Eng. & Tech. Journal, Vol.28, No.13, 2010

Effect of Masonry Units Type and Concrete Grouting on Compressive Strength of Prisms

Ali A. Jaber*

Received on: 25/11/2009
Accepted on: 6/5/2010

Abstract

Masonry is a well proven building material possessing excellent properties in terms of appearance, durability and cost in comparison with alternatives. However, the quality of the masonry in a building depends on the materials used, and hence all masonry materials must conform to certain minimum standards. The basic components of masonry are block, brick and mortar, the latter being in itself a composite of cement, lime and sand.

Two types of masonry units (brick and concrete block) were used to construct the prism and some of them were grouted by concrete. The uniaxial compressive strength test was done and stress-strain behavior has been obtained. Using linear regression analysis, a simple empirical equation has been proposed for obtaining the compressive strength for masonry that can be used in the analysis and design procedures.

Keywords: Brick, concrete block, mortar, grout, masonry prism.

تأثير نوع وحدات البناء وخرسانة الحقن على مقاومة انضغاط مواشير البناء

الخلاصة

ان البناء بالطابوق والكتل الخرسانية المجوفة أثبتَ بانه مادة إنشائية تَمتلكُ خواص جيدة من ناحية المظهر، المتانة وكلفتها القليلة لعدم احتياجها الى خبرة كبيرة للتشييد بالمقارنة بالبدائل.
ان أداء البناءِ في اي منشأ يعتمد على الموادِ المستعملة وان مواد البناءِ يجب أن تتوافق مع المواصفات والمعايير الدنيا لمواصفات القطر. إنّ المواد الاولية للبناءِ هي الطابوق الطيني والكتل الخرسانية ومونة البناء كمادة رابطة. المادة الرابطة تتكون من سمنت ورمل والنورة.
تم تشييد مواشيرالبناء باستخدام نوعين من وحدات البناء (الطابوق والكتل الخرسانية المجوفة) وكذلك حقن قسم منها بالخرسانة. تم فحص مقاومة انضغاط المواشير تحت احمال مركزية محورية ورسمت علاقة الاجهاد والانفعال واحتساب معامل المرونة الساكن.
ومن ملاحظة نتائج هذه الفحوصات والاطلاع على دراساتِ سابقة وبإستعمال تحليل الإنحدار الخطي البسيط اقترحت معادلة تطبيقية بسيطة لحساب مقاومة انضغاط المواشيرَ لتستخدم في التصميم والتحليل.

*Building & Construction Engineering Department, University of Technology/ Baghdad

1. Introduction

Clay bricks have always been and will remain for the foreseeable future as the main building material in Iraq. But with the advent of other types of building materials and masonry units, notably, hollow concrete blocks that were introduced into the country over 60 years ago there is a growing interest in the new types of materials as acceptable and possibly more economical alternatives to clay bricks. To select the appropriate type of material for construction, reliable information about the strength and behavior of each type of masonry unit need to be made available to engineers and all those concerned with the construction industry [3]. Extensive studies have been conducted about the properties and strength of each types of masonry units notably that by Sahlin [4] and others [5, 6 and 7]. The usual material for joining the units is the cement-sand mortar or gypsum mortars which are also subject to variations in strength, thickness, methods of placing and workmanship. It has been recognized that geographical location is also important and the best way to predict the strength of masonry units by testing prisms made by these units [1]. Material modulus of elasticity and stress–strain properties are required in the nonlinear analyses of Structures. Such relationship for masonry units was needed to understand this behavior, however, there are many factories producing these units with different types of material [3&8].

Analysis and design of buildings with masonry units require material properties as strength and modulus of elasticity in the case of linear static analysis and stress–strain curves of masonry for more detailed nonlinear analyses. The object of this research is to describe the properties of the prism constructed by different masonry type (solid and perforated brick as well as concrete block) in which the effect of grouting was included also. In the present comprehensive experimental study, compressive stress–strain relationships for masonry are determined by testing masonry prism specimens constructed using brick and concrete block with and without grouting and one type mortar grades. By regression analysis of experimental data, analytical expressions are proposed to estimate the modulus of elasticity of masonry. An analytical model is proposed to adequately plot the stress–strain curves for masonry. A simplified analytical model is also proposed that can be conveniently used in finite element analysis proposed that can be conveniently used in finite element analysis programs.

