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EFFECT OF USING GREEN BUILDING MASONRY MORTAR ON THE BEHAVIOR OF MASONRY WALLS

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ملخص عربي

يهدف هذا البحث إلى دراسة خصائص خلطات مختلفة من المونة باستخدام انواع مختلفة من الأسمنت CEM II A- S 42.5N و CEM II B-L 32.5N بدلا من الأسمنت التقليدي

CEMI 42.5N بالإضافة إلي خلطات بها نسب احلال مختلفة تصل الي 25 %من الأسمنت التقليدي بتراب المسارات الجانبية للأسمنت (تراب الأسمنت) وكذلك بالجير. تم أيضا بناء عدد ست حوائط و 18 منشور مكون من 5 طوبات واختبارهم تحت تأثير الأحمال الرأسية لدراسة تاثير استخدام انواع مختلفة من الأسمنت وكذلك الأحلال بالمواد سالفة الذكر علي سلوك الحوائط المختبرة وتبين من النتائج بعض االأستنتاجات والتوصيات التى تتلخص في وجود جدوي اقتصادية وبيئية من استخدام انواع اسمنت تحتوي علي نسب اقل من الكلنكر وكذلك احلال جزء من الأسمنت المستخدم بتراب االسمنت او بالجير.

ABSTRACT

Buildings mortar is considered an important element in the majority of masonry work as it has a direct effect on the masonry structures′ behavior and cost. This research studies the possibilities of using different types of cement and replacing part of the used cement with lime powder and CKD (Cement Kiln Dust). The experimental program was divided into two phases; phase one includes different types of cement (CEMI 42.5N, CEM II B-L 32.5N and CEM II A-S 42.5N) with different replacement ratios namely (0, 10, 15, 25%) of each cement type by lime and CKD, For each mortar mix compressive strength at 2&28 days were demonstrated and the flowability was kept constant. Phase two includes testing of 18 clay brick prisms and 6 masonry walls with replacement percentage of 25% of the cement content in compression. The experimental results of phase one proved the availability of using CEMII A-S 42.5N or CEMII B-L 32.5N instead of CEMI42.5N in masonry mortar mixes and also it can be demonstrated that use of lime and CKD as cement replacement of masonry mortar achieved good cracking behavior and mode of failure with respect to reduction of 25% of cement of control specimen cement content. Also, the compressive strength, initial stiffness and toughness of the wall were relatively accepted if compared with the control walls (100% CEMI42.5N). It was found that the use of CEMII B-L 32.5N instead of CEMI42.5N reduced only 4% of the compressive strength of the tested wall compared to that of 100% CEMI42.5N.

KEYWORDS

Mortar, CKD, Pollution and Masonry walls.

INTRODUCTION

Masonry is one of the oldest forms of construction known to humanity. The term masonry generally refers to brick, stone, concrete-block, etc., or combination therefore, bonded with mortar. Masonry can be defined as “construction usually in mortar, of natural building stone or manufactured units such as brick, concrete block, adobe, glass, block tile, manufacture stone, or gypsum block".

Concrete is counted as one of the mostly consumed construction materials where it was estimated by 31 Gt/year in 2006 according to European concrete platform [1], and cement consumption was estimated by 4 Gt/year [2, 3]. This figure is constantly increasing due to the increase in world population and to the continuous development in the infrastructures. Cement production negatively affects the environment not only by consuming the virgin materials but also by releasing CO_2. It is argued that in order to produce 1 ton of cement, 1.8 tons of raw materials are needed and around 0.8 ton of CO_2 is released, which is understandable if the reaction that shown in Eq. 1 is considered. Surprisingly, cement industry is arguably regarded as the second largest producer of the greenhouse gases that cause global warming phenomenon, which contributes by 5–8% of the worldwide CO_2 emissions referring to Scrivener K and Kirkpatrick R (2005); Malhotra V and Mehta P (2005). Cement production results in massive quantities of solid waste material called Cement Kiln Dust (CKD), where the quantity of CKD is estimated by 3–4% of the total produced cement. This material has not been widely utilized in a beneficial manner as indicated in Eq. (1).

$$CaCO3+\Delta\rightarrow CaO+CO2 \qquad (1)$$

Several researchers [4-6] have used supplementary cementitious materials (SCMs) in the past to evaluate the effect of pozzolanic materials on the properties of fresh and hardened cement mortars. The natural pozzolana has been widely used as a substituent of the Portland cement in the concretes in addition to its environmental and economic benefits; this also includes the decrease of permeability [7-9]. that the binary and ternary blends of SCMs have shown improvements in economy, early and later strength, durability and decrease in the heat of hydration as compared to unary and binary concrete blends [10]. Several studies have reported utilization of Fly Ash (FA), Ground Granulated-Blast Furnace Slag (GGBFS) and Silica Fume (SF) as supplementary cementitious materials in binary, ternary and quaternary binder blends.

