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Effects of Crushed Waste Aggregate from the Manufacture of Clay Bricks on Rendering Cement Mortar Performance

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***Abstract*—**This paper reports an experimental work that aimed to investigate the effects of clay brick waste, as part of fine aggregate, on rendering mortar performance. The brick, in crushed form, was from a local brick manufacturer that was rejected due to being of-standard. It was used to replace 33.33 %, 50 %, 66.66 % and 100 % by weight of the quarry sand in mortar. Effects of the brick replacement on the mortar key properties intended for wall plastering were investigated; these are workability, compressive strength, flexural strength, linear shrinkage, water absorption by total immersion and by capillary suction. The results showed that as the brick replacement level increased, the mortar workability reduced. The linear shrinkage increases over time and decreases with the introduction of brick waste. The compressive and flexural strengths decrease with the increase of brick waste because of their great water absorption.

***Keywords*—**Clay brick waste, mortar, properties, quarry sand.

I. Introduction

Clay bricks have long been among the most important materials used in construction industry. The use of dried-clay bricks was recorded as far back as 8000 BC, while fired-clay bricks were used as early as 4500 BC [1]. Clay bricks are produced in large quantities throughout the world and the demand for them is expected to continuously rise. In spite of the advanced production technology used nowadays, a significant proportion of bricks are rejected due to being of-standard: these units may be broken, distorted, damaged, underburned or overburned. Denmark's annual clay brick production, for example, was estimated as 0.75 million tons to 0.90 million tons, with 2 % of generated waste production. Poland and Lithuania have produced 5 % of waste for an annual clay brick production of 4 million tons and 0.57 million tons, respectively, while Great Britain's annual production was estimated as 5 million tons to 7 million tons with 3.2 % of rejected production [2]. These waste materials are usually dumped in sites around brick factories and constitute a serious environmental problem, especially in developing countries where the amount of waste production is higher.

Locally, in the region of Guelma (northern Algeria), the annual production of the two main brick factories was estimated in 2009 at about 80,000 tons in the first, Bendjerrah factory, with nearly 10 % of rejected units and about 15 % in the second, Bordj Sabath factory, for a production of 39,100 tons.

Research on crushed clay brick has generally been undertaken on their effects as finely ground materials to replace cement in mortar and concrete due to their pozzolanicity [2]. Levy et al. [3] have studied several mortars with the same idea and concluded that a reduction of 30 % of cement consumption could obtained compared to a traditional mortar with similar mechanical performances. Hadjoudja et al. [4] have conducted a study on clay brick waste as filler into dune sand concrete. They have concluded that mechanical resistances have been enhanced due to the best compactness of the new product material. Other studies on clay brick waste have concerned its effects on the mechanical performance when it is used as coarse aggregate in concrete [5]-[8]. On the other hand, research concerning the properties of mortar prepared with crushed waste from the manufacture of clay bricks as fine aggregate in mortar is limited.

The aim of the study was to evaluate experimentally the effects of these granulated brick waste on the key properties of mortar intended for plastering walls. The mortar aggregate was replaced by crushed brick waste in proportions of 33.33 %, 50 %, 66.67 % and 100 % by weight, and the effects of crushed brick replacement were investigated on compressive strength, flexural strength, linear shrinkage and weight loss, water absorption by total immersion and by capillary.

II. Raw Materials

Brick Waste (BW) for this study was obtained from a brick manufacturing plant located in Bendjerrah municipality (department of Guelma, northern Algeria). These were first crushed and then grounded and screening (a sieve opening of 2 mm) to achieve the same granular class of the quarry sand used to prepare the proposed mortar. The physical characteristics of both BW and QS are reported in Table I, while the chemical composition of BW is presented in Table II. The QS used was a limestone sand of class 0/2 collected from a locally quarry. Its absolute density and porosity are 2.63 and 44.12, respectively. Portland cement CPJ 42.5 compatible with the Algerian standard NA442-2000 was used in this study. Its Blaine fineness is 3702 cm^2/g and its absolute density is 3.1. Tap water with pH ~ 7 was used to mix the several batches prepared for this experimental work.