2. Factors Influencing the Compressive Strength of Prisms

Prism behavior should reflect as far as possible the masonry to be used in a building. Hence, the prism should be built with similar material units, workmanship, joint thickness, bond pattern, and should be subjected to similar type of curing and failure mode. It was observed that for the strong and stiff units and mortar of lesser but comparable strength and stiffness, the strength of prism do not necessarily fall in between those of units and mortar [2]. The major factors that influence the compressive strength of prism are:

- **Height:** the main object of many investigations on masonry prism is to arrive at a minimum specimen height that represents the strength of the final structure. As prisms are normally tested between steel plates which are much stiffer than masonry, the lateral expansion at the ends of the prisms is restrained by friction. Due to this end restraint, the specimens will fail by shear rather than tensile spitting as evidenced in a few cases of storey-height walls tested under axial compression. It has long been established in the case of clay brickwork that the effect of platen restraint diminishes as the height of test specimen increases [9]. The minimum height prescribed by the various codes varies from 300 mm to 400 mm. Shorter prisms are desirable due to height limitations in the test machines and handling difficulties. A reduction factor must be applied in the case of prisms shorter than the prescribed standard heights. In this research available material in Iraq were used with constant h/t to get the correction factor for height.
- **Number of courses:** there should be enough courses to allow adequate representation of the interaction of mortar and masonry unit [9]. In the case of standard clay brick masonry, the number of mortar joints is more for the same height of prisms than that made of higher units such as concrete blocks. Four courses for brick work while for concrete block three course were used in this research.
- **Capping:** the capping material between the prisms and the steel plates can also affect the prism strength. Capping ensures a uniform distribution of the load to the prism and reduces the platen restraint. The common capping recommended is given in [9]. If the top and bottom of the prism are single units they can be ground flat or fiber board or plywood sheet can be used if the unit has a flat surface. Soft materials such as mortar, dental plaster or sulphur can be used for capping together with fiber board or plywood sheets. It was used plywood sheet to test the prism in this research.
- **Test age:** the standard test age is 28 days [17]. However, in many cases, shorter periods would be convenient if prisms are used for site qua1ity control.
- **Loading rate:** loading rates, usually specified in terms of load as opposed to strain, range from 2.5 N/mm^2 to 28 N/mm^2 per minute. This range of loading has not been shown to have significant effect on the ultimate strength. The method of load control may cause differences in the

ultimate strength. Some standards require that the rate of loading control should not be altered near failure even though the loading rate is falling [11].

3. The Experimental Work

All the experimental works were achieved and tested in Al Technology university laboratory

3.1 Materials

Ø Cement

Ordinary Portland cement type (I) manufactured by Tassloja cement factory was used in all mixes in this research. The chemical composition and physical properties of the ordinary Portland cement are listed in Tables (1) and (2) respectively. The cement conforms to the Iraqi specification No.5/1984.

Ø Fine Aggregate

Natural sand brought from Al-Ukhider region was used as a fine aggregate in this research. Table (3) shows the grading of sand used in this work. The grading of sand is conformed to the requirement of the Iraqi specification No.45/1984 zone (3).The chemical and physical properties of sand are shown in Table (4).

Ø Coarse Aggregate

Crushed gravel with (10 mm) maximum size brought from Al-Nebai region is used in this work. Table (5) shows the grading of sand used in this work. The grading of sand is conformed to the requirement of the Iraqi specification No.45/1984 .The chemical and physical properties of sand are shown in Table (6).

Ø Clay Bricks

The clay bricks were brought from 17 July Factory located near Baghdad. A randomly 10 samples of bricks was taken from the batch to conduct the standards tests on bricks according to the Iraqi Specification No.24/1988 as indicated in Table (7). The average dimensions, compressive strength, percentage of absorption and efflorescence tests were carried out to assess the quality of bricks used throughout this study. The results of the brick can be classified according to the Iraqi specification No.25/1986 as class B.

Ø Concrete Blocks

The concrete brocks were brought from Abo Kreeb Company located near Baghdad. A randomly 3 sample of blocks was taken from the batch to conduct the standards tests according to the Iraqi Specification No. 1077/1987 as indicated in Table (7). The average dimensions, mean compressive strength and percentage of absorption tests were carried to assess the quality of concrete block used throughout this study. The results of the concrete block can be classified according to the Iraqi specification No.1077/1987 as hollow concrete block class A.