Solid waste management is one of the major environmental concerns around the world. Cement kiln dust (CKD), also known as by-pass dust, is a by-product of cement manufacturing. The environmental concerns related to Portland cement production, emission and disposal of CKD is becoming progressively significant. CKD is fine-grained, particulate material chiefly composed of oxidized, anhydrous, micron-sized particles collected from electrostatic precipitators during the high temperature production of clinker. Cement kiln dust so generated is partly reused in cement plant and landfill. Rafat Siddique (2006) concluded that the beneficial uses of CKD are in highway uses, soil stabilization, use in cement mortar/concrete, controlled low strength material CLSM, etc.

Cement mortar occupies around 50% of the concrete volume, and it is highly responsible for the physico-mechanical properties of the concrete beside the coarse aggregate and the bonding between mortar and aggregate [11]. Therefore, by considering the massive consumed concrete, mortar is of importance to be focused on.

To achieve the aim of the current study, an experimental program consisting of two phases including testing different mortar mixes and testing six wall panels 1000 by 1000 mm using selected mortar mixes from phase one under uniform vertical load was conducted.

RESEARCH PROGRAM

The experimental test program was designed to achieve the research objectives of the study. Two phases were carried out; the first include casting and testing 21 mortar mixes, each mix was tested at 2&28 days in accordance with ESS 2421/2005 (Fig.1), using three types of cement namely (CEMI 42.5N, CEM II B-L 32.5N and CEM II A-S 42.5N) with different replacement ratios namely (0, 10, 15, 25%) of each cement type by lime and CKD separately. while phase two included 18 prisms (Fig. 2 and Table 4) and 6 walls (Fig. 3 and Table 5) with 25% replacement that selected from mixtures of phase 1. Wall panels 1000 by 1000 mm were manufactured for this experimental program using clay bricks. All wall panels were constructed using the same mason to maintain the same level of workmanship.

The mortar joint thickness was kept 10mm throughout all panels. The joint thickness was controlled by wooden bar 10mm square section. Water curing process was applied for about 7 days using sprinkler to wet the wall panels by fresh water once a day.

MATERIALS PROPERTIES

The structural behavior of masonry walls depends on the properties of the materials which are used in construction of the walls such as (brick, mortar, cement …etc.). So, several tests were carried out on these materials during the phases of the construction of the walls in order to control the quality of walls constructions to minimize the variations in different properties that may appear in the construction and testing processes.

Clay bricks with dimensions (200 x 100 x 60) mm were used; quality control tests were carried on a three specimens according to the Egyptian standard specifications ESS No. 619, 48-2003 [12]. The average compressive strength of the clay brick was 5.465 MPa. Average unit weight of clay bricks was 1.22 t/m^3.

Local sand from natural sources complying with Egyptian standard specification ESS No. 1109- 2001 [13], was used for masonry mortar, lime and CKD (by-product of cement industry). The sand used was free from any impurities and the maximum permissible weight percent of deleterious substances did not exceed 1%. Sieve analysis was carried out on the sand; and the sand grading was found to be within the limits of Egyptian standard specification.

CEM I 42.5 N and CEM II B-L 32.5N produced by Helwan Cement Company, Egypt was used in this research work. The physical and mechanical tests were carried out as according to ESS No. 2421-2005 [14]. The physical and mechanical properties are complying with ESS. No 4756 -2013 [15].

CKD was brought from Suez Cement Company, Egypt. Percentage retained on sieve No.170 was less than 9%. Tables 1 and 2 indicated the physical properties and chemical composition of used CKD.

Table. 1: Physical properties of CKD

Property	Test results
Plain specific surface area (cm^2/gm)	2975
Bulk density (kg/m^3)	1145
Specific gravity	2.80
Color	Gray
Physical Form	Fine powder

Table. 2: Chemical composition of CKD

Oxide	Content %
SiO2	17.11
Al2O3	4.58
Fe2O3	2.13
CaO	40.95
MgO	2.51
K2O	5.18
SO3	2.27
Na2O	4.19
Cl	3.37
LOI	11.25

MORTAR MIXES

Mortar mix (cement: sand = 1:3), fulfilling the Egyptian Code of Masonry ECP 204- 2005 [16], was tested using different types of cement and it was also used in the construction of the prisms and wall panels. This type has been widely used in Egypt by most masons.

These proportions have a minimum compressive strength value exceed 42.5MPa at 28 days except CEMII B-L 32.5N. The water was established by the mason's requirements for suitable workability. The mortar used in prisms and wall panels was mixed automatically in cement mixer compatible with EN 196/2005. In order to maintain constant flowability which considered an important property of the plastic mortar, measures of workability in the laboratory were made on mortar mixes by the flow test according to ASTM C 230, using standard flow table, to control the mason's requirements. In this test, the flow of mortar is measured by the increase in diameter of a cone of mortar after 25 drops on the standard flow table. The suitable flow was depending on the day temperature, relative humidity, and materials conditions. Furthermore, compressive strength of masonry mortar after 28 days was kept between (29.4 MPa and 43.8 MPa). 6 prisms (40 x 40 x 160 mm) for each mortar mix were cast. These prisms were tested in axial compression at 2, 28 days respectively. The average compressive strengths for the different mortar mixes at the age of 2&28 days were shown in figures 1a,1b and1c. These values exceeded the guide value required by (ECP 204-2005), which equals 15.0 MPa for mortar type No.1 (in which the ratio between cement to sand is 1:3).

