Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (42) No. (1) January, 2020

# EFFECT OF USING GREEN MORTAR ON SHEAR BEHAVIOR OF MASONRY WALLS

**Amal Belal Mohammed**
Housing and Building National Research Center, Cairo, Egypt.

## ملخص البحث

يهدف هذا البحث إلى دراسة تأثيراختلاف خصائص خلطات مختلفة من المونة باستخدام انواع مختلفة من الأسمنت CEM I 42.5N و CEMII B-L32.5N بالإضافة إلي خلطات بها نسب احلال مختلفة تصل الي% 25 من الأسمنت المستخدم بتراب المسارات الجانبية للأسمنت( تراب الأسمنت )وكذلك بالجير .تم أيضا بناء واختبارعدد ست حوائط تحت تأثير حمل القص في الاتجاه القطري للحائط لبيان تاثير المتغيرات علي سلوك الحوائط في القص .

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

Masonry is composed of two different materials namely: the masonry units and the mortar joints. Therefore, mortar is considered an important element in the majority of masonry work as it has a direct effect on the masonry structure's behavior and cost. This research studies the effect of using different mortars containing different types of cement with replacing part of the used cement with lime powder or Cement kiln dust (CKD) on the shear behaviour of masonry walls. The experimental program includes testing 6 masonry clay bricks walls of different types of cement mortars containing (CEMI 42.5N and CEM II B-L 32.5N) with replacement ratio of 25% by weight of each cement type content by lime or CKD. The results proved the availability of using CEMII B-L 32.5N instead of CEMI42.5N in masonry mortar mixes and also it can be demonstrated that using of lime and CKD as cement replacement of masonry mortar by 25% achieved an accepted shear behaviour 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 the ultimate diagonal load of the tested wall only by about 10% if compared to that of control.

## KEYWORDS

Mortar, CKD, Lime, Shear and Masonry walls.

## INTRODUCTION

Construction using masonry remains relatively popular in many parts of the world and is practiced widely even today. The two material phases in masonry (the masonry units and the mortar phase) are joined by a weak interface and hence masonry is generally weak in tension and shear while masonry structures are expected to resist only compressive forces [1]. The conventional design practice emphasizes that masonry structures are subjected to compressive stresses alone [2], and hence, an accurate determination of compressive strength was extremely common. The lateral load resistance of masonry buildings is mainly due to in-plane shear resistance of the masonry elements/piers. Therefore detailed investigation on the in-plane shear behavior of masonry piers thus becomes necessary [3].

Concrete is counted as on of the mostly consumed construction materials where it was estimated by 31 Gt/year in 2006 according to European concrete platform [4], and cement consumption was estimated by 4 Gt/year [5, 6]. This 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 CO2. It is argued that in order to produce 1 ton of cement, 1.8 tons of raw materials are needed and around (0.8-1) ton of CO2 is released, 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 CO2 emissions referring to 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.
Several researchers [7-9] 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 SCM in concrete to enhance its properties and to gain its environmental and economic benefits

[10-12], 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 [13]. 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. The beneficial uses of CKD are in highway uses, soil stabilization, use in cement mortar/concrete, controlled low strength material.

Shear strength resisting the lateral earthquake force stems from the bond called sliding shear strength and residual frictional force that develops after the failure of the bond at the interface of brick and mortar. Different experimental models and methods are used to determine the sliding shear strength and frictional force between mortar and brick. Studies showed that the compressive strength of the mortar and even the plaster are the two most important parameters in determining sliding shear strength, since the strength of the brick is higher than the strength of the mortar and plaster. That is why in this study to investigate the sliding shear strength of masonry, only compressive strength of mortar is taken into consideration [14]. In many seismically active regions around the world unreinforced masonry buildings represent a significant portion of the building stock. There is a large building stock of low-rise residential unreinforced masonry buildings in different countries. Their vulnerability is caused by the failure of unreinforced masonry shear walls due to the in-plane or out-of plane seismic loading. Large quantities of masonry structures do not satisfy the latest code provisions and therefore application of strengthening methods is necessary [15].

## AIM OF THE STUDY

The aim of the research was to study the effect of using different mortars containing different types of cement with 25% replacing part of the used cement with lime powder or cement kiln dust (CKD) on the shear behaviour of masonry walls. To achieve the aim of the current study, an experimental program consisting testing six different wall panels 1000 by 1000 mm under shear load was conducted.

## RESEARCH PROGRAM

The experimental test program was designed to achieve the research objectives of the study.

