Using Hydrated Cement in Mortar for Masonry Walls

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Abstract

Large amounts of hydrated cement are accumulated on construction site due to improper storage and become a problem which requires getting rid of it.

The objective of this investigation is to prepare a good cement from hydrated cement which is useful as a binding material, the effect of hydrated cement content as a partial replacement of cement on compressive strength and volume change of different mixes is studied. The investigation also extends to evaluate the structural performance of clay brick walls built from cement-hydrated cement mortar as a binding material, and to evaluate the effect of type of mortar, eccentricity and number of courses on compressive strength of clay brick prisms and to find the ultimate strength of load bearing clay brick walls and compare the experimental values of the ultimate strength of the wall with predicted values.

The experimental results show that using hydrated cement as a partial replacement of cement up to 30% can be made without significant change in compressive strength compared with control mix. However the effect on volume changes is within the acceptable limit. The results also indicate that the load carrying capacity of clay brick prisms built from cement-hydrated cement mortar at different point loads and different courses is convergent with the load carrying capacity of prisms built with cement mortar. Comparison was made between experimental results for the ultimate strength wall and some of the available empirical formulae.

الخلاصـــــــة

إن تجمع كميات كبيرة من الأسمنت التالف نتيجة لسوء الخزن في المشاريع الإنشائية يعتبر من المشاكل المألوفة والتي يتطلب صرف مبالغ من اجل التخلص منها.

إن الهدف الرئيسي من هذا البحث هو تحضير اسمنت صالح من الأسمنت المتميأ لغرض الاستفادة منه كمادة رابطة في أعمال البناء. تضمن البحث دراسة تأثير استعمال الأسمنت المتميأ كبديل لجزء من الأسمنت على مقاومة الإنضغاط والتغير الحجمي لمونة الأسمنت. كما تضمن أيضاً دراسة السلوك الإنشائي للجدران المشيدة من الطابوق الطيني ومونة (الأسمنت+ سمنت متميأ) كمادة رابطة وإيجاد تأثير نوع المونة ، والأحمال مركزية وغير مركزية ،وعدد السوف على مقاومة إنضغاط المواشير وكذلك إيجاد المقاومة القصوى للجدران الطابوقية.

أظهرت النتائج إن استخدام الأسمنت المتميأ كبديل لجزء من الأسمنت ولحد 30% لا يؤثر على مقاومة الإنضغاط مقارنة مع الخلطات المرجعية بينما تأثيره على التغير الحجمي لمونة الأسمنت كان ضمن الحدود المسموح بها ، كذلك بينت النتائج إن قابلية التحمل للمواشير الطابوقية المبنية بمونة (سمنت+ سمنت متميأ) عند نقاط تحميل مختلفة وارتفاعات مختلفة كانت متقاربة مع تلك المبنية بمونة الأسمنت الأعتيادي. وقد جرت مقارنة بين النتائج الفعلية لقوى التحمل القصوى مع المعادلات التجريبية المتوفرة.

1. Introduction

Cement is damaged due to bad and uncontrollable storage process in construction projects, where the cement is stored for a long time and without being used regularly after its arrival date. As a result the cement is hydrated by absorbing moisture from the atmosphere or other sources, large amounts of hydrated cement are accumulated on construction sites and become a problem which requires large amounts of money to get rid of.

The binding property and strength of cement depend upon its capacity for chemical reaction, which can take place in the presence of water. Cement if not stored properly can absorb moisture from the atmospheric air or any other source and reacts with it chemically. The strength of such type of cement when used would be adversely affected to the extent that reaction would take place [1].

Storage time in paper bags is much more limited. In damp climates or damp weather condition cement can become lumpy in as little as (4-6) weeks. And if the lumps are screened out, the remaining cement is normally satisfactory for use [2].

The cement is not affected if it absorbs moisture by about (1-2) % by weight of cement, but if it increases above 2% and up to 5% it would decrease cement strength and delay its hardening, the cement would become unusable if the ratio increases more than 5% [3]. As for the field of effect of cement storage time on the compressive strength of concrete, the results show that the cement stored under covered area for a week and leaving it for 3, 6, 12, and 24 months without cover leads to a decrease in compressive strength by 25, 35, 50, and 67% respectively [4]. The aim of this study is to prepare good cement from hydrated cement which is useful as a binding material.

2. Experimental Program

The experimental program includes the processes of crushing and grinding hydrated cement after that it studies the chemical and physical properties of the hydrated cement and the effect of hydrated cement content on compressive strength, shrinkage and swelling of cement mortar. The study includes also an investigation on behavior of clay brick prisms and walls subjected to eccentric and concentric loads and built by using the cement-hydrated cement mortar as a binding material.