The water content at the time of laboratory tests was 0.6 % for QS and 3.36 % for BW (three times higher). This

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difference was taken into account in the preparation of the studied mortar.

TABLE I
PHYSICAL CHARACTERISTICS OF BW AND QS USED IN THIS WORK

Characteristics	BW	QS
Granular class	0/2	0/2
Fineness modulus	02.82	02.96
Bulk density	01.25	01.47
Absolute density	02.50	02.63
Porosity (%)	50.00	44.12
Compactness (%)	50.00	55.88
Sand equivalent (%)	98.15	91.56
Water content (%)	03.36	00.60
Water absorption coefficient (%)	16.08	1.20

TABLE II
CHEMICAL COMPOSITION OF THE BW USED IN THIS WORK

Oxyde	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	TiO_2	P_2O_5	Na_2O
%	70.30	23.01	1.10	0.73	2.90	0.33	0.04	1.14

A. Mix Proportions

Preliminary composition of the control mortar (CM) based on the normalized mortar composition with a water to cement ratio of 0.5 was prepared. It has consisted of sand: 1350 g, cement: 450 g and water: 225 g.

This standard composition, with sand replacement by brick waste aggregate, generated mortar samples virtually with a lack of cohesion, as shown in Fig. 1, including samples with high contents of brick waste.

Fig. 1 View of the samples prepared with W/C = 0.5

Table III presents the compressive strengths values obtained with this standard composition at various levels of replacements.

The low compressive strengths obtained are caused by the mixing water shortage, they are not significant. For these reasons, five compositions (M_1 to M_5) were produced having different W/C ratios to achieve a same consistency for all compositions: 11 mm ± 2 mm from the bottom of Vicat apparatus (EN 196-3:2005 standard), i.e. a depth of probe penetration between 27 mm and 31 mm. Mixture proportions are reported in Table IV, as well as the values of the corresponding water to cement ratios and Vicat probe penetration.

It is noteworthy that at equal consistency W/C = 0.60 for the mortar-control (0 % of BW) will correspond to W/C = 0.85 for the mortar with 100 % of BW aggregates.

B. Preparation of Samples and Test Procedures

All the mixtures were prepared in a 5 liter CONTROLAB mixer with variable speeds according to the European norm EN 196-1. The following steps were respected: a) the water was poured into the mixer container, b) the mixture composed of cement, QS and BW aggregates were added, c) the mixer was turned on for 1 minute at low speed and then 2 minutes at high speed, d) the container wall and the mixer beater were cleaned, e) the mixer was restarted for 2 minutes at high speed.

TABLE III
COMPRESSIVE STRENGTH OF MORTARS WITH W/C = 0.5 AT VARIOUS LEVELS OF REPLACEMENT

Replacement rate of QS	Compressive strength (MPa)
0.00	25.21
33.33	12.61
50.00	4.89
66.67	3.22
100.00	1.55

TABLE IV
MORTAR MIXTURES PROPORTIONS FOR PRODUCING 3 SPECIMENS OF 4 MM X 4 MM X 16 MM

Mortar mixtures	M_1	M_2	M_3	M_4	M_5
QS (g)	1321	869	644	425	0.00
BW (g)	0.00	435	644	849	1253
Portland cement (g)	440	435	429	425	418
Mixing water (ml)	264	287	309	327	355
W/C	0.60	0.66	0.72	0.77	0.85
Vicat probe penetration (mm)	31.00	28.00	30.00	27.00	29.00

For this study, some prismatic specimens were prepared, demoulded after 24 hours of casting and then cured in water at ambient temperature of 20 ± 3 ºC until testing.

The flexural strength measured through a three points method and the compressive strength were determined according to the EN196-1 standard.

