sciendo

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2020; 30 (3): 0200-0213
DOI: 10.2478/ceer-2020-0040
Original Research Article

PHYSICAL CHARACTERIZATION AND DURABILITY OF BLENDED CEMENTS BASED ON BRICK POWDER

Ghania NIGRI[1], Yacine CHERAIT[2], Soraya NIGRI[3]
[1,2]Civil Engineering Department, University May 8, 1945, Guelma, Algeria
[1,2]Laboratory of Civil Engineering and hydraulic, University May 8, 1945, Guelma, Algeria
[3]Laboratory of Industrial Analysis and Material Engineering, University May 8, 1945, Guelma, Algeria

Abstract

This research work discusses both the physical and durability characteristics of newly blended cement containing waste crushed brick. This waste is used as a partial substitution for clinker in cement. Thus, blended cements are obtained by grinding and homogenizing clinker, waste brick, and gypsum. Four compositions containing 0%, 10%, 20%, and 30% of waste materials were prepared and submitted to various characterization tests.

The introduction of brick powder improved the physical characteristics, therefore; it improved the mechanical properties and durability performance of the new cement compared to the reference, prepared with 0% addition. More particularly, it resisted sulfuric acid (H_2SO_4) attack after fixation of portlandite by pozzolan.

Keywords: waste brick, blended cement, durability, capillarity, porosity, pozzolanic reaction, X-ray diffraction

1. INTRODUCTION

---

[1] Corresponding author: Civil Engineering Department, University May 8, 1945, Guelma 24000, Algeria, e-mail: ghanianigri@gmail.com

Bricks are one of the oldest building materials. They are generally a ceramic product in which clays, and sometimes other additives, are the raw material. In Algeria, the production of brick exceeded 30 million tons in 2016. The percentage of debris represents some 10% to 15% of the national production [5]. This quantity has either been less recycled or unrecycled until now.

The aim of this research is a physical characterization and durability study of newly blended cements, which are manufactured by replacing an amount of clinker with a finely ground waste brick powder. This new addition (brick powder) is not found in the Algerian standard NA 442. However, its use in the cement industry has several technical, economical, and environmental advantages, namely:

-It improves the mechanical strength, impermeability, and the resistance to both chemical attack [8, 14] and thermal origin cracking.

-As the addition is a by-product, its cost is practically the cost of transportation. Therefore, it reduces the price of cement and concrete.

-It reduces emissions of carbon dioxide (CO_2), positively affecting the amount of greenhouse gas which is generated by clinker manufacture [12] (the production of one ton of Portland cement releases an almost equivalent amount of carbon dioxide into the atmosphere).

Several researchers have studied the effect of adding brick waste on the behaviour of concretes and mortars. This waste is used either in the form of aggregates (sand and gravel) [2], or in the form of powder to replace cement [7, 12] or substitute the clinker in cement [6].

Concrete based on recycled brick aggregate has high absorption when compared to concrete based on natural aggregates [2]. This is mainly due to the greater capillarity of these concretes. The water absorption test clearly illustrates the significant decrease in concrete resistance which is formed with recycled aggregates because of its high porosity and, especially, its wide capillarity.

The sorptivity of mortars which are prepared by substituting cement with crushed brick decreases with the increase of the substitution volume [12]. According to the same authors, this decrease is due to refining of the pore structure of the mixtures containing the brick. This refining is produced by filler and the pozzolanic effect of the brick powder.

The resistance of brick-based mortars to expansion is generally increased, and the loss in strength is reduced, when the replacement level of the cement with ground brick increases by up to 30% when compared to the reference mortar [9].

In order to study the resistance to magnesium sulphate, mortar samples are immersed in water for up to 28 days. Then, they are immersed in a solution of 5% magnesium sulphate ($MgSO_4$) for 100 and 200 days [12]. The results of this research show that the strength loss of mortars which are formulated with 10%

and 20% of the ground brick is almost the same as that of the reference mortar after 100 days immersion in the magnesium sulphate solution. However, after200 days of immersion, the brick mixture presents loss of resistance which is notably lower than that of the reference mortar, for example, the reference sample resistance loss is 12%, whereas, the samples which are formulated with 10% and 20% ground brick have losses of 3% and 5%, respectively. This phenomenon is explained by the reduction of calcium hydroxide $Ca(OH_2)$, the reduction of C_3A due to the substitution of clinker (the C_3A gives the ettringite after hydration), and the formation of the additional hydrates C-S-H, which reduces the permeability and increases the density of the structure (creating difficulties of penetration for aggressive agents) [12].