2-1 Materials

1. Ordinary Portland cement manufactured by Kubayisa Cement Factory was used and it conforms to the Iraqi specification No.5/1984.
2. Hydrated cement, the ordinary Portland cement from the same plant and batch was subjected to the natural weather condition and continuously moisturized by wet burlap until the cement hydrated completely (100% hardened cement), after that, the hydrated cement was prepared according to method reported by Ahmed [5]. The grinding time was (5.5) hrs to obtain specific surface area about 6624 cm^2/gm. The chemical analysis and

physical properties of the hydrated cement are listed in **Tables (1)** and **(2)** respectively. The mineralogical analysis for hydrated cement was done by x-ray diffraction as shown in **Fig.(1)**.

3. Natural sand brought from Al-Ukhaider region was used as a fine aggregate and conforms to requirement of the Iraqi specification No. 45/1984, zone (3).

4. Clay bricks were manufactured by 17 July Factory and conform to the requirement of the Iraqi specification No.25/1986.class (B).

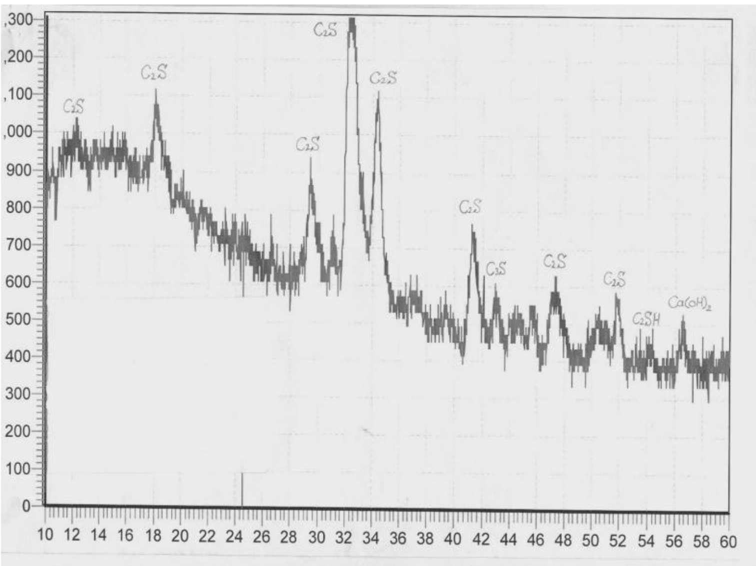
Table (1) Hydrated cement characteristic

Chemical Analysis		Physical Properties	
Oxides	% by weight		
CaO	58.30	Fineness (Blain) (cm^2/gm)	6624
SiO_2	22.50		
Al_2O_3	4.55	Initial setting time(min)	73
Fe_2O_3	2.95	Final setting (min)	140
MgO	1.68		
SO_3	1.45	Compressive Strength (N/mm^2)	
Na_2O	0.18	3 days	10.6
K_2O	0.67	7 days	16.3
L.O.I	8.85	Soundness(Le Chatelier) mm	1.2

Table (2) Compressive strength of 1:2 cement-hydrated cement mortars at the same consistency

Mix Description (C+Hc):Sand	W/(C+Hc)	Compressive Strength (MPa)						
		Age (Days)						
		1	3	7	28	60	90	180
(1.0+0.0):2	0.57	13.21	16.69	19.30	29.20	32.30	34.50	36.32
(0.9+0.1):2	0.57	12.30	15.75	18.60	28.50	31.90	34.10	36.00
(0.8+0.2):2	0.57	10.20	14.10	18.30	28.00	31.20	33.20	35.36
(0.7+0.3):2	0.56	7.50	12.55	16.50	26.40	29.54	31.80	34.52
(0.6+0.4):2	0.55	6.12	9.75	13.50	22.00	25.32	28.00	30.58
(0.5+0.5):2	0.54	5.40	9.64	12.10	19.50	21.92	23.50	25.55
(0.0+1.0):2	0.52	4.50	7.50	9.70	15.90	18.00	19.20	20.10

Intensity



Diffraction angle - 2θ

Figure (1) X-ray diffraction analysis of hydrated cement

2-2 Mixes and Preparation of Specimens

For the strength test mortar cubes of 1:2 and 1:3 cement to sand ratio with 0, 10, 20, 30, 40, 50 and 100% hydrated cement replacement by weight of cement and having the same consistency (as determined by flow test) were used. Cubes of 50mm were molded from each mix. All specimens were cured and stored in water at temperature of 23±2 C°. The specimens were tested in compression after 1, 3, 7, 28, 60, 90 and 180 days of casting. For shrinkage and swelling measurement of mortar, six mixes of 1:2 cement to sand ratio were used with 0, 10, 20, 30, 50 and 100% hydrated cement replacement by weight of cement. For each test, two prisms of 25×25×280 mm were prepared for each mix.

For masonry walls works, thirty six prism specimens were built by an experienced mason using clay bricks and four types of mortar (the first two types were 1:2 and 1:3 cement:sand and the other two type using 30% hydrated cement replacement by weight of cement). The prisms dimensions were (240 × 240) mm in cross section and 467, 580, 695 mm in height for each twelve prisms respectively. On the other hand, one short wall was built depending on the results of prism specimens by the same mason to standardize workmanship using clay bricks and one type of mortar (1:3) and having nominal dimensions (1000 mm) in length, (1200 mm) in height and (240 mm) width. The thickness of the mortar used to build the prisms and wall was (10 mm) .All specimens were cured in a laboratory environment and tested at the age of 28 days.