Ø Water

Ordinary tap water was used in this investigation for mixing and curing requirements.

3.2 Test Specimens

Ø Mortar

Mortar is the binding element, its quality consistency; strength and thickness have direct effect on the structural strength of masonry walls. The primary function of mortar is to develop a strong and durable interlock between brick [4]. Local materials were used in preparation of the mortar of masonry prisms. Three cubes 50×50×50 mm were cast according to the ASTM C109/C109M-05 [12] using 1:3 (cement: sand) with 0.74 w/c ratio, cured and tested at 28 days for compressive strength as indicted in Table (8). The specimens prepared and all mortars mixed were used within one hour after mixing.

- **Grout**

Fluid concrete grout having nearly the same strength of units used to build the prism was used for filling the cavities between the two wythes of each of the composite prisms [8]. Mix proportions were done to get the compressive strength as possible as the units. Three cubes 150×150×150 mm were cast according to the ASTM C144-04 [14] using 1:1.75:2.6 (cement: sand: gravel) with 0.56 w/c ratio, cured and tested at 28 days for compressive strength as indicated in Table (8) .

3.3 Constructing of Prism

The prism specimens were built first by preparing a plan layer of 10mm mortar and then lay the units in between the mortar joints and ending by mortar layer too with dimension as shown in Table (8). The specimens were covered with wet burlap for insuring the hydration process treated and spraying them with water continuously for 7 days, and then the grouted prism were filled with workable concrete and cured for other 7 days. Compaction of concrete was done using hand steel rod, while the empty ones were left in laboratory conditions until testing time ACI committee 531.1-86[15].

4. Experimental Tests

4.1 Strength of Masonry (Units, Mortar, Grout and Prisms):

Average results of dimension and compressive strength for ten for clay brick and three for hollow concrete block *(f_b)* were tested according to ASTM C140-05a [16] and listed on Table (7). Average of three cubes for mortar (the difference in result of present specimens due to different time of cast and laboratory conditions) (f_j) and grout compressive strength (f_g) was recorded in Table (8). Masonry prisms were constructed using combinations of brick and mortar layers and stress-strain curves were obtained by averaging the data from three specimens of each combination. Approximate height of four-brick high masonry prism with 10 mm thick mortar joints was about 400 mm. Compression testing was done following ASTM C1314-03b [13].

Relation between strength of masonry units and prism were shown in Fig (1), in which the prism strength was almost less than the unit and mortar. The stress-strain curves for masonry prisms are shown in Fig (2) and the summary of results including prism are given in Table (8). ELE digital testing machine with a capacity of 2000 kN was used to determine the compressive strength of prism specimens and the values are listed in Table (8).

Failure of the majority of the prism specimens was due to the formation of vertical splitting cracks along their height. It's of about 10–20% of specimens in each set took place because of crushing of a weaker brick in the prism or bond failure by flexural bending of specimens, probably due to "poor" alignment of the specimen with the loading. The stress- strain curve was found to be linear for up to about one-third of prism strength after (*f'm*) which cracks began to form in the bricks introducing the nonlinearity. Concrete block prisms behaves the same as brick prism but the compressive strength was weaker than brick prisms, due to difference in size of unit and height. The stress strain relations of concrete block prisms were indicated in Fig (3).

Modulus of elasticity (*Em*) was ranged from (192 to 1736.6 *f'm*) as shown in Table (8), and an average value was proposed. The Canadian masonry code S304.1 CSA 2004 recommends *Em* as 850 times *fm* with an upper limit of 20,000 depending on experimental results which were coinciding with our results. The propped equation as:

$$Em = 850\, f'_m$$

4.2 Estimation of Prism Strength of Masonry

Researches were achieved to calculate masonry prisms strength and simple empirical relation between the units, mortar, grout and prism strength was adopted [3]. *f'm* is the intrinsic property of masonry which can be used in the design of a variety of masonry elements, particularly the walls. *f'm* is also used to estimate *Em* and for plotting the masonry stress-strain curves. Therefore, *f'm* is one of the most basic and required properties that must always be available for a given masonry. However, it is not always feasible to conduct compression testing of masonry prisms. On the other hand, f_b , f_j and f_g are readily available in the design codes or can be obtained easily by conducting tests. The three compressive strengths can be conveniently related as done in Eurocode6 CEN 1996[2] as:

$$f'm = K f_b^{\alpha} f_j^{\beta}$$

Where *K*, α and β = constants. In addition, a few other factors have also been specified which take care of size and shape of bricks, dry strength of brick, "normalized" strength of bricks, etc.