Our research aims to study the physical properties and durability of newly blended cement, which is obtained by grinding and homogenizing clinker, waste crushed brick, and gypsum. The degree of clinker substitution by the brick powder varies from 0% to 30%. The initial approach physically characterizes the standard mortar test bars which are prepared with the new cements. Based on a detailed experimental protocol, the different durability performances of new binders will be evaluated.

2. EXPERIMENTAL TECHNIQUES

2.1. Cements preparation

The new cement is prepared by separating grinding clinker, waste brick, and gypsum until the fineness is lower than 100 μm. After dosing and homogenization, we developed four blended cement samples by varying the proportion of brick waste from 0% to 30%. The gypsum content was maintained constant, equal to 5% for all the samples.

Table 1. Codes of cement samples and contents of clinker, brick, and gypsum mixture ratios.

Codes of cement	*C0*	*C10*	*C20*	*C30*
Clinker (%)	95	85	75	65
Brick (%)	0	10	20	30
Gypsum (%)	5	5	5	5

2.2. Preparation of standardized mortars

The tests were carried out on standard mortar bars of (40×40×160) mm^3. The tested cement was mixed with standardized sand and water using the following proportions:

450 g ± 2 g of cement, 1350 g ± 5 g of standardized sand, 225 g ± 1 g of water. These quantities corresponded to the preparation of three test bars.

The European Standard EN196-1 describes in detail the procedure for this test.

2.3. Performed Tests

In order to evaluate the pozzolanic activity of the waste brick powder, three methods were used, being the saturated lime test (chemical test), X ray diffraction (physico-chemical test), and the relative resistance test (mechanical test).

The study of brick pozzolanicity, which is determined by the saturated lime test, is a simplified approach to that of cement paste in which the main reaction is the fixation of portlandite originating from the hydration of C_3S by pozzolans, which produces the secondary C-S-H.

The pozzolanic reactivity, which is determined by the saturated lime test, is indicated by the percentage of Ca^{+2} lime ions fixed by the silica and alumina of the used waste brick.

To better characterize the pozzolanic reactivity of brick powder, we used the X-ray diffraction (XRD) method.

Finally, the pozzolanicity of the brick was determined by relative resistance. This method is based on determining the compression strengths of the standardized cement mortars containing 0% to 30% of waste brick after 2, 7, 28, and 90 days of conservation. The relative compression resistance at age (n) is defined as the ratio of the compression resistance of brick-based mortars to the compression resistance of the reference mortar for the same curing age.

In accordance with the European standard EN 12390-7, the mass and volume of the specimens of hardened mortar are determined, and the density is calculated.

The water absorption capillarity test was carried out in accordance with the European standard EN 480-5. Prismatic mortar specimens (4×4 ×16) cm^3 were kept for 28 days in water (two samples per composition), then extracted, dried to a constant mass, and pre-sealed with resin on the four lateral faces. Then, the first 5 millimetres of the specimen surface were immersed in the water to determine the water absorption coefficient due to capillary action.

The water absorption by total immersion test is determined according to the prescription of standard NBN B15-215: 1989 norm., and is expressed as a percentage (%) of the dry mass.

The accessible porosity to water was measured by hydrostatic weighing according to standard EN18-459. This method is certainly the simplest among the available methods that allow access to the different sustainability indicators.

The durability of elaborated cement mortars is evaluated by measuring the mass of the specimens which are prepared with normal mortar. After 28 days in water, the test bars were weighed to determine the initial mass M_0. Then, three test bars of each sample were immersed in an acidic solution containing 5% of sulfuric acid (H_2SO_4). The acidic solution was renewed every 15 days. At each determined period, the test bars were extracted from the solution and weighed.

3. PROPORTIONS, TEST RESULTS, AND DISCUSSION

The different obtained results and the interpretations of the physical and mechanical phenomenon and durability are presented below.

The pozzolanic reactivity, which is determined by the saturated lime test, is indicated by the percentage of Ca^{2+} lime ions fixed by the silica and alumina of the waste brick powder.