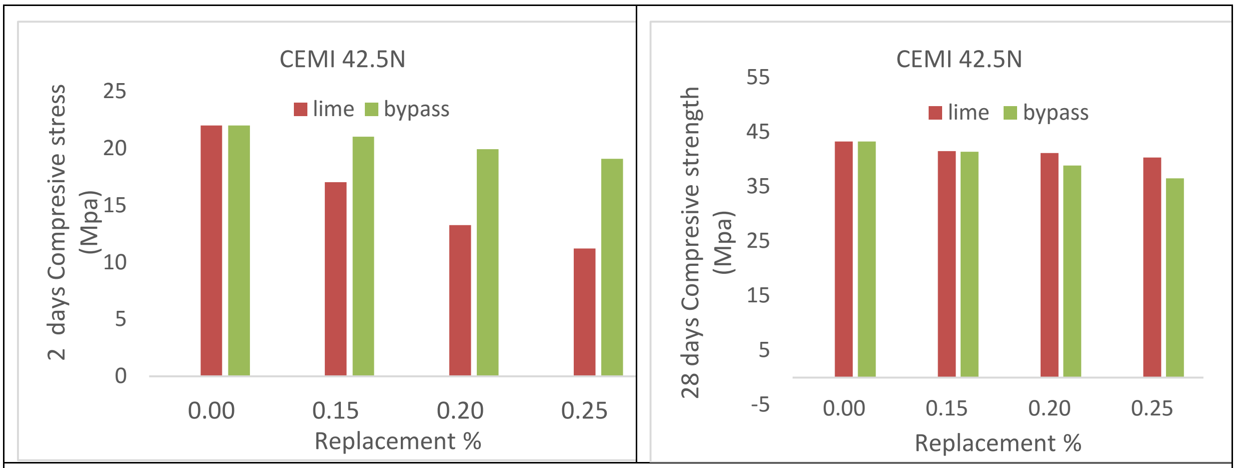

Fig. 1 (a). 2& 28 days compressive strength of CEMI 42.5N Mortar

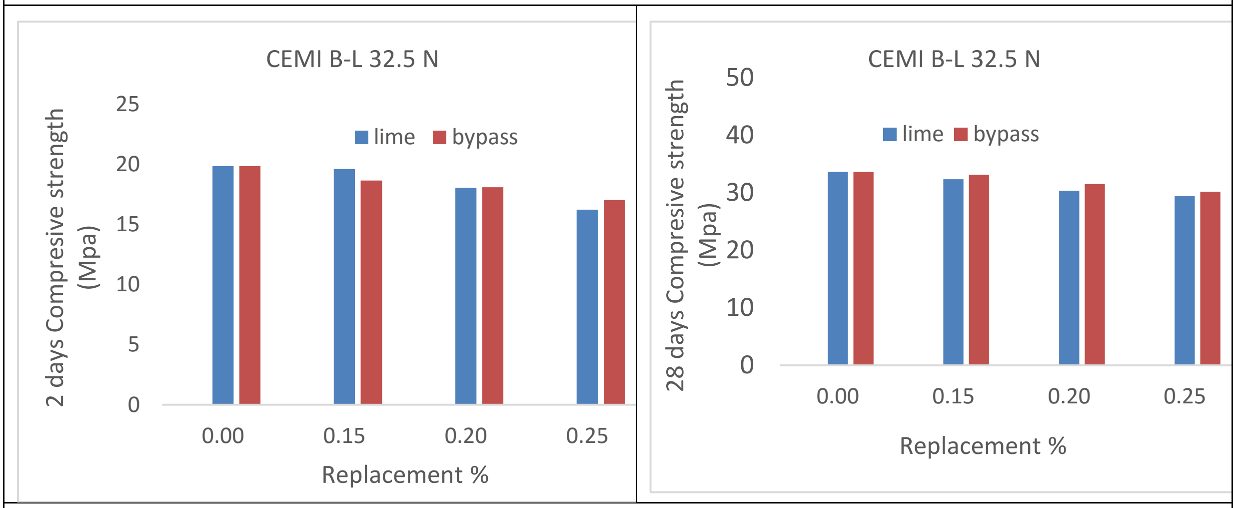

Fig. 1 (b). 2& 28 days compressive strength of CEMII B-L 32.5N Mortar

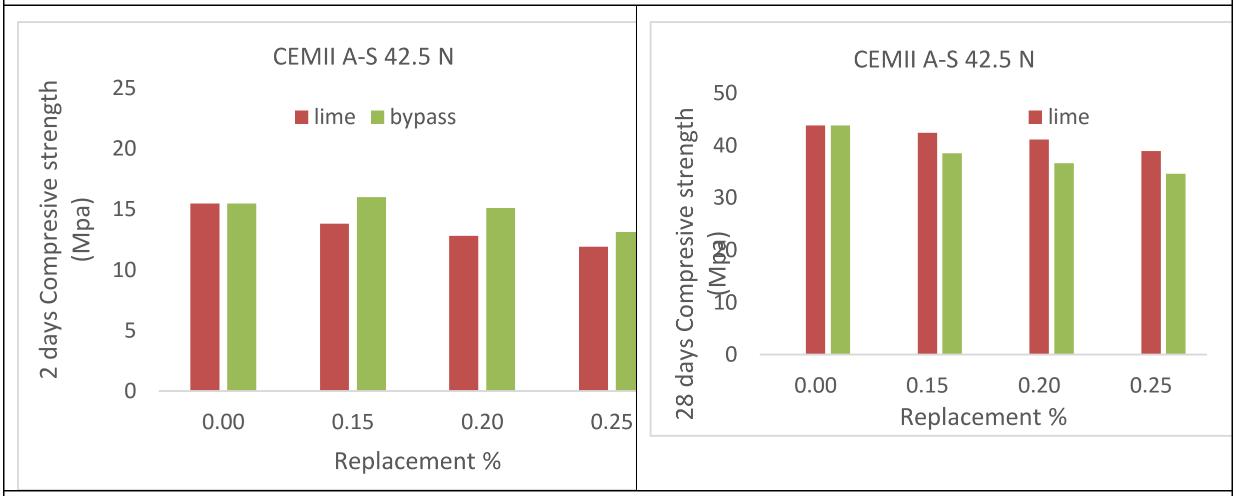

Figure 1 (c). 2& 28 days compressive strength of CEMII A-S 42.5N Mortar

From the previous results, it can be observed that the replacement of cement by CKD up to 25% gave a nearly similar behviour in compressive strength as that when using 100% cement, which is considered an economical and environmental gain as it saved 25% of cement by using a by-product (CKD), Also, it can be noted that replacement of cement by lime gave the same behaviour thats why a replacement percentage of 25% was chosen in prisms and walls investigations.

MASONRY PRISMS TESTS AND RESULTS

Three clay brick prisms, one for each mortar mix during wall construction were built using the same mortar mix for the walls. The height to thickness ratio for all prisms was about three, which fulfill the (ASTM C1314-2003 [17]. Prisms were built consisting of a single-Wythe specimen laid in stack bond of five clay bricks. The mortar used in in prisms and wall panels was mixed by hand on a steel plate and then used directly after mixing. The brick prisms were cured in the same conditions of the corresponding walls. Gypsum-capping layers were applied on the top and bottom of the prisms in order to achieve good levelling under loading and avoid local stresses. To test the prism, it is placed in the compression machine (50 tons) using displacement control system of 2 mm/ min. The both centroidal axes of the specimen aligned with the