Experimental studies on the structural characteristics of masonry and masonry Materials

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Abstract- *An attempt is made to investigate the performance of different materials used for the construction of brick masonry to check their suitability in the construction. Bricks from two different units have been collected and after conducting various tests like rate of moisture absorption, compressive strength in dry as well as wet state, prism compressive strength test, shear bond strength test, etc., suitability of using the same in construction has been verified. Cement Mortars of different mix proportions like 1:4 and 1:6 have been tested for flow value and compressive strength to know about the workability of mortars and also strength. Stack bonded masonry prisms of suitable dimensions have been constructed to study the masonry compressive strength. Shear bond strength is tested using three bricks with suitable mortar proportions.*

Keywords- Bricks, masonry, shear bond, prism strength

I. INTRODUCTION

Now a day's masonry works are being carried out in some of the places without knowing the properties of materials used in masonry and also the strength of masonry. The present work has been initiated to know the detailed information about masonry and masonry materials.

Masonry is the building of structures from individual units laid in and bound together by mortar; the term masonry can also refer to the units themselves. The common materials of masonry construction are brick, building stone such as marble, granite, travertine, and limestone, cast stone, concrete block, glass block and cube. Masonry is generally a highly durable form of construction. However, the materials used, the quality of the mortar and workmanship, and the pattern in which the units are assembled can significantly affect the durability of the overall masonry construction.

Burnt clay bricks are widely used for load bearing masonry in India. There is wide variation in the characteristics of commonly used bricks from different geographical locations of the country. At present, the commonly available varieties of bricks in India can be grouped into 3 categories, that are: country bricks, table moulded bricks, and wire cut bricks.

Burnt bricks have been used in South Asia for more than 4000 years. The discovery of the archaeological sites of Harappa and Mohenjo-Daro (Pakistan) in 1921 revealed the great antiquity of brick use in south Asia. Later, a large number of Harappan sites were found in places like Lothal and Kalibangan (India) showing the extensive spread of brick culture in northern parts of south Asia. Bricks of various sizes were used and English bond mode of wall construction was known to the Harappan culture. This civilisation came to sudden end around 1500 B.C. Apparently, brick making also seems to have vanished at that point of time. Bricks making seems to have re-emerged around 600 B.C. at Kaushambi (near modem Allahabad) as it was used extensively for retaining a mud brick platform. Burnt brick has been continuously used since then for a variety of construction in India.

Brick masonry is made of brick units bonded together with mortar. Masonry work is one of the major building crafts and one of the oldest technologies. It is normally used for construction of foundations, walls, columns and other similar structural components of buildings. The basic advantage of masonry construction lies in the fact that in load bearing structures it performs variety of functions such as supporting load, sub-dividing space on affording fire and weather protection etc. Brick masonry prisms have also been constructed to study the load carrying capacity.

II. LITERATURE REVIEW

Review of literature regarding the properties of bricks, mortar and masonry has been studied in detail and these information are very much useful in the present work for the comparison purpose.

Dayaratnam, Ranganathan and others (1981) studied number of aspects of brick masonry like compressive strength of brick masonry, peak compressive and tensile strain of masonry, tensile bond strength between brick and mortar and the modulus of elasticity of masonry were studied. Later they studied the strength of reinforced brick masonry slabs through experiments. Bricks in Chidambaram were studied by Elangonmani in 1983 for their properties and for strength

characteristics of masonry prisms using different mortars. Prism strengths have been studied for various prism heights and for four mortars. Dayaratnam authored the first book on brick masonry in India.

Ganesh B. Mogaveer(2009) has carried out detailed investigation on studies on laterite block units and also laterite block masonry studies like water transportation study, prism compressive strength and shear bond strength study.

G. Sarangapani, B.V. Venkataramana Reddy and K.S. Jagadish have carried out experiments to understand the nature of stresses developed in the mortar joint and brick in the masonry. The results reveal that the bricks around Bangalore have rather low module compared to cement mortar. The brick modulus is in the range of about 5 to 10% of the modulus of 1: 6 cement mortars. This kind of situation leads to a masonry where mortar joints develop lateral tension while brick develops lateral compression (triaxial) and this is an unfavourable situation due to the brittle nature of mortar**.**

Jahangir Bakhteri numerically verified the results of experimental investigations on the effect of mortar joint thickness on compressive strength characteristics of axially loaded brick mortar prisms. Composite material model gave more accurate prediction of the stress distribution in the prisms and hence this model is more appropriate than the homogenous material model.

III. EXPERIMENTAL INVESTIGATIONS

In the experimental investigation, an attempt has been made to study the properties of various materials and also strength parameters on brick and brick masonry for the bricks collected from two different manufacturing units and also 1:4 cement mortar and 1:6 cement mortar is studied.