2-3 Tests on Masonry Walls

Concentric and eccentric loads were applied through a special steel joint which was fabricated to provide a smooth hinged reaction and assured the specified location of the eccentric load on the prism. The loads were applied at 0, 10 and 20 mm from center of prism.

Figure (2) shows the details of the loading arrangement on the different heights of prism (4, 5 and 6 courses), while the uniformly distributed vertical load was applied concentrically to the short wall. Measurements of longitudinal and transverse strains were made on both faces of the clay brick wall, using mechanical extensometer of 200 mm gauge length. From these measurements it is possible to assess the strain distribution in the wall throughout the test up to failure. In addition, dial gauges were fixed at four vertical axes to measure the vertical movement between the top and bottom of the specimen.

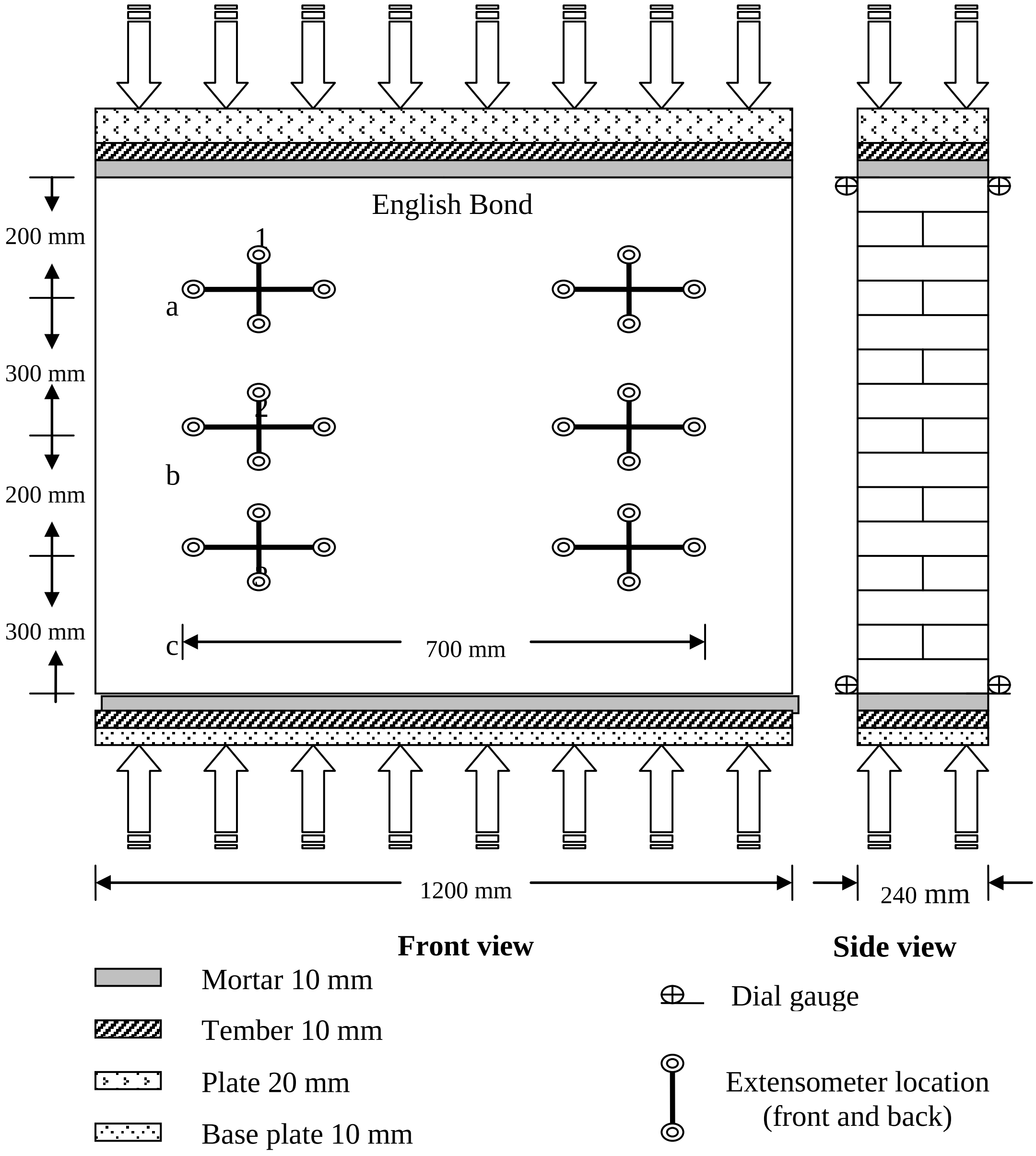


Figure (2) Details of wall

3. Results and Discussion

3-1 Chemical and Mineralogical Analysis of Hydrated Cement

The chemical analysis of hydrated cement is shown in **Table (1)**, which indicates that the value of loss on ignition is 8.85% and it is higher than that limited in Iraqi specification while the value of loss on ignition of unhydrated cement is 1.1%. This difference in value of loss on ignition may be due to the extent of carbonation and hydration of free lime and free magnesia due to exposure of cement to the atmosphere [6].

