evaluate the deterioration of mortars and concretes under acid attack [40, 41]. Fig. 11.a and 11.b 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 the mortar structure is mainly due to the reaction between the calcium hydroxide ($Ca(OH)_2$) present in cement and the sulphuric acid, which can induce tensile stress, resulting in mortar cracking and scaling [42].

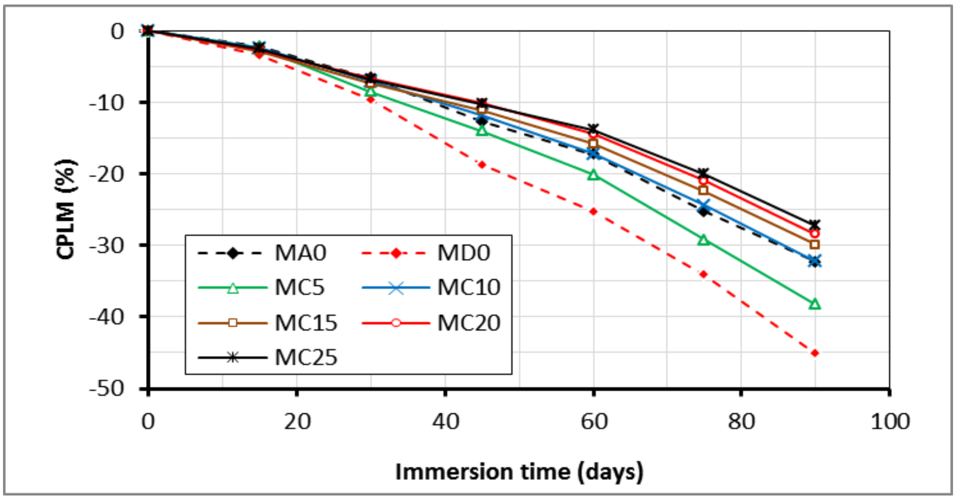


Figure. 11.a. Mass loss of mortar samples made with CW

As shown in Fig. 11.a, the replacement of part of dune sand by CW increased the mortar's ability to resist to acid attack. A mortar containing 10% of CW (MC_{10}) may have the same acid resistance as a control mortar. Beyond 15% the CW mortars exhibited higher acid resistance than that of control mortar. At the end of the test period, the incorporation of 25 % of CW results in an acid resistance improvement of approximately 40 %.

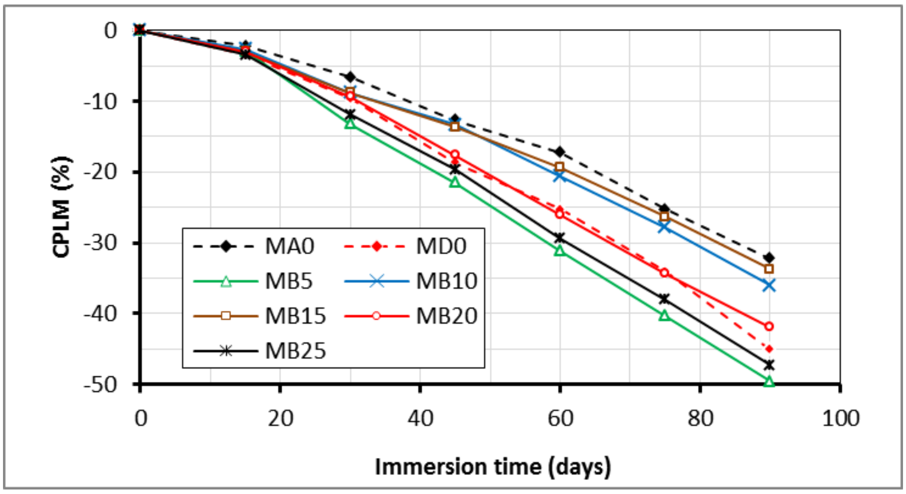


Figure. 11.b. Mass loss of mortar samples made with BW

Concerning BW, as illustrated in Fig. 11.b, 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.

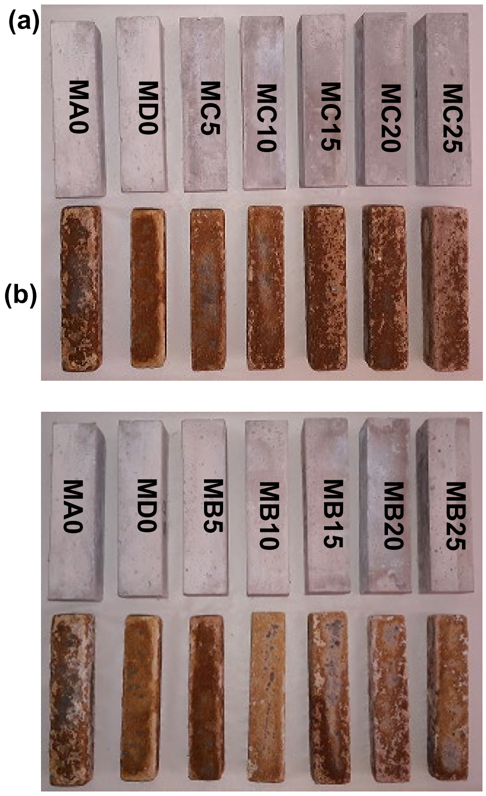


Figure. 12. Deterioration of CW (a) and BW (b) samples after 90 days of immersion in 5% H_2SO_4 solution

After 90 days of immersion in sulfuric acid solution, the correction of dune sand with 15 % BW contributes to reducing the deterioration of mortar structure by 25%. Visually, the fig. 12.a 12b reflects the deterioration of mortar samples in sulfate environment, particularly for the mortar with 5% of BW.

6. Conclusion

This study was conducted to assess the possibility of utilizing crashing waste of ceramic tiles (CW) and red clay brick waste (BW) as a partial replacement of dune sand for valorizing them in mortar manufacturing. Based on the results of the experimental program conducted in this investigation, the following main conclusions are drawn:

- At the same W/C ratio, the progressive substitution of dune sand by CW and BW 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 BW exhibit good to very good workability, however, it is medium to low for those based on CW.
- The incorporation of CW results in a higher bulk density of hardened mortars compared to

that of mortars containing BW. The optimal filling of the voids between grains of dune sand, which corresponds to maximum compactness and bulk density, is obtained for CW content between 15% and 20%, and for 15% of BW.
-The use of CW and BW as a partial replacement for dunes sand can lead to very good improvements in compressive strength at 90 days; around 70% and 40% for 25 % CW and 20 per cent BW respectively. These improvements make it possible to reach compressive strength close to that of the control mortar in the case of CW and to attain 81% of its strength for BW. The effect of the addition these crushed wastes on the evolution of compressive strength with time is very significant, especially after 28 days; this is mainly attributed to the pozzolanic activity that has become important in this period.
- The correction of dune sand with the studied additions makes it possible to achieve flexural strengths at 90 days higher than that of the control mortar (MA_0); the 90-days strengths at 25% of CW and 15% of BW exceed that of the control mortar by 19% and 2%, respectively; This reflects the efficiency of CW and BW to improve this characteristic.
- The results of drying shrinkage at an early age show that the incorporation of CW leads to a clear reduction in the drying shrinkage (reduction of 26% for 20% incorporation) in comparison with that the mortar MD_0, The opposite effect was noticed with the incorporation of BW.
- The addition of CW increased the mortar's ability to resist to acid attack; this is not possible in the case of BW except for incorporation rates 10% and 15%. Beyond the incorporation rate of 15%, the CW mortars exhibited higher resistance to sulfuric acid attack than that of mortar based on alluvial sand (control mortar).

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