Six walls with 25% replacement of used cement by lime or CDK. Wall panels 1000 by 1000 $mm^2$ and thickness 100mm were manufactured for this experimental program using clay bricks (60*100*200)mm. 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 7 days using sprinkler to wet the wall panels by fresh water once a day.

The results of tested mortars at 28 days in accordance with ESS 2421/2015 [16], using three types of cement namely (CEMI 42.5N and CEM II B-L 32.5N) with 25% of each cement type by lime or CKD separately are presented in table (1). While, compressive results of 18 prisms; each prism consists of five bricks, covering the 6 types of mortars used in the tested wall panels are shown in table (2)

**Table (1): Compressive strength of different used mortars [17]**

| Cement / Rep. | CEM I 42.5N | CEM II BL 32.5N |
|---|---|---|
| | 28 days compressive strength ($N/mm^2$) | |
| No replacement | 44.8 | 33.65 |
| 25% rep by lime | 40.3 | 29.39 |
| 25% rep by CKD | 36.5 | 30.19 |

**Table (2): Ultimate compression load and corrected masonry compressive strength of tested prisms[17]**

| *Prism No | Mortar proportions | Average 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 |

The results illustrated are the average of three prism specimens

## MATERIALS PROPERTIES

The structural behaviour 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 five specimens according to the Egyptian standard specifications ESS No. 48-619,2003 [18]. The average compressive strength of the clay brick was 5.5 MPa. Average unit weight of clay bricks was 1.22 t/m3.
Local sand from natural sources, complying with Egyptian standard specification ESS No. 1109- 2001 [19], was used for masonry mortar, lime and CKD (by-product of cement industry) were used for masonry mortar. 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 mechanical tests were carried out as according to ESS No. 2421-2015 [16]. The physical and mechanical properties are complying with ESS. No 4756 -2013 [20].

CKD was brought from Suez Cement Company, Egypt. Percentage retained on sieve No.170 was less than 9%. Tables 3 and 4 indicated the physical properties and chemical composition of used CKD.

**Table (3): 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 (4): Chemical composition of CKD**

| Oxide | Content % |
|---|---|
| $SiO_2$ | 17.11 |
| $Al_2O_3$ | 4.58 |
| $Fe_2O_3$ | 2.13 |
| CaO | 40.95 |
| MgO | 2.51 |
| $K_2O$ | 5.18 |
| $SO_3$ | 2.27 |
| $Na_2O$ | 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 [21], 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.

From previous researches results, it can be concluded that the replacement of cement by CKD or lime up to 25% gave a nearly similar behviour in compressive strength as that when using 100% cement, which is considered an economical and environmental achivement as it saved 25% of cement by using a by-product (CKD) or lime, thats why a replacement percentage of 25% was chosen in mortar mixes used in walls investigations under diagonal shear load [17].

## WALL PANEL TESTING SETUP AND MEASUREMENTS PROCEDURES

The wall panels were tested using a compression hydraulic jack with a maximum capacity 500 tons under diagonal shear loading on the mortar joints. Tests were conducted according to ASTM E519–07 [22]. For testing the walls in diagonal shear two steel loading shoes were used to transfer the load to the wall according to ASTM E519.