machine's center. The load increased gradually with constant rate up to failure. The maximum load and type of fracture is recorded. Prism strength is calculated from the maximum load divided by the prism net area. This prism strength is then corrected as described below.

The masonry compressive strength (fm') was calculated according to ACI530-(MSJC) [18]. Correction factor was taken according to the height to thickness ratio as shown in Eq. (2) [19].

$$fm' = [P_{max} / (l * t_{min})]*C.F \qquad (2)$$

Where:

fm' : masonry prism compressive strength

Pmax: Max. Crushing load of prism

l: prism cross section min. length (200 mm)

tmin: prism cross section min. width(100 mm)

C.F: Correction factor was shown in Table 3 where Slenderness is calculated by divided the brick prism's height by its thickness.

Table. 3: Slenderness correction factors for f'm, ASTM 1314-99 [17]

ASTM slenderness	1.3	1.5	2.0	2.5	3.0	4.0	5.0
Correction Factor	0.75	0.86	1.00	1.04	1.07	1.15	1.22

The masonry compressive strength was illustrated in Fig. 4 for the tested prisms. Results of compressive strengths were corrected according to prism aspect ratio correction factors in ASTM C 1314 [17] and shown in Table 4

Table. 4: Ultimate load and corrected masonry compressive strength of tested prisms

Prism No	Mortar proportions	Ultimate Load (KN)	Corrected Load according to aspect ratio (kN)	Masonry Compressive Strength after correction (MPa)
1	Control CEM I 42.5N	105.82	113.23	5.7
2	Control CEM II B-L 32.5N	102.17	109.32	5.5
3	75%CEM I + 25% lime	95.03	101.68	5.1
4	75%CEM II + 25% lime	94.84	101.48	5.1
5	75%CEM I + 25% CKD	97.2	104.00	5.2
6	75%CEM II + 25% CKD	94.2	100.79	5.0