The EDTA volumes of non-fixed calcium ions on brick powder at the 7th, 14th, 21st, and 28th days are given in Table 2.

Table 2. EDTA Volume of calcium ion assay in solutions.

	EDTA volume (ml) at 7 days	*EDTA volume (ml) at 14 days*	*EDTA volume (ml) at 21 days*	*EDTA volume (ml) at 28 days*
Brick	3.5	2.9	2.1	1.9

According to the obtained results, the average EDTA volume of non-fixed calcium ions on the brick powder is low and decreases further with time (Table 2). This shows that the c Ca^{2+} consumption of portlandite by the brick powder is significant and testifies to the prolonged pozzolanicity of the brick powder.

Figure 1 represents the X-ray diffraction patterns of the used brick powder. This diffractogram shows the majority phases; silica (SiO_2) whose peaks are situated at 2.θ = 20.81°, 26.60°, 33.55°,36.50°, 39.44°, 42.43°, 67.76°, 68.16°, and at 2.θ = 69.26°; alumina (Al_2O_3) whose peaks are situated at 2.θ = 14.17°, 59.67°, and 68.26°; ferrite oxide (Fe_2O_3) whose peaks are situated at 2.θ = 6.30° and 49.96°, and orthoclase ($KAlSi_3O_8$) which is detected at 2.θ = 23.53°. Between 2.θ =17° and 40°, we observed the presence of a dome indicating the formation of an X-ray amorphous phase (Figure 1).

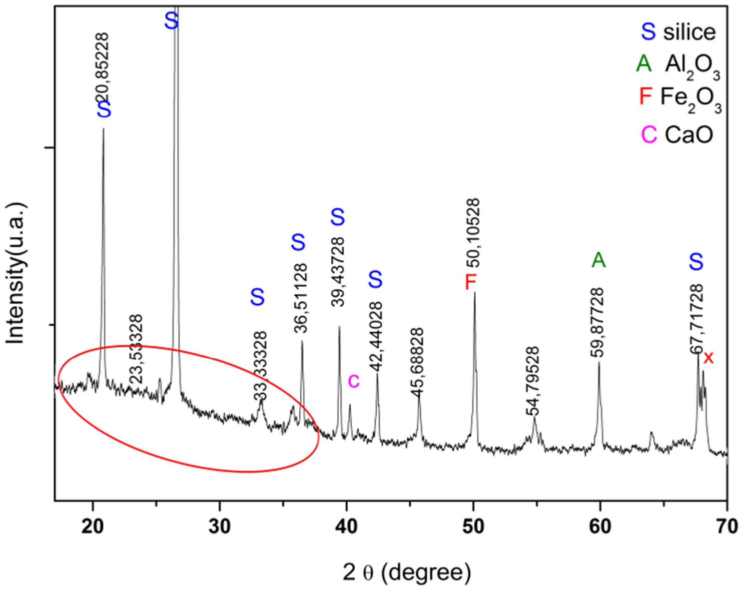

Fig.1. XRD patterns of brick powder

The pozzolanic reactivity, which is determined by the mechanical test, consists of studying the relative compressive strengths of normal mortar specimens. In such a mortar, the only variable is the nature of the hydraulic binder, therefore, the strength of the mortar signifies the strength of the used binder. The results of this test are illustrated in Figure 2.

Figure 2 shows the change in relative compression strength over time and in accordance with brick content. The compression strengths of the reference cement mortar (C0) at the 2nd, 7th, 28th, and 90th days are 18.3 MPa, 38.5 MPa, 50.9 MPa, and 53.9 MPa, respectively. The gain in compression strength of the reference cement depends mainly on the degree of hydration. However, for cements based on waste brick, the compression strength gain not only depends on the degree of hydration but also on the pozzolanic reaction [11, 13] (the substitution of cement with brick powder accelerates the process of strength gain at a later age due to the reduction of loss on ignition and the increased alkali in the brick [3, 4]).

For 10% substitution, there is a near constant variation between the 2nd and 7th day. However, up to 90 days, a linear increase is observed. From 20% substitution, the increase of the relative compression resistance becomes very clear between 7 and 28 days. This increase becomes more and more important with the increase of the substitution rate. Thus, these results confirm the results obtained by other authors [6, 8].