The water absorption test by immersion was carried out on prismatic specimens of 40 mm x 40 mm x 160 mm in size at 28 days. Saturated specimens were kept in a hot air oven at 105 °C until a constant weight was attained. These are then immersed in water and the weight gain was measured at regular intervals until a constant weight is reached. The gain in weight, expressed as a percentage of the dry weight, was of the water absorption of the specimens. The test was conducted in triplicate and the average reported.

The linear shrinkage was evaluated on 40 mm x 40 mm x 160 mm prismatic specimens according to the French standard NF P15-433. After demoulding at 24 hours, specimens were cured at the ambient conditions of the laboratory and length measures were taken at 1 day, 7 days, 14 days, 21 days and 28 days.

The water absorption test by capillary was carried out on prismatic specimens of 40 mm x 40 mm x 160 mm in size, which have been beforehand even-dried at 105 ºC until constant weight. The sides of the specimens were hermetically sealed with a plastic film in order to achieve unidirectional flow. Test specimens were exposed to water on one face at a depth of about 5 mm. The water level was maintained at a constant height throughout the experiment. At regular intervals, the weight of the specimens was measured using a balance with an accuracy of 0.01 gr. The amount of water has been calculated and normalized by the cross-sectional area of the specimen exposed, i.e 1600 mm^2.

III. Results and Discussion

A. Compressive and Flexural Strengths

In this study, the choice has been made to investigate only the 28 day compressive and flexural strengths, they represent the conventional mechanical characteristics. Fig. 2 shows the compressive and the flexural values of all types of mortar tested. Each data in the histogram represents the average of three values.

At reading of the results, it can be seen that replacement of QS by BW aggregates induces a progressive decrease in the mechanical strengths. The 28 day compressive strength decreases from 29.53 MPa (M_1) to 15.78 MPa (M_5) and the 28 day flexural strength decreases from 6.59 MPa (M_1) to 3.69 MPa (M_5) representing a maximum decrease in ratio of 87 % and 78 % respectively. This can be attributed to the high water absorption capacity of the BW aggregate (16.08 %) as indicated previously in the Table I. This high hygric characteristic is caused by the affinity of BW to water as well as its porosity (50 %), see Table I.

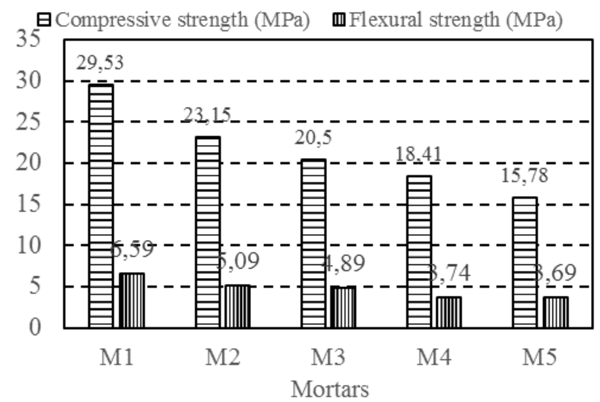

Fig. 2 Compressive and flexural strengths of the elaborated mortars at 28 days

Similar results were obtained by [9] and [10], while contrary [11] has concluded that the replacement of 10 % and 20 %, respectively, of aggregate with brick does not have a negative influence on compressive strengths.

In order to estimate the decrease correlation between the 28 day compressive strength with the W/C ratio, the curve of Fig. 3 was drawn and the polynomial tendency relationship (1) has been found to best describe this correlation.

$$y = 11.669\, x^{-1.748} (R^2 = 0.9849) \quad (1)$$

where, y is the 28 day compressive strength and x is the W/C ratio used.