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

**Fig1 (a):Walls before testing**

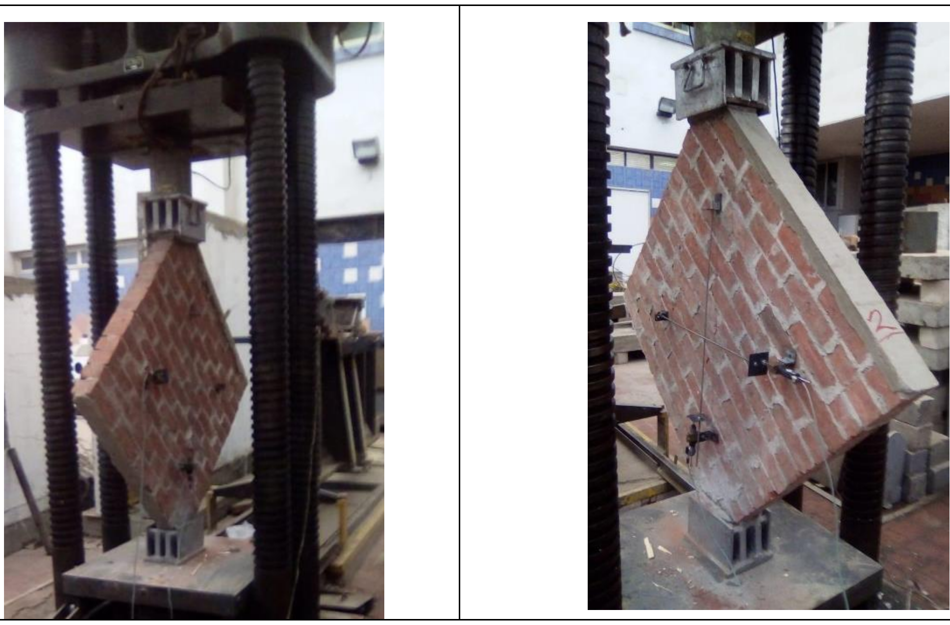

**Fig1 (b):Test Setup and Instrumentaions**

**Fig1 (c):Cracking Pattern and failure mode**

**Figure 1: Walls before, during and after  testing**

## TEST RESULTS AND DISCUSSION

Table 5 summarizes the outcome of the experiments: the maximum ultimate diagonal load P and corresponding strain.

**Table (5): Ultimate load and corresponding strain of tested walls**

| Wall No | Mortar proportions | Ultimate Load (KN) | Corresponding strain (mm/mm) at max. load | Toughness N.mm |
|---|---|---|---|---|
| W1 | Control CEM I 42.5N | 99.63 | 0.00086 | 251 |
| W2 | Control CEM II B-L 32.5N | 93.58 | 0.0005 | 233 |
| W3 | 75%CEM I + 25% lime | 89.77 | 0.0028 | 331 |
| W4 | 75%CEM II + 25% lime | 84.06 | 0.001 | 176 |
| W5 | 75%CEM I + 25% CKD | 85.98 | 0.00168 | 174 |
| W6 | 75%CEM II + 25% CKD | 81.57 | 0.0017 | 238 |

## EFFECT OF CEMENT TYPE

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

Fig.2 shows the load-strain relationship of walls W1, W2 which were tested as control walls. As illustrated in Table 5, W1 recorded an ultimate load of 99.63 KN while the W2 resulted in a negligible reduction in ultimate capacity of 6 % (Pult = 93.58 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.

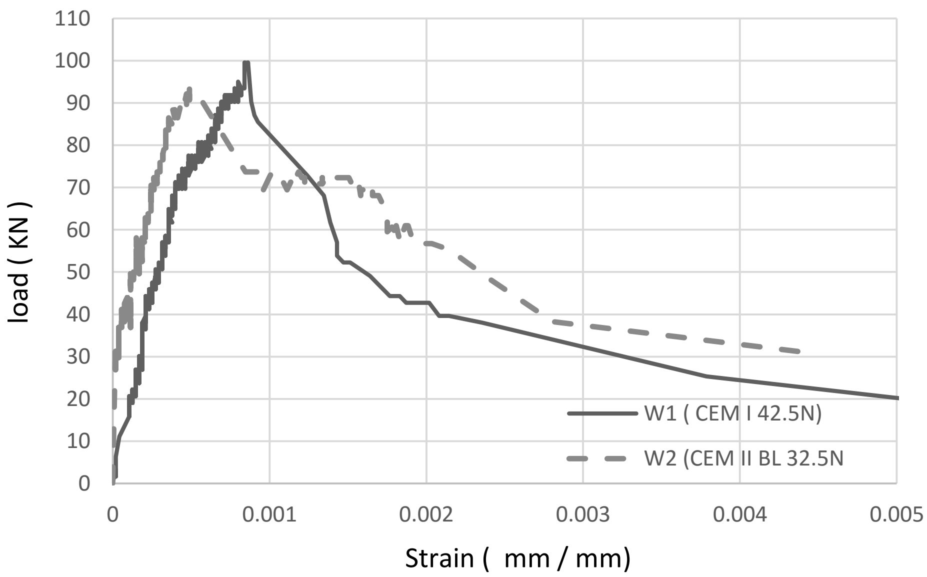


**Figure 2: Load-strain relationship of walls W1, W2**

Failure cracks pattern of all walls were almost the same as the failure plane had a stepped shape due to debonding along the mortar joints and tensile failure of masonry units, see Figure 1. The wall exhibited a brittle failure due to splitting along the diagonal mainly due to splitting in the bricks and passing through the joints. 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.