As already discussed, *f'm* does not depend upon the mortar and grout strength as much as it does on the units strength, therefore α must be higher than β. In Eurocode6 CEN 1996, the values of α and β have been specified as 0.65 and 0.25, respectively, and *K* varies from 0.4 to 0.6 depending upon units properties and units –mortar joint configuration. These values of α and β are valid for mortar having compressive strength not more than 20 MPa or two times f_b, *whichever* is less. Then the empirical equation was [2]:

$$f'm = 0.63 f_b^{0.49} f_j^{0.32} \qquad R^2 = 0.93, \sigma = 0.48\, MPa$$

$$R^2 = 1 - \frac{\sum (f_i - \hat{f}_{Ri})^2}{\sum (f_i - \bar{f})^2}$$

$$\sigma = \sqrt{\frac{\sum (f_i - \hat{f}_{Ri})^2}{n - 3}}$$

where f_i and $\hat{f}_{Ri}$ = *i*th experimentally obtained and regression estimated prism strength, respectively, $\bar{f}$ = mean of the experimentally obtained prism strengths; and n = total number of data points. The divisor (n −3) is used in rather than n in order to make an unbiased estimation of since three estimators K, α and β are required in the calculation. The same equation was used to calculate compressive strength of masonry prisms as shown in Table (9).

For grouted masonry the effect of grout was taken and the equation became:

$$f'm = K f_b^{\alpha} f_j^{\beta} + K_1 f_g^{\gamma}$$

In which the grout strength was included f_g^{γ}, K_1 *and* γ are constants, γ ranges from 0.4- 0.5 and K_1 varies from 0.4 to o.6. Depending on the experimental results and regression analysis the following equation was proposed for estimation of masonry compressive strength is:

$$f'm = 0.63 f_b^{0.49} f_j^{0.32} + o.5 f_g^{0.5}$$

The theoretical results using proposed equation were indicated in Table (3) the differences were ranging from (0.88 to 2.59)

5. Conclusions

Uniaxial compressive testing of masonry prisms was conducted using two different bricks and concrete block. Based on experimental observations, modulus of elasticity of masonry is found to vary and an average value of 850 times the prism strength is proposed. The compressive strength of masonry was found to increase with the compressive strength of bricks and mortar. With concrete grout the compressive strength of prisms was increased about (17-21) %.

Increasing the height of prisms indicated reduction in compressive strength about 30 %.

Stress-strain curves for grouted **and hollow prisms behave the same, and an empirical equation was proposed, which gave good** results so the different was between (12-30) %.

6. References

[1]A.W.Hendry, B.P.Sinha and S.R.Davies "**Design of Masonary Structures**", 3rd Edition of Load Bearing Brickwork Design, Department of Civil Engineering, University of Edinburgh, UK, 2004, pp.22.

[2]Hemant B. Kaushik, Durgesh C. Rai and Sudhir K. Jain, M.ASCE "**Stress-Strain Characteristics of Clay Brick Masonry under Uniaxial Compression**" Journal of Materials in Civil Engineering, September 2007, pp. 728-739.

[3]Hashim M. Said, "**The Structural Behavior of Axially Loaded Masonry Short Wall of Different Materials**", Research Report, Building Research Center, Baghdad, Vol. 5, No.2, 1986, pp. 65-85.

[4]Sahlin, S., "**Structural Masonry**", Prentice - Hall, 1971 .

[5]Hamid, A. A. and Drysdale, "**Suggested Failure Criteria for Grouted Concrete Masonry Under Axial Compression**", ACI Journal, Vol. 76, No.10, Oct.1979.

[6]Cranston, W. B. and Roberts, J. J. ,"**The Structural Behavior of Concrete Masonry-Reinforced and Unreinforced**", The Structural Engineer, No. 11, Vol. 54, Nov. 1976.

[7]Hatzinikolas, M., Longworth, J. and Warwaruk, J., "**Failure Modes for Eccentrically Loaded Concrete Block Masonary Walls**", ACI Journal, No. 4, Vol. 77, July/August 1980.

[8]El-Katib, M. T., Amso, N. N., Haider, A. A., "**Stress-Strain Relationships of Brick-Concrete Masonary Beams**", Journal of Building Research, Building Research Center, Baghdad, Vol. 4, Part 2, October 1989.