Fig. 2: Prisms during testing

Prisms and Walls before testing

Testing of W1

Testing of W2

Testing of W3

Testing of W4

Testing of W5

Testing of W6

Fig. 3: Walls during testing

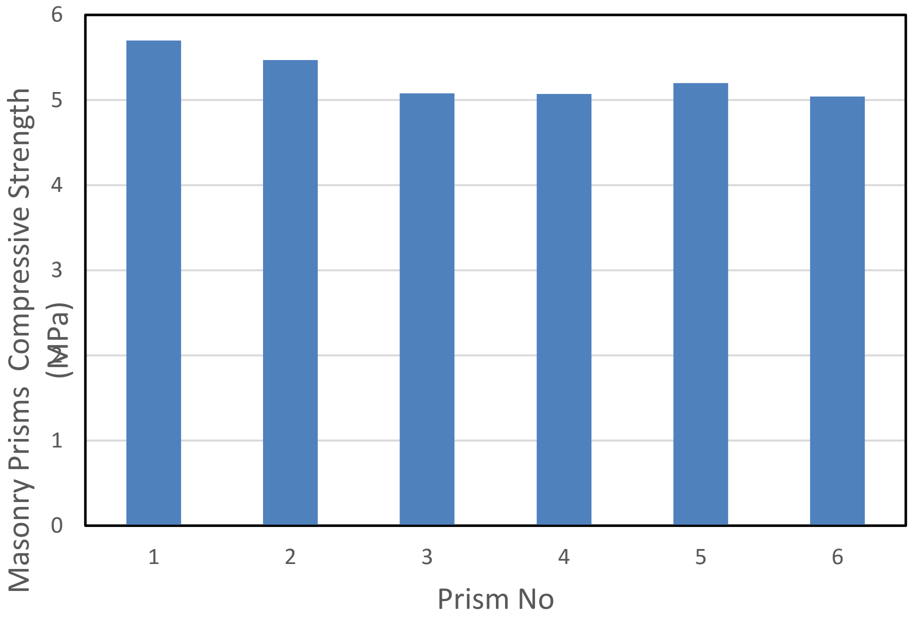

Fig. 4: Prisms compressive strengths

From the above results it can be observed that using CEMII B-L 32.5N (Prism 2) instead of CEMI 42.5N (prism 1) showed a negligible effect on the prism compressive strength. Also replacement of 25% of CEMI 42.5N by lime or CKD (prism 5) reduced the prisms compressive strength by about 10% with respect to CEMI and 8% with CEMII which considered good achievement compared to saving 0.25 of cement, saving energy, reduce the CO_2 emitted during the cement industry and efficiently get rid of industrial byproduct which is CKD.

WALL PANEL TESTING SETUP AND MEASUREMENTS

The wall panels were tested using a compression hydraulic jack with a maximum capacity 500 tons. For testing the walls, they were transported using a wire crane to a large frame and placed on it. In order to simulate uniform loading a steel □- beam was rested on the top on the wall with a depth 200 mm welded with 7 stiffeners at a distance 200 mm between them.

Two Linear Voltages Displacement Transducers (LVDT), were fixed on the surface of the wall panels' faces with appropriate length, using steel angles for fixation. The type of (LVDT) used has a maximum displacement 25 mm (tension and compression). Two three (LVDT) were fixed to measure vertical and horizontal displacements. The cracking and the failure loads were observed and recorded. Also the crack pattern was mapped on the panels to determine its cracking behaviour.

DISCUSSION OF EXPERIMENTAL RESULTS

Table 5 summarizes the outcome of the experiments: the maximum ultimate load Pmax, corresponding strain and toughness (area under load displacement curve) also, Fig.3 shows the failure modes of all walls.

Tab. 5: Ultimate load, maximum displacement and toughness of tested walls

Wall No	Mortar proportions	Ultimate Load (KN)	Corresponding strain (mm/mm) at max. load	Toughness (KN.mm)
W1	Control CEM I 42.5N	568.3	0.4797	430
W2	Control CEM II B-L 32.5N	548.1	0.495	420
W3	75%CEM I + 25% lime	534.4	0.5057	360
W4	75%CEM II + 25% lime	484.8	0.5657	340
W5	75%CEM I + 25% CKD	537.2	0.16	220
W6	75%CEM II + 25% CKD	519.6	0.2445	300

EFFECT OF CEMENT TYPE

The effect of using different cement types on the ultimate load and behavior of the walls can be reflected by comparing wall one (mortar mix with CEMI 42.5N) and wall two with CEMII 32.5N.

Fig.5 shows the load-strain relationship of walls W1, W2 which are tested as control walls. As illustrated in Table 5, W1 recorded an ultimate load of 568.3 KN while the W2 resulted in a negligible reduction in ultimate capacity of 3.5 % (Pult = 548.139 KN) in case of using CEMII 32.5N instead of CEMI 42.5N. Moreover, replacement of CEMI 42.5N with CEMII 32.5N in the tested walls displayed toughness was also very close to the control wall W1 as shown in Table 5.