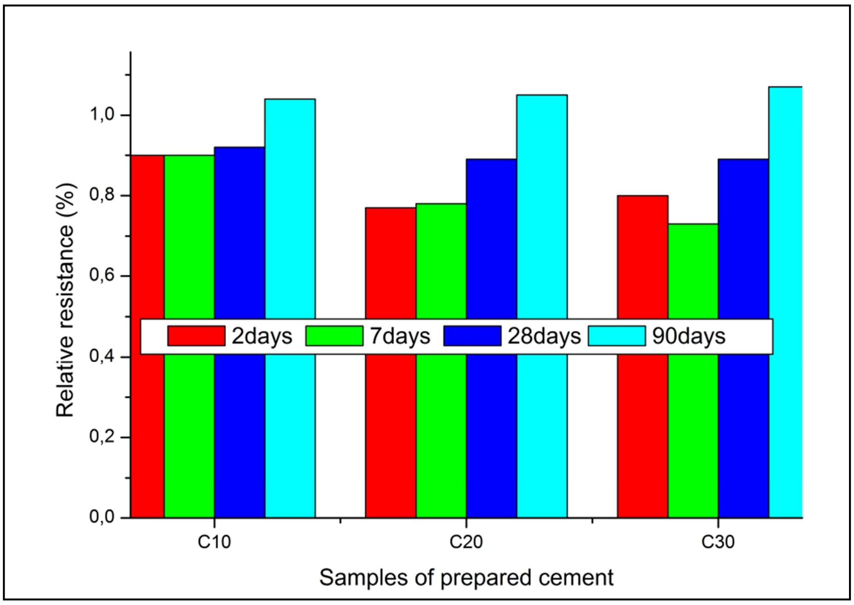

Fig. 2. Relative compression strength of the prepared mortar over time

The influence of the brick on the relative compression resistances at the 2nd, 7th, 28th, and 90th day is illustrated in Figure 3. After 2 days of hydration, it is noted that the relative compression resistance decreases linearly with the increase in the addition rate (accelerated hydration of the C0 sample). At 90 days, an increase in relative compression resistance is observed. This increase is explained by the pozzolanic effect of the brick (the pozzolanic reaction is prolonged over time, whereas; the reaction of the C0 sample is almost complete).

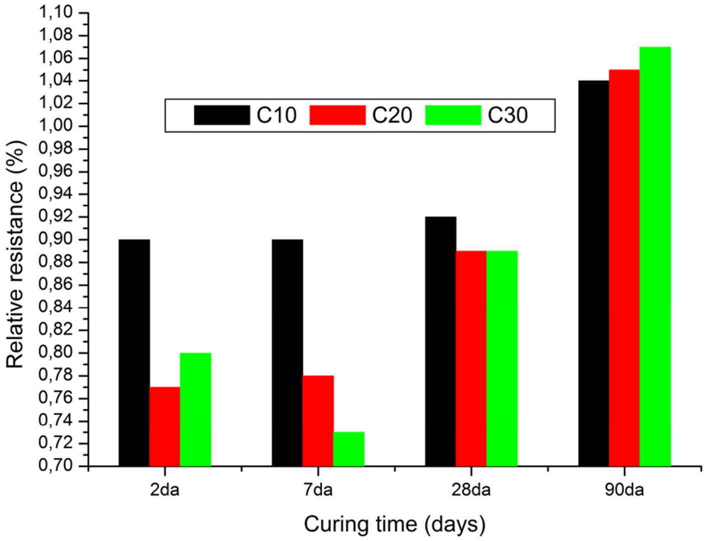

Fig. 3. Relative compression strength of prepared mortars in accordance with brick rate

The obtained results for the density measurement test at hardened and fresh states are summarized in Table 3.

Table 3. Density of elaborated cement mortars

Percentage of brick (%)	*C0*	*C10*	*C20*	*C30*
Specific gravity at hardened state (Kg/m^3)	2.152	2.070	2.012	2.063
Specific gravity at fresh state (kg/m^3)	2.337	2.272	2.278	2.298

From this table, we can see that the cement densities decrease in accordance with the increase in brick content. The observed decreases vary between 2.14% and 6.5% compared to the control mortar. This can easily be explained by the fact that the density of the waste brick (710.00 g/dm^3, 2.65 g/cm^3) is significantly lower than that of the clinker (993.60 g/dm^3, 3.38 g/cm^3) [6].