[9]G. Annamalait, R. Jayaraman and A. G. Madhava Rao, "**Investigation on Prism Tests for the Compressive Strength of Solid and Perforated wire-cut Brick Masonry Walls**", Structural Engineering Research Center, CSIR Campus Madras 20, India, 1981, pp. 156-166.

[10] Korkees, A. N., "**Behavior of Grouted Hollow Block Masonry Reinforced Columns Subjected to Eccentric and Concentric Axial Loading**", M.Sc Thesis, University of Technology, Baghdad, Nov.1998

[11] Canadian Standard Association, CSA Standard S304-1977, "**Masonry Design and Construction for Buildings**"

[12] ASTM C109/C109M-05, "**Standard Test for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)**", Annual Book of ASTM standard, Vol. 04.01, CS04, 2005

[13] ASTM C1314-03b. **"Standard Test method for compressive strength of masonry prisms."** Annual Book of ASTM standard, Vol. 04.05, CS04, 2003

[14] ASTM C144-04 **"Standard Specification for Aggregate for Masonry Mortar"** Annual Book of ASTM standard, Vol. 04.05, CS04, 2004

[15] ACI Committee 531.1-86 **"Building Code Requirements for Concrete Masonry Structure"**, ACI Manual of Concrete Practice 1986, Part 5, ACI, Redford Station, Detroit, Michigan, 48219, U.S.A.

[16] ASTM C140-05a **"Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units"** Annual Book of ASTM standard, Vol. 04.05, CS04, 2005

[17]ASTM C 1314-03a **"Standard Test method for compressive strength of masonry prisms."** In Masonry Test Methods and Specifications for the Building Industry Annual Book of ASTM standard, Vol. 04.05, CS04, 2003

Table (1) Chemical Composition and Main Compounds of Ordinary Portland cement

Oxides Composition	% By Weight	Limits of Iraqi Specification No.5/1984
CaO	63.22	-
SiO_2	20.11	-
Al_2O_3	5.53	-
Fe_2O_3	3.40	-
MgO	3.74	< 5.00
SO_3	1.61	< 2.81
Lose on Ignition	0.74	< 4.00
Insoluble Residue	1.23	< 1.50
Lime Saturation Factor	0.86	0.66-1.02
Main Compounds (Bogues Equations)	% By Weight of Cement	Limits of Iraqi Specification No.5/1984
C3S	57.73	-
C2S	14.21	-
C3A	8.91	> 5.00
C4AF	10.33	-

Table (2) Physical Properties of Ordinary Portland Cement

Physical Properties	Test Result	Limits of Iraqi Specification No.5/1984
Setting time (Vicate apparatus), Initial setting, h:min Final setting, h:min	1:25 2:47	≥ 01:00 ≤ 10:00
Compressive strength, N/mm² 3-day 7-day	19.6 27.8	≥ 15.00 ≥ 23.00
Soundness Le Chatelier method, mm	1	≤ 10

Table (3) Grading of Fine Aggregate

Sieve Size (mm)	% Passing by Weight	Limits of the Iraqi specification No.45/1984 (Zone 3)
10	100	100
4.75	92	90-100
2.36	86	85-100
1.18	77	75-100
0.6	62	60-79
0.3	18.2	12-40
0.15	6.4	0-10

Table (4) Chemical and Physical Properties of Fine Aggregate

Physical Properties	Test Results	Limits of the Iraqi specification No.45/1984
Specific Gravity	2.6	---
Sulfate	0.08	< 0.5 %
Absorption	0.75	---

Table (5) Grading of Coarse Aggregate

Sieve Size (mm)	% Passing by Weight	Limits of the Iraqi specification No.45/1984 max. size 10 mm
14	100	100
10	89	85-100
5	14	0-25
2.36	2.3	0-5

Table (6) Chemical and Physical Properties of Coarse Aggregate

Physical Properties	Test Results	Limits of the Iraqi specification No.45/1984
Specific Gravity	2.61	---
Sulfate	0.075	< 0.5 %
Absorption	0.77	---