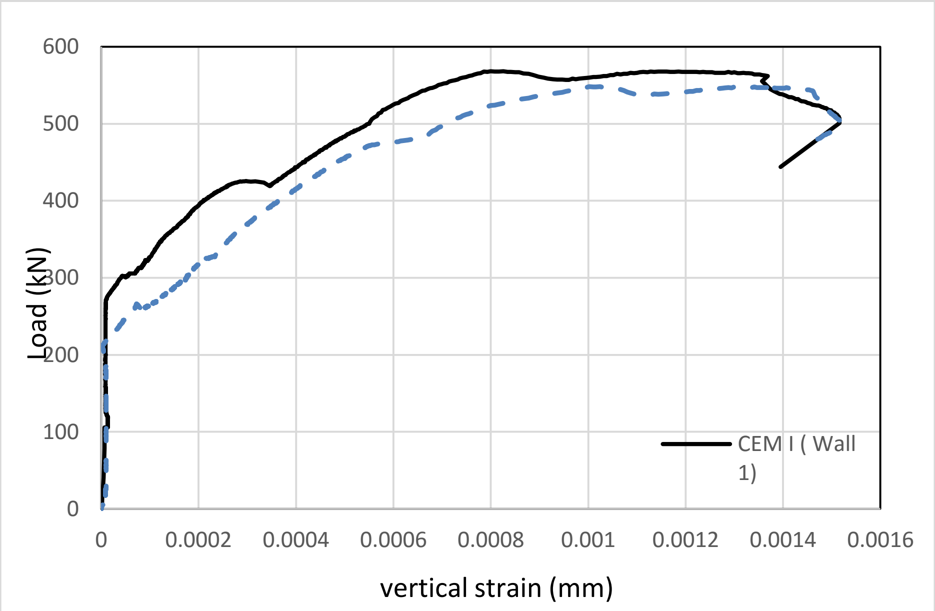

Fig. 5: Load-strain relationship of walls W1, W2

Failure cracks of W1 were mainly due to splitting in the bricks and passing through the joints. Cracks appeared near the top and propagated toward the bottom. On the other hand, replacement of CEMI 42.5N by CEMII32.5N in W2 showed a negligible change on the ultimate load and the mode of failure.

The same trend can be shown in Figs. 6 and 7 which present the load- vertical strain relationships of walls W3, W4, W5 and W6.

EFFECT OF REPLACEMENT 25% OF CEMENT

Fig.6 shows the load – strain relationship of W1 (control wall with CEMI 42.5N), W3 (25% of cement used in mortar mix is replaced by lime powder) and W5 (25% of cement used in mortar mix is replaced by CKD).W1 recorded an ultimate capacity of 568.3 KN while the walls W3 and W5 showed lower ultimate capacity when compared to wall W1. The decrease was about 6 % for both W3 and W5 (Pult = 548.1 KN), (Pult = 537.2 KN), respectively. On the other hand, the toughness was 430 kN/mm for wall W1 and reduced to 360, 220 for walls W3, W5 respectively. This behaviour clarifies that replacing 25% of cement with lime gave better ductility than using CKD. Also there were propagated cracks on the corner of tested walls up to failure. Also, propagated cracks through bricks were also observed up to failure.