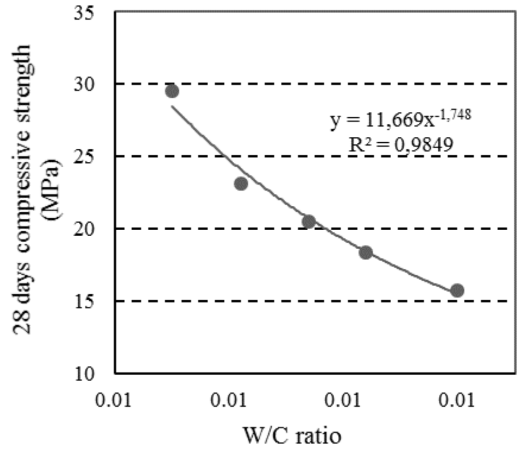

Fig. 3 Effect of W/C ratio on 28 day compressive strengths of the elaborated mortars

The toughness of the five mixtures was examined by the ratio of the 28 day compressive strength to the 28 day flexural strength. Results are presented in the Table V hereafter. It is found that the ratio is less than 5.00 for the totality of the mixtures, it varies between 4.19 (M_5) and 4.92 (M_4). The toughness does not seem to be affected by the BW rate incorporated into the mortar mixtures. There is no obvious tendency; the values vary in a random manner.

TABLE V
Ratio of the 28 Day Compressive Strength to the 28 Day Flexural Strength

Mixtures	f_{c28} (MPa)	f_{f28} (MPa)	f_{c28}/f_{f28} ratio
M_1	29.53	6.59	4.48
M_2	23.15	5.09	4.54
M_3	20.50	4.89	4.19
M_4	18.41	3.74	4.92
M_5	15.78	3.69	4.27

f_{c28}: 28 day compressive strength, f_{f28}: 28 days flexural strength

B. Linear Shrinkage and Weight Loss

The shrinkage and weight loss of the elaborated mortars are among the most important parameters that describe their stability. They were measured continuously on the same specimens for all the mixtures, from 1 day to 28 days. Figs. 4 and five show the linear shrinkage and weight loss respectively of the elaborated mortars.

It can be noted that the linear shrinkage increases over time for all the mixtures and at all ages. There is a similar trend. Otherwise, this shrinkage decreases with the progressive introduction of BW at all ages: shrinkage M_5 < shrinkage M_4 < shrinkage M_3 < shrinkage M_2 < shrinkage M_1 and BW rate into M_5 < BW rate into M_4 < BW rate into M_3 < BW rate into M_2 < BW rate into M_1. Khatib [12] also reported a decrease in the shrinkage as the content of crushed brick increases. Bektas et al. [11] concluded after a similar experimental study that the brick particles may be acting as a self-curing agent: it keeps the initially absorbed mixing water in its pores for longer periods and releases it slowly as it ages. On the other hand, [13] reported that beyond W/C = 0.65, the additional water disappears without causing shrinkage. In this study, apart from the control mortar (M_1), all the mortars (M_2 to M_5) were produced with W/C > 0.65.

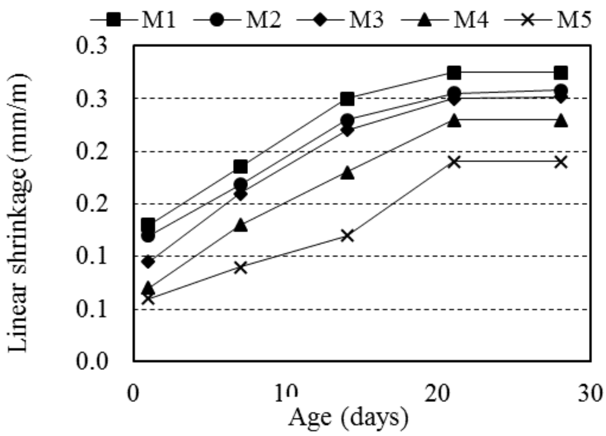

Fig. 4 Linear shrinkage of the elaborated mortars

The evolution of the weight loss, as presented in the Fig. 5, is similar in all mortars, but the greater loss of mass occurs in those with the greatest replacement ratio required for the suitable consistency of the mortars with BW aggregate. The extreme value at 28 days was obtained for the M_5 mortar with 100% of BW replacement. It was 10.30 %.