Table (7) Dimensions and Strength of Masonry Units

Research	Type of Units	Units Identification	Dimensions-mm			(f_b) Compressive Strength-MPa
			Length	Width	Height	
Present	Clay Brick	Perforated	243	115	74.3	18.1
Present	Concrete Block	Hollow	399.5	198.8	19.8	17.8
Present	Concrete Block	Grout	399.5	198.8	19.8	17.8
G. Annamalait[9]	Clay Brick	Perforated	230	110	75	13.2
G. Annamalait[9]	Clay Brick	Solid	230	110	75	13.7
El – Katib[8]	Clay Brick	Perforated	238.8	111.5	74.3	15.8
El – Katib[8]	Clay Brick	Solid	226.5	112	67	19.34
Korkess[10]	Concrete Block	Hollow	398.4	198.6	192.8	18.42
Korkess[10]	Concrete Block	Grout	398.4	198.6	192.8	18.42

Table (8) Prism specimen's Details and strength of binding and grout material

Research	Prism Dimension - mm			H/D*	(f_j) Mortar Strength (MPa)	(f_g) Grout Strength (MPa)	(f_p) Prism Strength (MPa)	Modulus of Elasticity** (MPa)
	Length	Width	Height					
Present	243	243	367	1.51	25.6	---	8.42	237f'm
Present	399.5	198.8	640	3.2	20.7	---	7.65	313f'm
Present	399.5	198.8	640	3.2	20.7	20.3	9.23	192f'm
G. Annamalait[9]	230	230	370	1.61	20.6	---	6.04	1736.6f'm
G. Annamalait[9]	230	230	370	1.61	20.6	---	5.87	670f'$_P$
El – Katib[8]	319	239.2	346.8	1.45	21.2	26.1	18.55	1395.6f'$_P$
El – Katib[8]	320	230.7	339.2	1.47	21.2	26.1	13.71	1509.8f'$_P$
Korkess[10]	398.4	198.6	640	3.22	14.4	---	7.32	1329.5f'$_P$
Korkess[10]	398.4	198.6	640	3.22	14.4	21.5	8.9	1623f'$_P$

* Ratio of height to prism width. **Modulus of elasticity was calculated at one third of prism strength.

Table (9) Comparison between Experimental and Theoretical Results on Masonry Prisms

Research	(f_b) Units Strength (MPa)	(f_j) Mortar Strength (MPa)	(f_g) Grout Strength (MPa)	($f'm$) Experimental MPa	(f'_m) Theoretical MPa	($f'm$) Experimental/ (f'_m) Theoretical
Present	18.1	25.6	---	8.42	8.35	1.02
Present	17.8	20.7	---	7.65	7.81	1.08
Present	17.8	20.7	20.3	9.23	9.93	1.24
G. Annamalait[9]	13.2	20.6	---	6.04	6.87	0.88
G. Annamalait[9]	13.7	20.6	---	5.87	6.98	0.92
El – Katib[8]	15.8	21.2	26.1	12.36	7.47	1.65
El – Katib[8]	19.34	21.2	26.1	9.14	8.15	1.12
Korkess[10]	18.42	14.4	---	7.32	7.17	1.11
Korkess[10]	18.42	14.4	21.5	8.9	9.32	1.305