The results of mineralogical analysis of hydrated cement by using x-ray diffraction are shown in **Fig.(1)**. Generally it can be seen from the figure that the main phase of hydrated cement specimen is anhydrous compounds of calcium silicates, large proportion of C_2S and a little proportion of C_3S.Also it can be seen that amorphous compounds are in the form of calcium hydroxide ($Ca(OH)_2$) and calcium silicate hydrate (C_2SH), and it may be possible to find anamorphous materials as calcium silicate hydrate that is not discovered by frequency waves of x-ray diffraction [7].

3-2 Compressive Strength

Mortar mixes of different mix proportions have been used to investigate the effect of hydrated cement as a partial replacement by weight of ordinary Portland cement on compressive strength at various ages. The results are shown in **Tables (3)** and **(4)** and **Figs.(3)** and **(4)**. These data show that, in general, the higher percentage of hydrated cement content, the lower compressive strength at early ages.

Table (3) Compressive strength of 1:3 cement-hydrated cement mortars at the same consistency

Mix Description (C+Hc):Sand	W/(C+Hc)	Compressive Strength (MPa)						
		Age (Days)						
		1	3	7	28	60	90	180
(1.0+0.0):3	0.74	10.40	13.45	15.15	23.50	26.70	28.60	30.50
(0.9+0.1):3	0.74	8.50	11.95	14.00	22.40	25.62	28.00	30.40
(0.8+0.2):3	0.73	7.30	10.60	13.55	21.70	24.90	27.50	30.00
(0.7+0.3):3	0.72	5.65	9.25	11.80	19.50	23.30	25.63	28.46
(0.6+0.4):3	0.71	4.35	7.55	9.90	16.50	20.00	22.90	25.20
(0.5+0.5):3	0.70	3.80	7.05	8.90	14.90	17.70	19.70	21.60
(0.0+1.0):3	0.67	2.20	4.45	6.00	11.00	13.40	14.50	15.80

Table (4) The effect of hydrated cement content on compressive strength at different point load and different courses and different courses

Mix Description (C+Hc):Sand	Number of Courses	Ultimate Compressive Strength From Center (MPa)								
		e = 0 mm			e =10 mm			e= 20 mm		
		Observed Comp. Strength (MPa)	Reduction Factor For h/t ratio	Corrected Comp. Strength (MPa)	Observed Comp. Strength (MPa)	Reduction Factor For h/t ratio	Corrected Comp. Strength (MPa)	Observed Comp. Strength (MPa)	Reduction Factor For h/t ratio	Corrected Comp. Strength (MPa)
(1.0+0.0):2	4	11.25	0.84	9.45	11.12	0.84	9.34	10.85	0.84	9.11
(1.0+0.0):2	5	10.24	0.94	9.62	10	0.94	9.4	9.92	0.94	9.32
(1.0+0.0):2	6	9.32	1.03	9.6	9.1	1.03	9.33	9.01	1.03	9.28
(0.7+0.3):2	4	11.15	0.84	9.36	11.03	0.84	9.26	10.73	0.84	9.01
(0.7+0.3):2	5	10	0.94	9.4	9.94	0.94	9.34	9.8	0.94	9.21
(0.7+0.3):2	6	9.23	1.03	9.5	8.96	1.03	9.23	8.89	1.03	9.16
(1.0+0.0):3	4	10.03	0.84	8.42	9.67	0.84	8.12	9.13	0.84	7.67
(1.0+0.0):3	5	9.61	0.94	9.03	9.11	0.94	8.56	8.49	0.94	7.98
(1.0+0.0):3	6	8.7	1.03	8.96	8.18	1.03	8.42	7.97	1.03	8.21
(0.7+0.3):3	4	9.81	0.84	8.24	9.37	0.84	7.87	8.76	0.84	7.36
(0.7+0.3):3	5	9.24	0.94	8.68	8.61	0.94	8.09	8.12	0.94	7.63
(0.7+0.3):3	6	8.03	1.03	8.27	7.61	1.03	7.84	7.43	1.03	7.65