C. Water Absorption by Total Immersion

Fig. 6 illustrates the water absorption by total immersion of the five mortar mixes elaborated for the present study. As might be expected, water absorption of the BW aggregate mortars was greater than that of the QS aggregate mortar. Minimum water absorption was observed on control mortar (M_1) and maximum one on the 100% BW mortar (M_5). They were 14.05 % and 21.87 % respectively. The remain mixes present a water absorption of 15.91% (M_2), 17.38% (M_3) and 18.10 % (M_4). This evolution may be attributed to the affinity of the clay, to the water absorption of the BW aggregate (16.08%) and to its porosity (50%).

Water absorption and BW aggregate content might be related by the linear equation (2) hereafter:

$$y = 1.783x + 12.113 \quad (R^2 = 0.9379) \tag{2}$$

where, y is the water absorption by total immersion (%) and x is the rate of the BW aggregate content (%) designed by M_1 to M_5 mortar types.

D. Water Absorption by Capillary Suction

The technique used to evaluate the water absorption by capillary suction that will permit to calculate the water sorptivity values adopted by [14] and [15] in their respective mortars and concretes. Fig. 7 shows the kinetics of absorption measured on the five mortars studied.

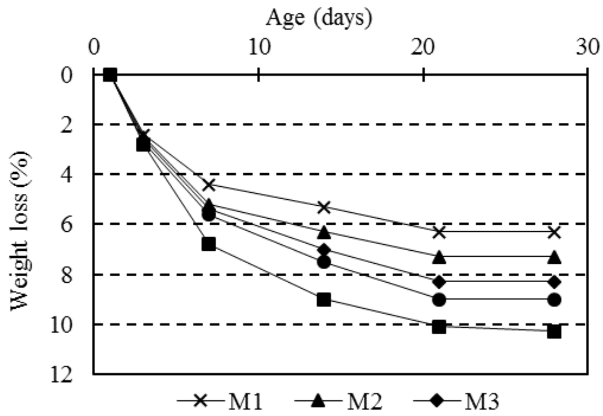

Fig. 5 Weight loss evolution of the elaborated mortars

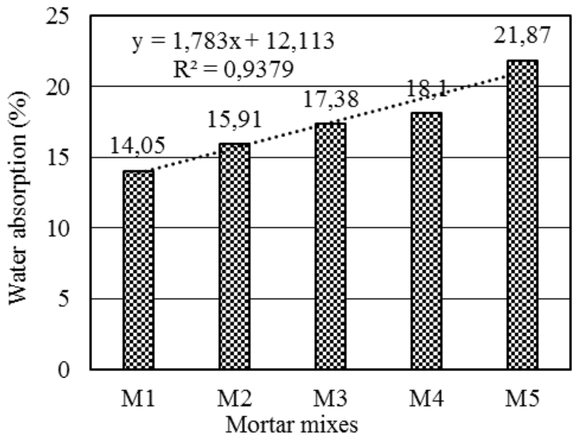

Fig. 6 Water absorption by total immersion of the elaborated mortars

It can be observed that the evolution of mass absorbed water is similar in time for all the mortars studied. The mortars containing less BW aggregate absorb water by capillary more quickly. This may be related to the nature of the fine aggregate (QS and BW aggregates). Pore size may be important in the case of BW mortars. The large pores (macropores) inhibit the rise of capillary water [15], [16].

The mass of absorbed water measured after 90 minutes was not significant, the capillary absorption began to be balanced by the gravity of absorbed water. As a result, they were not reported in the curves of Fig. 7. It is to be noted that more than 50 % of the mass of absorbed water was during the first 10 minutes.

On the subject of the sorptivity coefficient S (mm/s$^{1/2}$) of the designed mixtures, defined as the initial rate of water absorption, it was determined by measuring the absorbed water volume per unit area of contact i (mm^3/mm^2) as a function of the square root of time $\sqrt{t}$ (min$^{1/2}$). S is calculated from the gradient of the initial linear region of the curve described by (3):

$$i = S\sqrt{t} + i_0 \tag{3}$$

i_0 is an empirical coefficient which depends, according to [14], on the contact of the sample's area surface with water. It corresponds to the instantaneous pore filling when in contact with water.