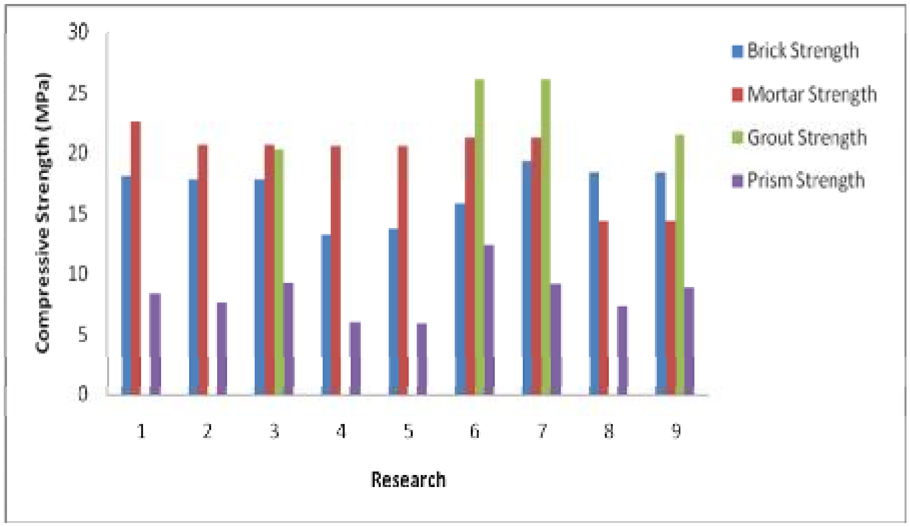

Figure (1) Strength of Masonry Units, Mortar , Grout and Prism

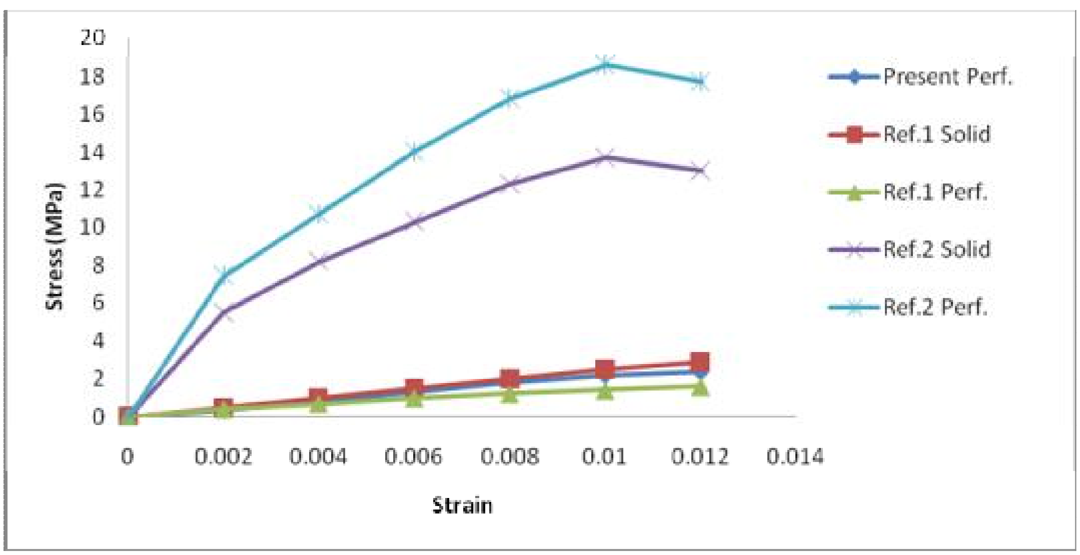

Figure (2) Stress-Strain Relationship for Brick Prism

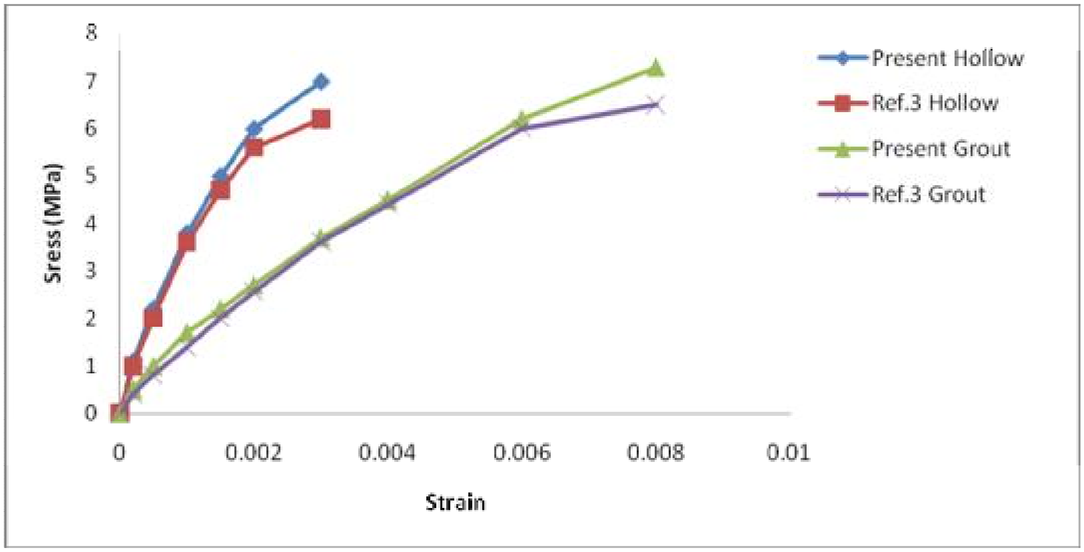

Figure (3) Stress-Strain Relationship for Concrete Block Prism