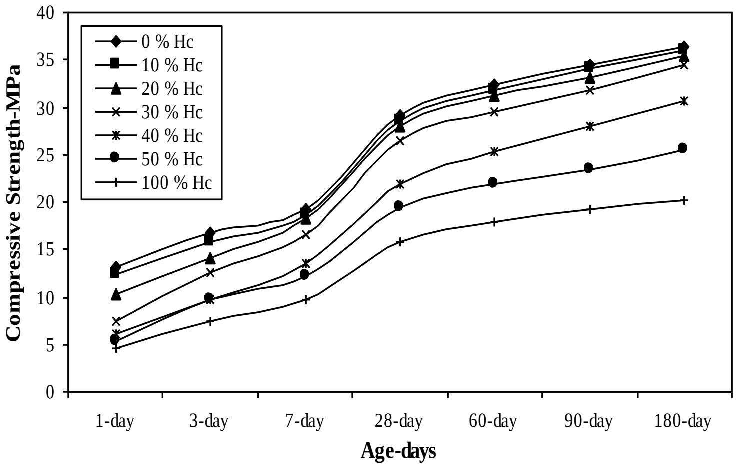


Figure (3) Compressive strength of 1:2 cement-hydrated cement mortars at the same consistency

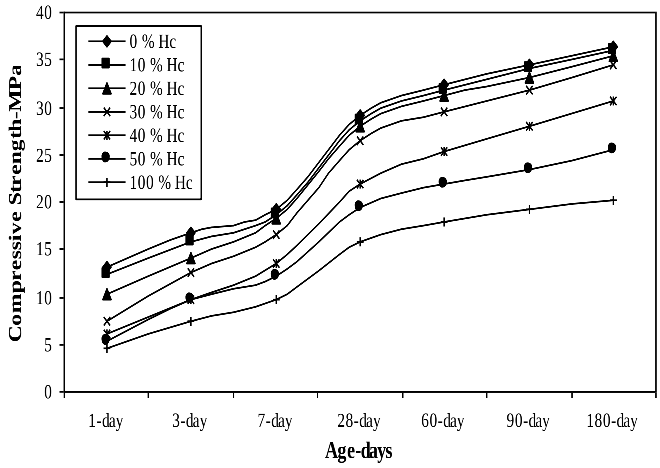


Figure (4) Compressive strength of 1:3 cement-hydrated cement mortars at the same consistency

On other hand, at 180 days the 1:2 and 1:3 mortar mix with 30% cement replacement reached approximately the same compressive strength as those of the corresponding plane mortar. For 50% and 100% cement replacement, there was a significant reduction in the compressive strength at early ages as well as at 180 days. The results also show that regardless of the agg./cement ratio of the mix, the rate of increase in the compressive strength of cement-hydrated cement mortars increases relative to those of plane mortar with progress of hydration. This behavior may be due to the high proportion of residue unhydrated dicalcium silicates (C_2S) grains, where the slower reacting of C_2S is probably responsible for the longer term and continuous development of strength which can extend for periods of a month or even a year [8].

3-3 Shrinkage and Swelling

Shrinkage and swelling characteristics of 1:2 cement-hydrated cement mortars are presented in **Figs.(5)** and **(6)** respectively. The results show that the higher the hydrated cement content, the higher are shrinkage and swelling. At 180 days, the drying shrinkage ratio of cement-hydrated cement mortar to that of cement mortar is 1.03, 1.09, 1.13, 1.2, 1.25 for 10, 20, 30, 50 and 100% cement replacement respectively, while the corresponding swelling ratios are 1.03, 1.06, 1.09, 1.16 and 1.21%. This percentage increase in drying shrinkage and swelling of mortar bars is within the values that are reported by (Neville) [6].

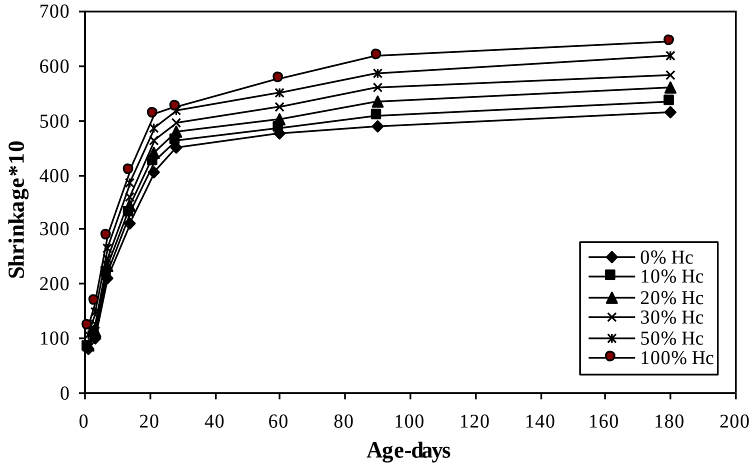


Figure (5) Effect of hydrated cement content on the shrinkage of cement-hydrated cement mortars