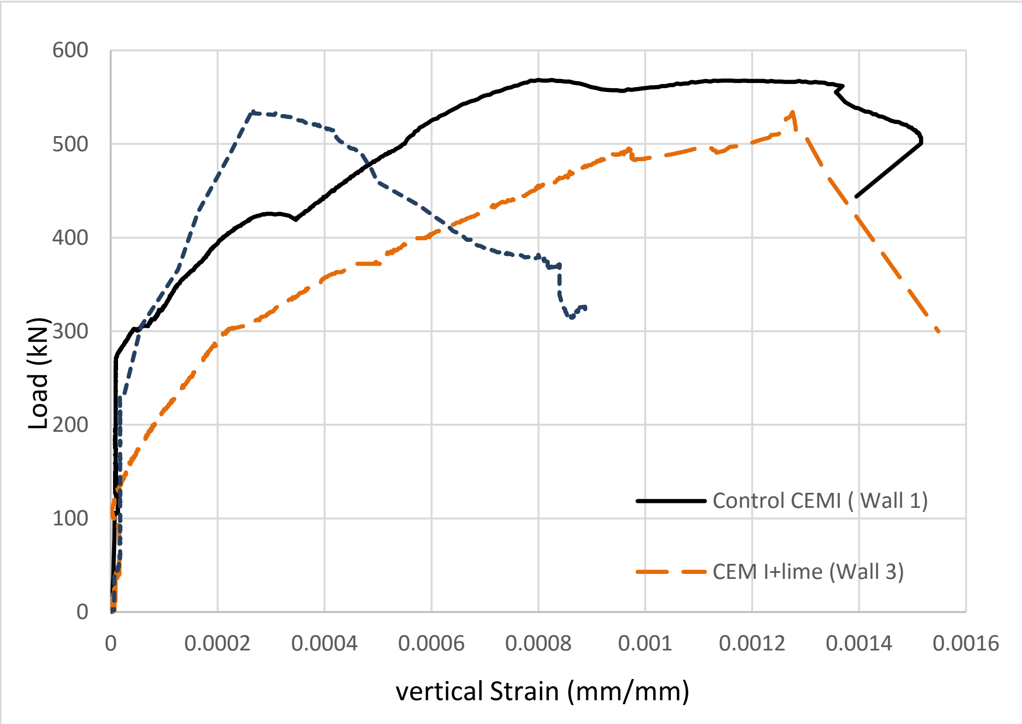

Fig. 6: Load-strain relationship of walls W1, W3, W5

In Fig.7 showed the load – strain behaviour of walls W2 (wall with CEMII 32.5N), W4 (25% of cement used in mortar mix is replaced by lime powder) and W6 (25% of cement used in mortar mix is replaced by CKD). Wall W1 recorded an ultimate capacity of 548.139 KN while the wall W4, W6 showed lower ultimate capacity when compared to wall W2 about 11.5% (Pult = 484.8 KN) and 5.2 % (Pult = 519.5 KN), respectively. On the other hand, the toughness was reduced from 420 for wall W2 to 340, 300 for walls W4, W6, respectively. As shown in Fig.3, failure cracks of W4 were mainly due to crushing in the bricks near the support at the bottom.

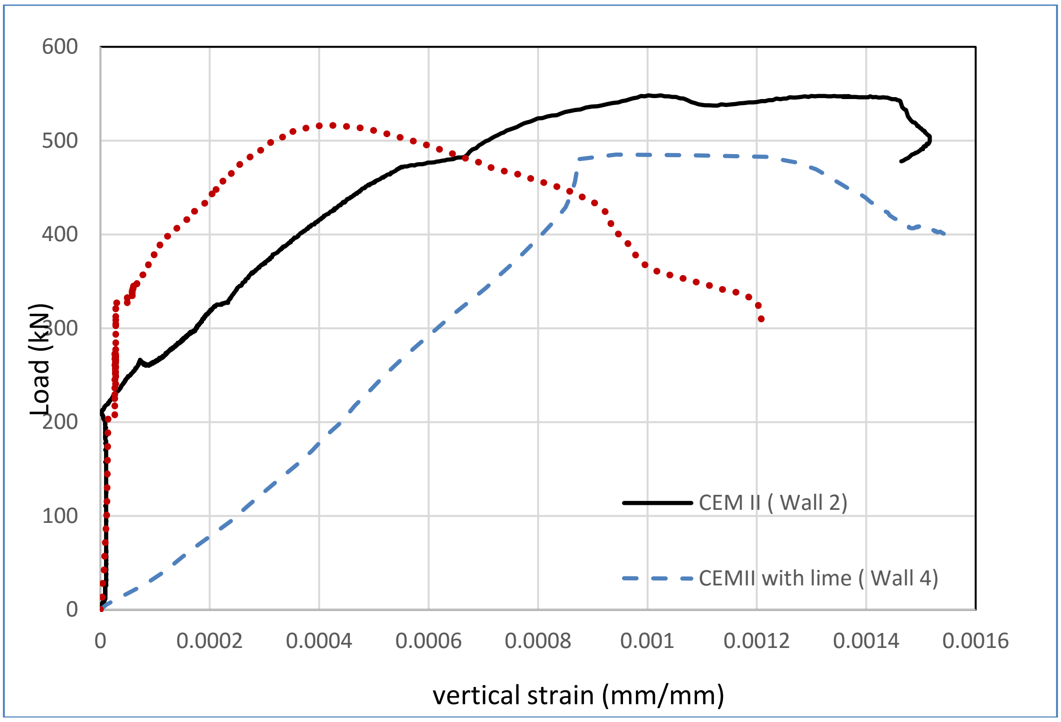

Fig. 7: Load-strain relationship of Walls W2, W4, W6

From the last results, it can be observed that the capacities of the walls with CEMI 42.5N and CEMII 32.5N were very close to each other as the difference was about 3.5% . Walls with 25% replacement of mortar cement by lime or CKD achieved only about 6% reduced capacities compared to the control wall except in W4, the capacity reduced by11.5% compared to the control wall W2.