The results of the water absorption by capillarity test are represented in Figure 4, according to which, it can be seen that:

- The mortars' water absorption capillarity increases in accordance with the substitution rate and over time.
- From the beginning of the experiment, the kinetics of capillary absorption of all the prepared mortars increases rapidly, following the typical theoretical behavioural rule of capillary absorption.

- The increase of water absorption by capillarity of mortars based on brick powder is similar and remains more significant than that of the reference mortar. This behaviour can be explained according to [9] by the fact that the capillary pores are not yet filled at these curing times (28 days of hydration) by the hydration products, which subsequently fill the capillary pores as well as increasing the resistance and impermeability of mortars and concrete by the refining of these capillary pores, and by transforming the large CH crystals into a weakly-crystallized hydration product (refining of the grains).

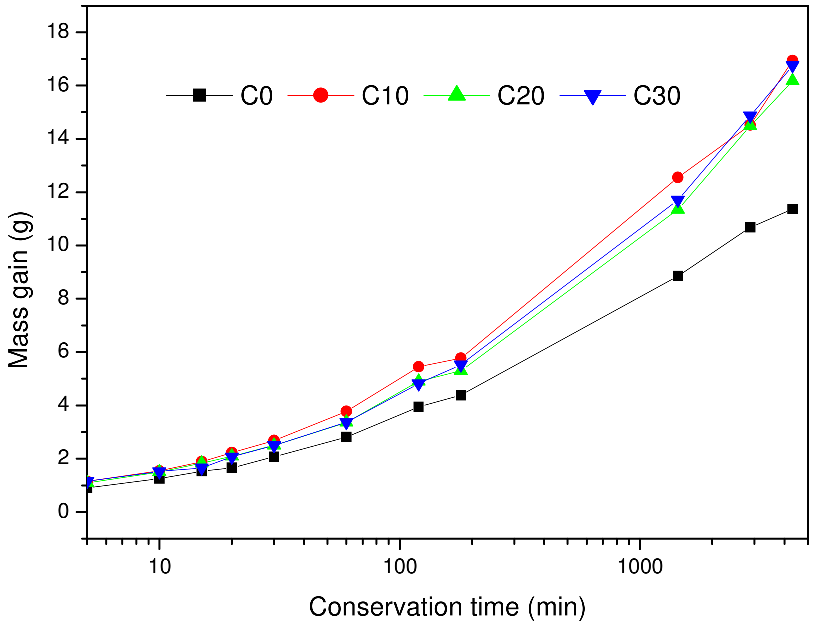

Fig. 4. Results of water absorption by capillarity

The results of the total immersion water absorption test and the water-accessible porosity test performed on cement-based standardized mortar specimens containing 0%, 10%, 20%, and 30% brick waste are shown in Figure 5. It can be seen from Figure 5 that:

The water absorption by total immersion increases with increasing clinker substitution by crushed waste brick. This increase represents 8.7%, 12.76%, and 11.7% for samples (C10), (C20), and (C30), respectively relative to the water absorption of the reference mortar containing 0% addition. This growth is due to the strong water absorption capacity of the brick (16.1%) [5]. Similar results have been found in the literature [10].

The water-accessible porosity which is obtained by hydrostatic weighing of specimens made with cements containing 0%, 10%, 20%, and 30% of brick powder increases slightly between 5.5% and 11.1% in comparison to the porosity of the reference mortar (C0). However, this may seem contradictory due to the positive effect the brick powder has on the densification of mortars and concretes (filler and pozzolanic effect of the brick powder [6].

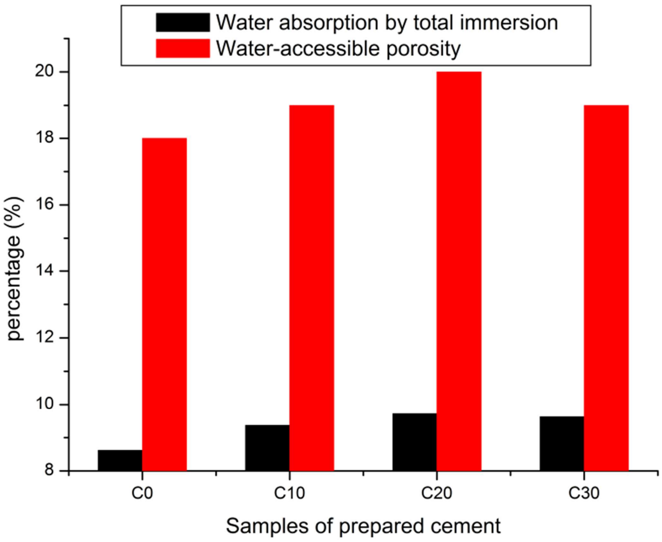

Fig. 5. Results of water absorption by total immersion and water-accessible porosity tests