## EFFECT OF REPLACEMENT 25% OF CEMENT

Fig.3 shows the load – strain relationship of W1 (control wall with CEMI 42.5N), W3 (25% of cement used in mortar mix was replaced by lime powder) and W5 (25% of cement used in mortar mix was replaced by CKD). W1 recorded an ultimate capacity of 99.63 KN while the walls W3 and W5 showed lower ultimate capacity when compared to wall W1. The decrease was about 9.9 and 13.7 %, respectively for W3 and W5 (Pult = 89.77 KN) and (Pult = 85.98 KN), respectively. On the other hand, the toughness was 251 N/mm for wall W1 and became 331 to 174 N.mm/mm for walls W3 and W5, respectively. This behaviour clarifies that replacing 25% of cement with lime gave better toughness than using CKD.

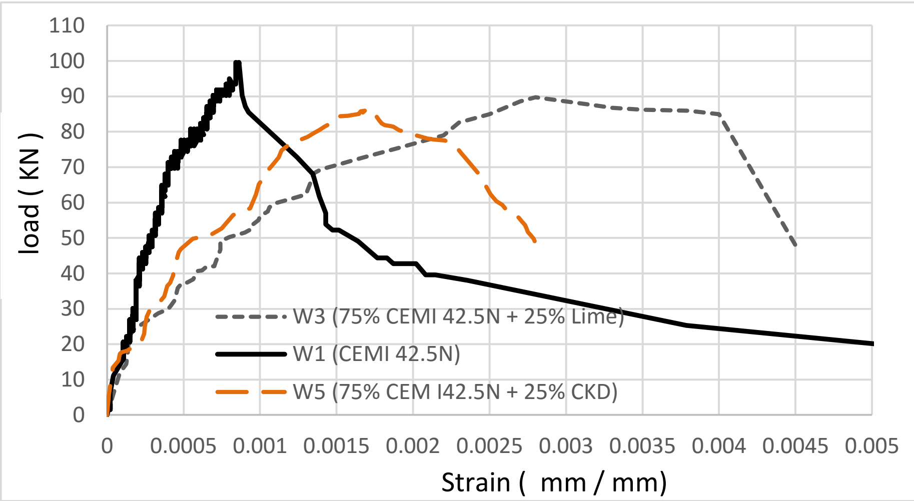


**Figure 3: Load-strain relationship of walls W1, W3, W5**

Fig.4 showed the load – strain behaviour of walls W2 (wall with CEMII 32.5N), W4 (25% of cement used in mortar mix was replaced by lime powder) and W6 (25% of cement used in mortar mix is replaced by CKD). W2 recorded an ultimate capacity of 93.58 KN while W4, W6 showed lower ultimate capacity when compared to wall W2 by 10.2 and 12.8 %, respectively ( Pult of W4 = 84.06 KN and Pult of W6 = 81.57 KN). On the other hand, the toughness was reduced from 233N.mm/mm for W2 to 176 N.mm/mm, for W4 while it kept the same for W6. It can be observed from Figs 3 & 4 that failure loads and wall behaviour is shear when replacing 25% of cement by lime or CKD gave an acceptable behaviour if compared to walls with 100% CEMI or CEM II with 25% saving in cement, energy and less CO2.