CONCLUSION

From the analysis and discussion of the test results obtained from this research, the following conclusions can be drawn:

1. Using of CEMIIA-S 42.5N or CEMII B-L 32.5N instead of CEMI42.5N and using lime or CKD as cement replacement of masonry mortar (up to 25%) achieved accepted compressive strength according to ECP 204/2005.
2. Using of CEMII B-L 32.5N instead of CEMI42.5N in wall mortar gave a tested wall behavior similar to that of CEMI42.5N where in W2 the ultimate capacity decreased by only 3.5%compared to the ultimate capacity of W1. Same behavior of the ultimate capacity was observed in the toughness. 3. Replacement of 25% of CEMI 42.5N in mortar mix by lime reduced the wall ultimate capacity by 6% which considered an economical and environmental gain compared to 25% reduction of used cement, while the toughness of W3 reduced by16.2%compared to that of W1.
4. Using an industrial byproduct cement Kiln dust (CKD) as a replacement material of 25% of CEMI42.5N decreased the ultimate capacity by less than 6% which considered an economical and environmental gain compared to 25% reduction of used cement. On the other hand, the toughness of W5 reduced by about 48.4% compared to that of W1 and that appeared clearly by comparing the corresponding displacement to the ultimate load in W1 and W5.

5. Replacement of 25% of CEMII 32.5N in mortar mix by lime reduced the wall ultimate capacity by 11.5% and that reduction was due to increasing the lime content in the mortar mix , where CEMII B-L32.5N contains up to 35% lime instead of clinker. Despite that reduction in wall ultimate capacity, it is considered an economical and environmental moderate gain compared to 25% reduction of used cement, while the toughness of W4 reduced by 19% compared to that of W2.
6. Using of CKD as a replacement material of 25% of CEMII32.5N decreased the ultimate capacity by less than 6% which considered an economical and environmental gain compared to 25% saving of used cement. On the other hand, the toughness of W6 reduced by 29% compared to that of W2.
7. In all tested walls, cracks were mainly due to splitting in the bricks and passing through the mortar joints and propagated to the wall corner above the support.

REFERENCES

[1]European concrete platform, 2009. Sustainable benefits of concrete structures. Brussels, Belgium

[2] Alexander M, Mindess S. Aggregate in concrete, 2005. London and New York: Taylor & Francis Group.

[3]Malhotra V, Mehta P, 2005. High performance, high volume fly ash concrete. materials, mixture, proportioning, properties, construction practice, and case histories", Supplementary cementing materials for sustainable development incorporated, Ottawa.

[4]Barger, S. Gregory, Lukkarila, R. Mark, Martin, L. David, Lane, B. Steven, Hansen, R. Eric, Ross, W. Matt, Thompson, L. Jimmie, 1997. Evaluation of a blended cement and a mineral admixture containing calcined clay natural pozzolan for high performance concrete. Proceedings of the sixth intpurdueconf on conc pavement design and materials for high performance, Purdue University, West Lafayette, Indiana, 21 p.

[5]A. Bentur, Cementitious materials, 2002. Nine millennia and a new century; past, present and future, ASCE J. Mater. Civ. Eng. 14 (1) 1–22.

[6]CEMBUREAU, T.E.C. Association; 2008, Brussels, 2005. European construction in service of society ecoserve network, Cluster 2. Production and Application of Blended Cements, 44.

[7]R.E. Rodriguez-Camacho, 1998. Proceeding of the 6th international conference on the use of fly ash, silica fume, slag, and natural pozzolan in concrete. ACI SP, Bangkok, , 178–53.

[8]N.Y. Mostafa, Q. Mohsen, S.A.S. El-Hemaly, S.A. El-Korashy, P.W. Brown, 2010. High replacements of reactive pozzolan in blended cements. microstructure and mechanical properties, Cem. Concr. Compos. 32 386–391.

[9]M. Ghrici, S. Kenai, E. Meziane, 2006. Mechanical and durability properties of cement mortar with Algerian natural pozzolana. J. Mater. Sci. 41 6965–6972.

[10] G. Kaur, S.P. Singh, S.K. Kaushik, 2012. Reviewing some properties of concrete containing mineral admixtures. Indian Concr. J. 86 35–51.

[11] Gang L, Kejin W., 2011. Theoretical and experimental study on shear behavior of fresh mortar. Cemment Concrete Composite. 33. p. 319–8.

[12] ESS No. 619,-48, Egyptian Standard Specification Clay Masonry Units, 2003 .

[13] ESS No 1109, Egyptian Standard Specification, 2001. Concrete Aggregates from Natural Sources, 2001.

[14] ESS No. 2421, Egyptian Standard Specification, 2005. Standard Methods of Physical and Mechanical Tests for Cement, 2005.

[15] ESS No. 4756 -1, Egyptian Standard Specification, 2007. Portland Cement, 2013.

[16] ECP, Egyptian Code of Practice for Design of Masonry Buildings, 2005. ECP 204. Ministry of development, New Communities, Housing and Utilities, Housing and Building National Research Center.

[17] ASTM C1314, 2003. Standard Specification Method for Constructing and Testing Masonry Prisms Used to Determine Compliance with Specified Compressive Strength of Masonry.

[18] ACI committee 530, 2005. Building Code Requirement for Masonry Structure. American Concrete Institute.

[19] Angel San Bartolomé and Daniel Quiun, 2007. Tests for Evaluation of Slenderness Correction Factor for Masonry Prisms. Tenth North America Masonry Conference. At St. Louis.