The last results which correspond to the durability study of the standard mortar are presented in Figure 7. The purpose of this part is to determine the durability of the new cements developed under the effect of an acidic environment. The measurements of mass variation are illustrated in Figure 6:

From Figures 6 and 7, it can be seen that for the specimens which are conserved in sulfuric acid, namely (C0), (C10), and (C20), loss of mass started from the 2nd day. However, for sample (C30), loss of mass is observed from the 7th day of the conservation.

Fig. 6. Test bars kept in sulfuric acid

In general, specimens prepared with mortars containing the brick powder showed lower mass losses than those of the (C0) sample. The losses measured after 60 days of storage in sulfuric acid were 74.57%, 75.13%, 69.78%, and 54.28% in samples (C0), (C10), (C20), and (C30), respectively. This behaviour is explained by the pozzolanic effect of the brick powder (fixation of the portlandite Ca $(OH)_2$ by the active silica and alumina of the brick).

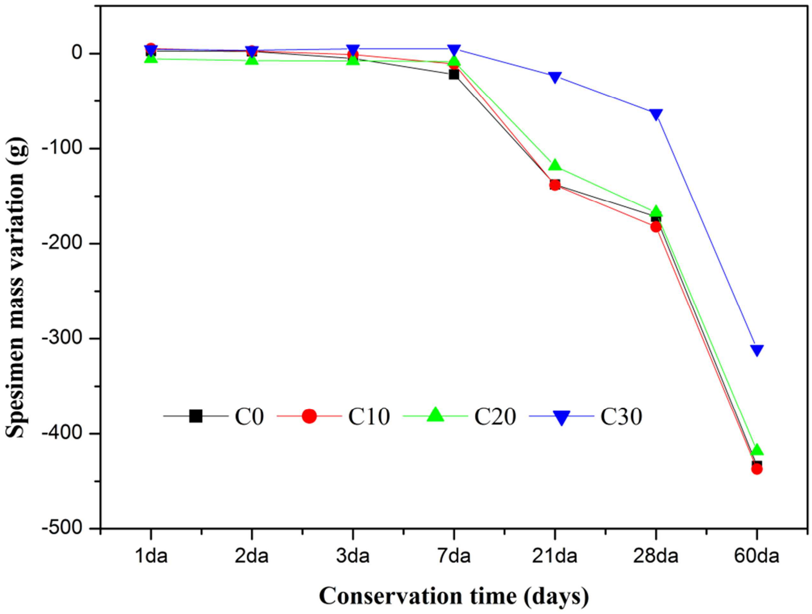

Fig. 7. Mass variations of specimens stored in sulfuric acid

4. CONCLUSIONS

The objective of this study was to develop a by-product of the red products industry as part of the valorisation and recycling of local materials. This consists of substituting the clinker which is manufactured at the Hadjar Soud plant (East of Algeria) with finely ground waste brick collected from the region of Guelma for the manufacture of a new blended cement. The chosen substitution rate varies from 10% to 30%. For comparison, a reference sample that contains 0% addition was also prepared. After undergoing chemical, physical, mechanical, and durability tests which are referenced according to Algerian and European norms for hydraulic binders; we were able to draw the following conclusions:

1. A gain in compressive strength is observed at the age of 90 days for cement-binders based on waste brick. This gain is due to the prolonged formation of the secondary C-S-H gel, which is formed by the reaction of the amorphous silica contained in the brick with the portlandite $Ca(OH)_2$ resulting from the clinker's hydration.
2. The densities of the mortars made with the new composite cements are lower than those of the reference sample. This may be an advantage for heavier structures.