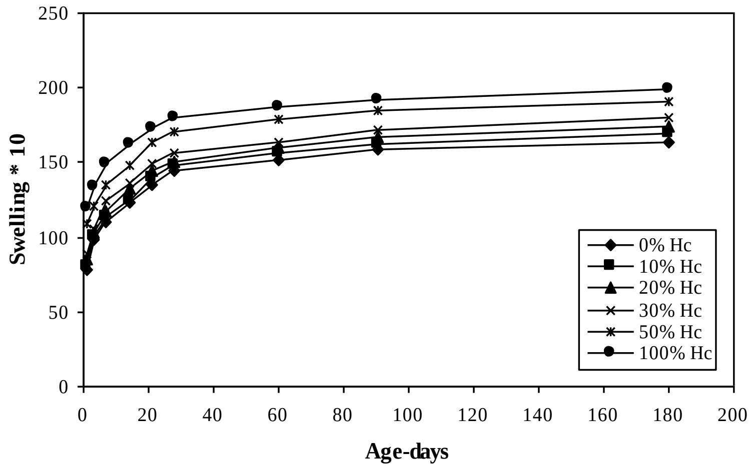


Fig (6) Effect of hydrated cement content on the swelling of cement-hydrated cement mortars

3-4 Compressive Strength of Clay Brick Prisms

The structural behaviour of the clay brick wall built from cement-hydrated mortar as a binding material was also studied [9]. Compressive strengths of clay brick prisms depend on several factors:

3-4-1 Clay Bricks Strength

Clay brick units exhibit a wide range of load carrying capacities when tested individually, whereas the load carrying capacities of the prism made of such units are significantly lower. **Table (4)** presents the results of clay brick prism strength at different point loads and different courses. These data show that, the compressive strength of clay brick prism ranges between (40 to 61%) of the compressive strength of clay brick. The main reason for this behavior may be due to the widely different strain characteristics of the brick and mortar joints, where the mortar is less rigid than the brick and under load its tendency is to spread laterally to a greater extent than the brick [10].

3-4-2 Mortar Strength

The effect of using different types of mortars on compressive strength of clay brick prism at different point load and different courses is shown in **Table (4)** and **Fig.(7)**. Generally, it can be seen that prism built with higher strength mortars shows higher compressive strength, where the compressive strength of clay brick prisms increases with increasing the compressive strength of mortar.

The results also indicate that, the compressive strength of the prisms built with cement-hydrated cement mortar is convergent with that of the prisms built with plain mortar.

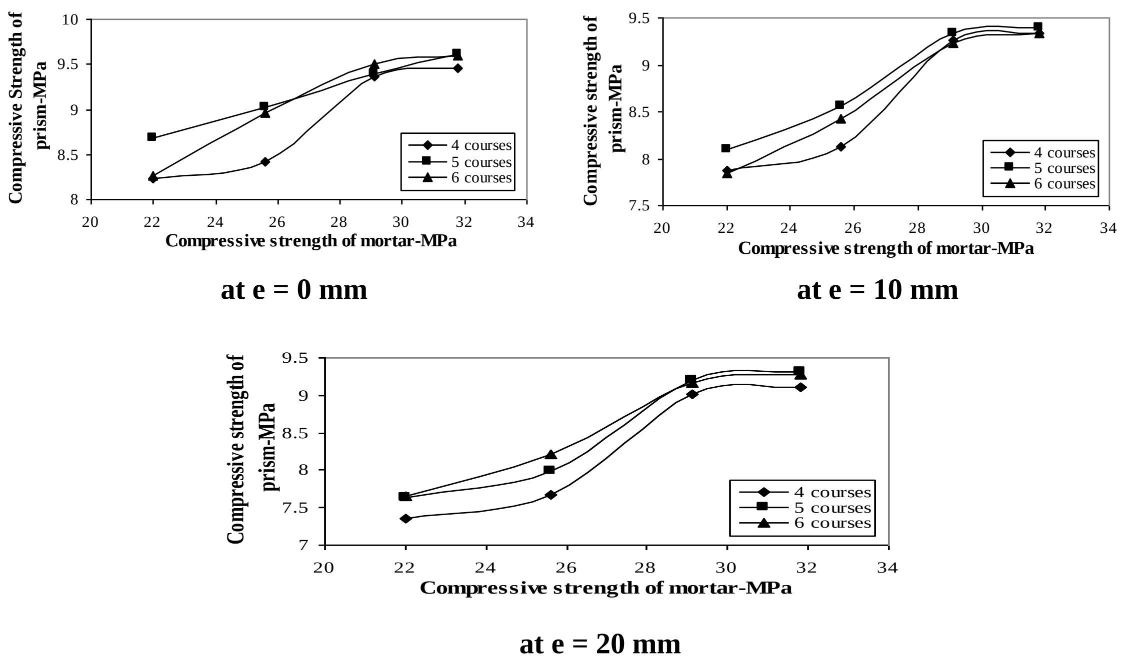


Figure (7) Relationship between compressive strength of prism and compressive strength of mortar

3-4-3 Eccentricity

The effect of eccentricity on compressive strength of clay brick prisms at various courses and different types of mortar is presented in **Table (4)** and **Figs.(8)**, **(9)**. The results show that, the maximum value of compressive strength is at (e/t = 0) and the compressive strength of clay brick prism decreases gradually with increase in the ratio of (e/t). The ratio of decrease in compressive strength of clay brick prism ranges between (3 to 12%) of the maximum value of compressive strength (at e/t = 0). This is due to none uniformly distributed stresses on the loaded area, where the loads are concentrated in some of loaded areas and lead to increase in the stresses in this area and decrease it in other areas, this difference in concentration of loads leads to the failure of prism under less load [10].