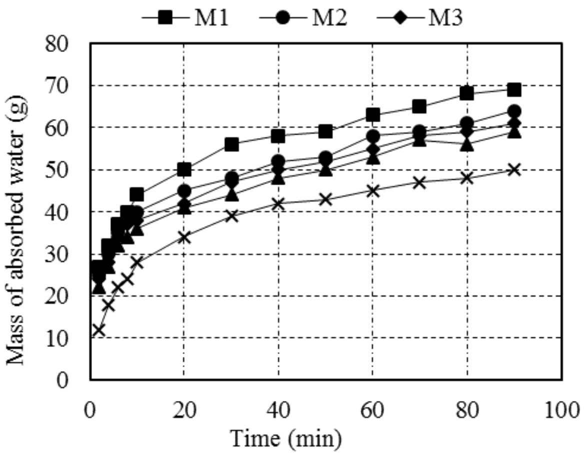

Fig. 7 Kinetics of water absorption of the elaborated mortars

Fig. 8 displays the evolution of water absorption rate during the 10 first minutes as a function of the square root of time of the five mortars studied.

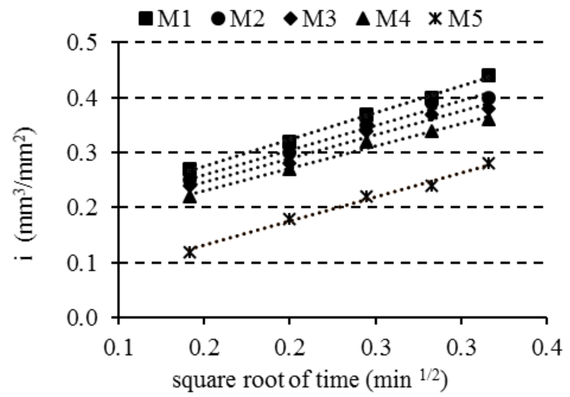

Fig. 8 Water absorption rate as a function of the square root of time of the elaborated mortars

It can be noted that the trend of evolution is similar for all the studied mortars. Experimental data points allowed us to calculate the sorptivity *S* of the tested mortars by (4):

$$S = (i - i_o)\, t^{-1/2} \quad (4)$$

S represents, in practice, the slopes of the linear curves of Fig. 8. The values of sorptivity, as well as BW rate, QS rate and W/C rate are regrouped in Table VI.

The sorptivity of the control mortar M_1 is the greatest comparing to the remain mortars which contains BW aggregate. The BW aggregate rate decreases the sorptivity: $S(M_1) < S(M_2) < S(M_3) < S(M_4) < S(M_5)$. It may be attributed to the nature of the fine aggregates, the BW aggregate may generate large pore size in mortar than the QS aggregate and smaller pore size induces higher sorptivity.

TABLE VI
SORPTIVITY OF THE ELABORATED MORTARS

Mortars	BW (%)	QS (%)	W/C (%)	S (mm/min$^{1/2}$)
M1	0	100	0.60	0.340
M2	33.33	66.67	0.66	0.308
M3	50	50	0.72	0.302
M4	66.67	33.33	0.77	0.285
M5	100	0	0.85	0.275

IV. CONCLUSION

The findings obtained from this experimental study are summarized below:

- BW aggregate rate induces a progressive decrease of the 28 day compressive strength.
- Replacement of QS aggregate by BW aggregate at various rates affects the 28 day flexural strength but toughness does not seem to be affected by the replacement.
- Linear shrinkage increases over time for all the elaborated mortars and at all ages. Otherwise, this shrinkage decreases with the progressive introduction of the BW at all ages.
- BW aggregate increases water absorption by total immersion. A linear tendency relates the two parameters with $R^2 = 0.9379$.
- BW aggregate rate decreases the sorptivity of the mortars because of the large pore generated by their incorporation in the prepared mixtures.

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