3. An increase in the water-accessible porosity and the capillary water absorption was measured at 28 days for the specimens prepared with brick addition, compared to the reference sample. This increase is explained by a total porosity growth because the pozzolanic reaction is not yet predominant (prolonged effect of pozzolan).
4. Incorporating finely ground brick into cement to slightly improve durability performance, and lengthening curing time, are both needed to better understand the effect of brick on mortar durability.

On reflection, we will conduct further testing to prolong the curing time of the specimens up to a year or more. In addition, we will conduct a microstructure study to better understand the pozzolanic reaction of the brick powder and its influence on the durability performance of cements, mortars, and concretes.

REFERENCES

1. Barger, GS, Hansen, ER, Wood, MR, Neary, T, Beech, DJ and Jaquier, D 2001. Production and use of calcined natural pozzolans in concrete. *Cement and Concrete Aggregate* **23** (**2**), 73-80.
2. Debieb, F and Kenai, S 2008. The use of coarse and fine crushed bricks as aggregate in concrete. *Construction and Building Materials* **22**, 886–893.
3. Kırgız, MS 2016. Strength Gain Mechanism for Green Mortar Substituted Marble Powder and Brick Powder for Portland Cement. European Journal of Environmental and Civil Engineering, Issue sup1: Supplement: Green Binder Materials for Civil Engineering and Architecture Applications **20**, 38-63.
4. Kırgız, MS 2015. Strength Gain Mechanisms of Blended-Cements Containing Marble Powder and Brick Powder. *KSCE Journal of Civil Engineering* **19** (**1**), 165–172.
5. Nigri, G 2018. Nouvelle élaboration d'un liant hydraulique. Thèse de doctorat. Université 8 Mai 1945. Guelma. Algérie.
6. Nigri, G, Cherait, Y and Nigri, S 2017. Characterization of eco- substituted cement containing waste ground calcined clay brick. *Canadian Journal of Civil Engineering* **44(11)**, 956-961.
7. O'Farrell, M, Wild, S and Sabir, B 2000. Resistance to chemical attack of ground brick. PC mortar Part II. Synthetic seawater. *Cement and Concrete Research* **30**, 757-765.
8. O'Farrell, M, Sabir, BB and Wild, S 2006. Strength and chemical resistance of mortars containing brick manufacturing clays subjected to different treatments. *Cement and Concrete Composite* **28**, 790-799.

9. O'Farrell, M, Wild, S and Sabir, BB 2001. Pore size distribution and compressive strength of waste brick mortar. *Cement and Concrete Composite* **23**, 81-89.
10. Poon, CS and Chan, D 2006. Paving blocks made with recycled concrete aggregate and crushed clay brick. *Construction and building materials* **20(08)**, 569-577.
11. Sabir, BB, Wild, S and Bai, J 2001. Metakaolin and calcined clays as pozzolanic for concrete. *Cement and Concrete Composite* **23**, 441- 454.
12. Tolido Filho, RD, Gonçalves, JP, Americano, BB and Fairbairn, EMR 2007. Potential for use of crushed waste calcined-clay brick as a supplementary cementitious material in Brazil. *Cement and Concrete Research* **37**, 1357-1365.
13. Wild, S, Gailuis, A, Szwabowski, J and Hansen, H 1999. Waste clay brick – A European of its effectiveness as a cement replacement material. Exploiting wastes in concrete. Proceedings of the international seminar held in Dundee. Ed Ravinda K. Dhir, ISBN 0727728334.
14. Wild, S, Khatib, JM and O'Farrell, M 1998. Sulphate resistance of mortar containing ground clay brick calcined at different temperatures. *Cement and Concrete Research* **28 (1)**, 83-92.

LIST OF USED STANDARDS

NA 442. 2000. Norme Algérienne. Liants hydraulique, ciments courants: composition spécification et critères de conformité 2eme édition. IANOR. Algérie.

EN196-1. 2016: European norm: Méthodes d'essais des ciments - Partie 1 : détermination des résistances mécaniques

EN 12390-7. 2012. European norm: Essai pour béton durci-7: masse volumique du béton.

EN 18-459. 2010. European norm: Béton- Essai pour béton durci: essai de porosité et de masse volumique.

EN 480-5. 2006. European norm: Adjuvants pour béton, Mortier et coulis- Méthodes d'essai partie 5. Détermination de l'absorption capillaire.

NBN B15215.1989. Concrete testing - Absorption of water by immersion.

Editor received the manuscript: 03.06.2020