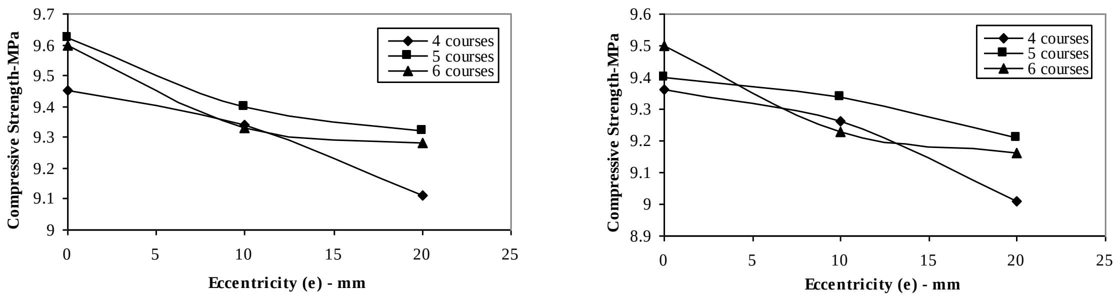


Figure (8) Variation of compressive strength of prism with eccentricity of 1:2 cement mortar

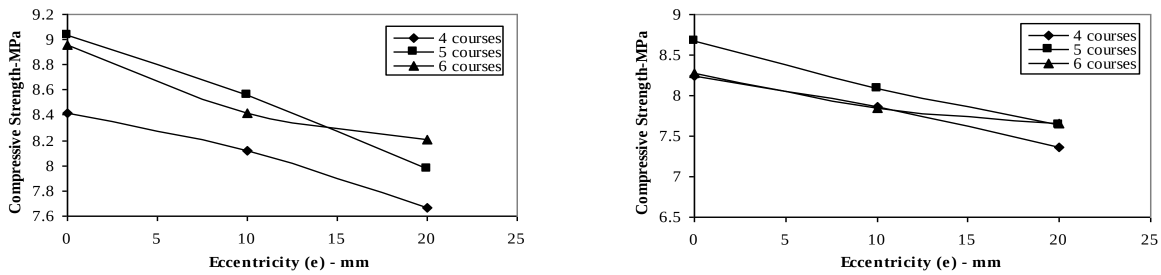


Figure (9) Variation of compressive strength of prism with eccentricity of 1:3 cement mortar

3-4-4 Number of Courses

The effect of the number of courses varying from 4 to 6 and having a suitable value for quality control test for the compressive strength of clay brick prism is also studied and shown in **Table (4)**. The results indicate that, for different types of mortar used and different applied point loads, the compressive strength of clay brick prism does not vary significantly for 4 to 6 courses height. This may be attributed to the non uniform compressive strength of clay brick. These results are in agreement with those obtained by Annamalait et. al. [11].

3-5 Compressive Strength and Stress-Strain Relationship of Clay Brick Wall

The wall specimen was tested to failure and the details of test results are given in **Table (4)**. It is clear that the compressive strength of the wall is lower than the compressive strength of clay brick greatly, where the compressive strength of wall was (4.12 MPa) while the compressive strength of clay brick when tested individually was (18.1 MPa). This is because of the difference between strain characteristics of the brick and mortar joints [10].

To compare the experimental values of the ultimate strength of the wall with predicted values, there are numerous empirical formulas that have been suggested. One of the better known formulas is that of Hilsdorf [12] which has the following general form:

$$f_u = \frac{f_b}{U}\left(\frac{4.1f_{bt} + \alpha f_m}{4.1f_{bt} + \alpha f_b}\right) \quad \text{.......... (1)}$$

where:

f_u = ultimate compressive strength of wall (MPa).

f_b = ultimate compressive strength of masonry unit (MPa).

f_m = uniaxial compressive strength of mortar (MPa).

f_{bt} = tensile strength of masonry unit ($\frac{f_b}{30}$) (MPa).

U = non-uniformity factor value ranges between 1.1-2.5 (assumed 2.5 in this study)

α = ratio of mortar thickness to brick height (=0.13).

From the test on masonry walls using different masonry units conducted at the building research center by Al-Ani and others [13], some empirical formulae were suggested. These formulae are given in the following general form:

$$f_u = \alpha_b . \alpha_s . \alpha_e . \alpha_m . \alpha_w . \sqrt{f_b} \quad \text{.......... (2)}$$

where:

$\alpha_{b.s.e.\,m\,.\,w}$ are the effect of masonry unit strength, slenderness, eccentricity of loading, mortar type, and wetness on wall strength respectively.