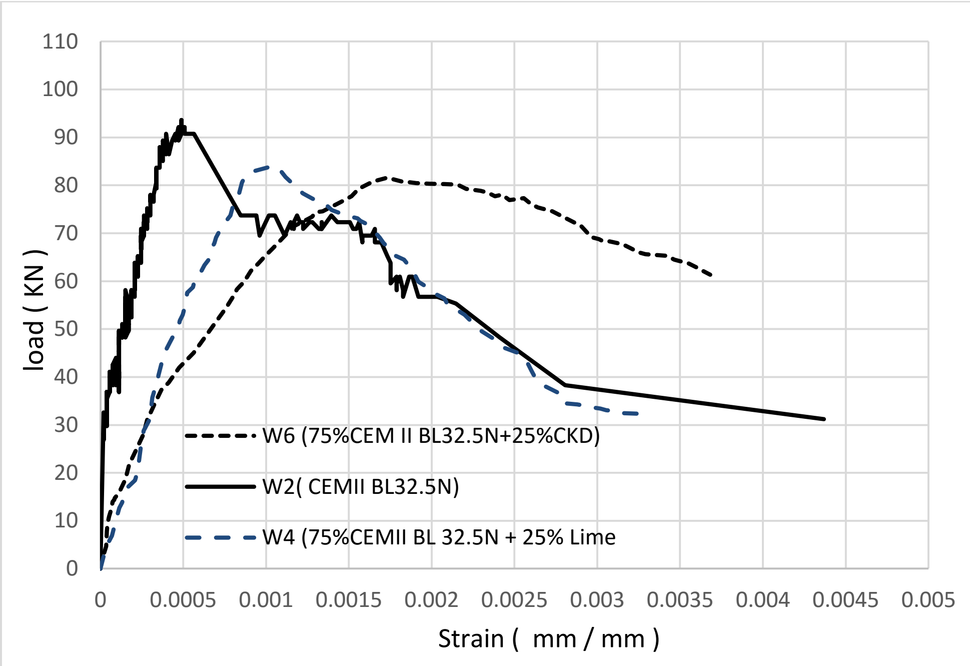


**Fig. 4: Load-strain relationship of Walls W2, W4, W6**

From the previous 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 6% . Walls with 25% replacement of mortar cement by lime or CKD achieved only up to 12.8% reduced capacities compared to the control wall which is considered an economic and environmental achievement.

## CONCLUSIONS

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

1. Using of CEMII B-L, lime and CKD in mortar mixes saves energy, decreases $CO_2$ emission thus, it is considered green mortar.
2. Using of CEMII B-L 32.5N instead of CEMI42.5N in wall mortar gave a behavior similar to that of CEMI42.5N where in W2 the ultimate capacity decreased by only 6%compared to the ultimate capacity of W1. Almost same behavior of the ultimate capacity was observed in the toughness, regardless the grade of cement.
3. Replacement of 25% of CEMI 42.5N in mortar mix by lime reduced the wall ultimate capacity by 9.9% which considered an economical and environmental gain compared to 25% reduction of used cement, while the toughness of W3 increased by 32%compared to that of W1.
4. Using an industrial by-product cement Kiln dust (CKD) as a replacement material of 25% of CEMI42.5N decreased the ultimate capacity by 13.7% which considered an economical and environmental gain compared to 25% reduction of used cement and using a by-product in a useful way. On the other hand, the toughness of W5 reduced by about 30% compared to that of W1.
5. Replacement of 25% of CEM II 32.5N in mortar mix by lime reduced the wall ultimate capacity by 10.2% and that reduction was due to increasing the lime content in the mortar, as 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 gain compared to 25% reduction of used cement, while the toughness of W4 reduced by 24% compared to that of W2.

6. Using of CKD as a replacement material of 25% of CEMII32.5N decreased the ultimate capacity by 12.8% which considered an economical and environmental gain compared to 25% saving of used cement and saving 35% of clinker in cement itself. On the other hand, the toughness of W6 was almost similar to that of W2.
7. Failure cracks pattern of all walls were had a stepped shape due to debonding along the mortar joints and tensile failure of masonry units, The walls exhibited a brittle failure due to splitting along the diagonal mainly due to splitting in the bricks and passing through the joints.

## REFERENCES


[1] Nassif Nazeer Thaickavil and Job Thomas, "Behaviour and strength assessment of masonry prisms" , case studies in construction materials, 8 (2018) 23-38.

[2] J. Thomas, "Concrete block reinforced masonry wall panels subjected to out-of-plane monotonic lateral loading", Proceedings of National Conference on Recent Advances in Structural Engineering, Hyderabad, India, February, 2006, pp. 123–129.

[3] S.R. Balasubramanian et al,"In-plane Shear Behavior of Unreinforced Brick Masonry" – A Literature Review, Structural Analysis of Historical Constructions, New Delhi 2006

[4] European concrete platform, 2009, "Sustainable benefits of concrete structures, Brussels, Belgium

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

[6] 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.

[7] 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.

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

[9] 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.

[10] 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.

[11] 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.

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

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

[14] Orhan Doğan, Orhan Gazi Odacıoğlu, "An Experimental Study To Determine Sliding Shear Strength And Internal Friction Coefficient Of Clay Brick Wall In A Masonry Building", International Journal of Engineering Research and Development Volume:11 Issue:2 June 2019

[15] S. Churilov University , E. Dumova-Jovanoska, "In-plane shear behaviour of unreinforced masonry walls ", 4th European Conference on Earthquake Engineering 2010 : Ohrid, Republic of Macedonia, 30 August - 3 September 2010 /; Vol. 2

[16] ESS No. 2421, Egyptian Standard Specification, 2015. Standard Methods of Physical and Mechanical Tests for Cement, 2015.

[17] Abdel hamid El Semary et al, "Effect of using green building masonary mortar on the behaviour of masonary walls" , Journal of l Azhr University – Engineering sector, volume 14, Issue 53 October 2019.

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

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

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

[21] 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.

[22] ASTM E519, Standard Test Method for Diagonal Tension (Shear) in Masonry Assemblages, 2007.