Based on the height/thickness ratio and on the types of mortar and masonry unit used in this study, the following values were used for the coefficients and parameters: α_b=0.695, α_e=1, α_m=1, α_w=1. While the value of α_s, is based on the recommended value listed in Ref.(13).

From a comparison between the experimental results and the predicated values using equations (1 and 2), it is clear that equation (1) generally over estimates the strength of the wall because the coefficients included in them are based on results of tests on clay bricks of higher strength than those for the present study, while the empirical formulae of equation (2) appear to be most approximately similar to the prediction of wall strength.

Typical strain variation along the height of specimen is shown in **Fig.(10)** and the average longitudinal strain is shown in **Fig.(11)**.

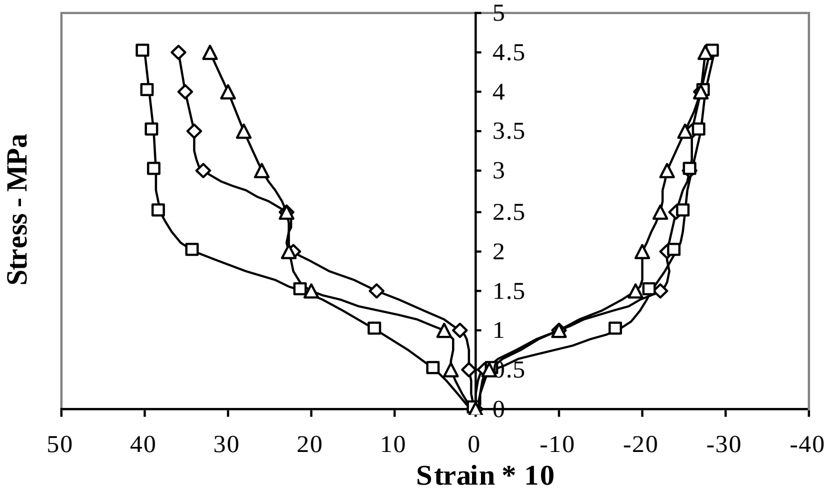


Figure (10) Stress-strain relationship for clay brick wall

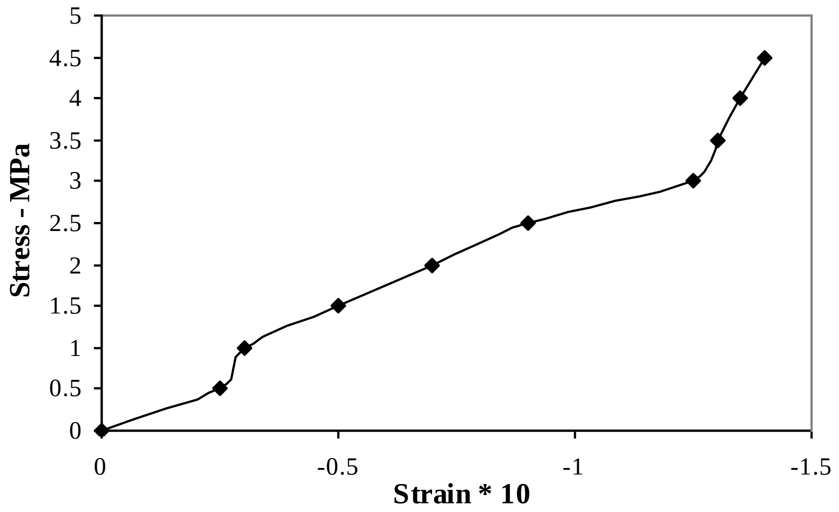


Figure (11) Longitudinal strain for clay brick wall

4. Conclusions

From the experimental results obtained, the following conclusions can be drawn:

1. The results of the chemical analysis for hydrated cement indicate a noticeable increase in loss on ignition and the mineralogical analysis by x-ray diffraction shows that, there is a significant amount of unhydrated (C_2S).

2. For 1:2 and 1:3 mortar mixes of standard consistency, the optimum percentage of hydrated cement that can be replaced by weight of cement is 30%, which can be made with no significant change in compressive strength at 180 days compared with control mix.

3. The higher the percentage of hydrated cement, the higher are the volume change characteristics compared with those of the corresponding plain mixes. However, the percentage increase in drying shrinkage and swelling of mortar at age of 180 days seems to be within the limit.

4. The load carrying capacity of prisms built from bricks with 1:2 and 1:3 cement-hydrated cement mortars is convergent with the load carrying capacity of prisms built with ordinary cement mortar, and binding mortar with higher strength produces brick wall with higher load carrying capacity.

5. The compressive strength of clay brick prisms built from bricks with 1:2 and 1:3 cement-hydrated cement mortar dose not vary significantly for four to six courses high in spite of different types of mortar and eccentricity.

6. The empirical formulae of equation (2) appear to be most appropriate for the prediction of strength of the wall that contains hydrated cement.

7. It is possible to use cement-hydrated cement mortar as a binding material for brick wall construction.

5. References

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