3.1 TESTS ON BRICKS

3.11 Water Absorption Test

The aim of the test is to determine the percentage of water absorption of brick. A sensitive balance capable of weighing within 0.1% of the mass of the specimen and ventilated oven. Three numbers of whole bricks from samples collected for testing should be taken. Dry the specimen in a ventilated oven at a temperature of 105°C to 115°C till it attains substantially constant mass. Cool the specimen to room temperature and obtain its weight (M1) specimen too warm to touch shall not be used for this purpose. Immerse completely dried specimen in clean water at a temperature of 27+2°C for 24 hours. Remove the specimen and wipe out any traces of water with damp cloth and weigh the specimen after it has been removed from water (M2).Water absorption, % by mass, after 24 hours immersion in cold water in given by the formula,

$$W = \frac{M_2 - M_1}{M_1} X\ 100$$

Plate 1 Bricks soaked in water for Water Absorption test

3.12 Compressive Strength Test on Bricks

To determine the compressive strength of brick Compression testing machine, the compression plate of which shall have ball seating in the form of portion of a sphere centre of which coincides with the centre of the plate. Three numbers of whole bricks from sample collected should be taken. The dimensions should be measured to the nearest 1m. Remove unevenness observed the bed faces to provide two smooth parallel faces by grinding. Immerse in water at room temperature for 24 hours .Remove the specimen and drain out any surplus moisture at room temperature. Fill the frog and all voids in the bed faces flush with cement mortar (1 cement, 1 clean coarse sand of grade 3mm and down). Store it under the damp jute bags for 24 hours filled by immersion in clean water for 3 days. Remove and wipe out any traces of moisture. Place the specimen with flat face as horizontal and mortar filled face facing upwards between plates of the testing machine. Apply load axially at a uniform rate of 14 N/mm² (140 kg/cm²) per minute till failure occurs and note maximum load at failure. The load at failure is maximum load at which the specimen fails to produce any further increase in the indicator reading on the testing machine.

3.2 TESTS ON MORTARS

Different tests conducted on mortars of different proportions are as follows.

3.21 Flow Test

The flow table test or flow test is a method to determine consistency of fresh concrete. Application when

fresh concrete is delivered to a site by a truck mixer, its consistency needs to be checked before it is poured into formwork. If consistency is not at the desired level, concrete will not have the required strength and other qualities once it has set. If concrete is too pasty, cavities may form within it. Rebar may become corroded, and concrete will crack. Cavities also reduce the concrete strength. Flow table with a grip and a hinge, 70 centimetres (28 inches) square. In the American version of this test, the table is 10 inches (25 cm) diameter per ASTM C 230. Abrams cone, open at the top and at the bottom - 30 centimetres (12 inches) high, 17 centimetres (6.7 inches) top diameter, 25 centimetres (9.8 inches) base diameter. Water bucket and broom to wet the flow table. Tamping rod, 60 centimetres (24 inches) long. The flow table is wetted. The cone is placed in the centre of the flow table and filled with fresh concrete in two equal layers. Each layer is tamped 10 times with a tamping rod. Wait 30 seconds before lifting the cone. The cone is lifted, allowing the concrete to flow. The flow table is then lifted up 40mm and then dropped 15 times, causing the concrete to flow. After this the diameter of the concrete is measured.

Plate 2. Flow Table test

3.32 Cube Compressive Test

To find the compressive strength of standard cement sand mortar cubes. 7.06cm cubes moulds (50cm^2 face area), apparatus for gauging and mixing mortar, vibrator, compression testing machine etc are used.

Mix the cement and sand in dry condition with a trowel for 1minitues and then add water. The quantity of water shall be (p/4+3)% of combined weight of cement and sand where, p is the % of water required to produce a paste of standard consistency determined earlier. Add water and mix it until the mixture is of uniform colour. The time of mixing shall not be < 3 minutes & not > 4 minutes. Immediately after mixing the mortar, place the mortar in the cube mould and prod with the help of the rod. The mortar shall be prodded 20 times in about 8 sec to ensure elimination of entrained air. If vibrator is used, the period of vibration shall be 2 minutes at the specified speed of 12000±400 vibrations/minutes. Then place the cube moulds in temperature of 27±2^{o}C and 90% relative humidity for 24 hours. After 24 hours remove the cubes from the mould and immediately submerge in clean water till testing. Take out the cubes from water just before testing. Testing should be done on their sides without any packing. The rate of loading should be 350 kg/cm^2/minute and uniform. Test should be conducted for 3 cubes and report the average value as the test result for both 7 days and 28 days' compressive strength.

3.3 TESTS ON MASONRY

Various tests conducted on brick masonry are as follows.

3.31 Prism Compressive Strength

Compressive strength of masonry can be examined by testing five brick high stack bonded masonry prism. Prism were prepared using burnt clay brick having suitable compressive strength (mean value) and using 1:4 and 1:6 cement mortar with sand. Further the compressive strength of the prism made of bricks of different units with different cement mortar is tested under the compression testing machine.

3.32 Shear Bond Strength of Masonry

Shear bond strength of brick masonry has been examined through triplets. A three brick assembly is used to obtain the shear bond strength of brick mortar joints. The arrangement is made in the triplet are in such a way that the shear load can be applied at the middle block. The middle block is free to move in the vertical direction, whereas the end blocks are restrained. The shear bond strength is calculated by using the formula given below.

Shear bond strength = F/2bd

where F = load at failure

b = width of the prism at the plane of failure

d = length of the prism at the plane of failure

A test programme was planned to determine the shear bond strength for different type of masonry with and without pre-compression. Prisms were built using only one type of brick combinations with two different types of mortar mixes. Bond enhancing parameters were also used in some of the cases. The ratio of various materials shown is by weight

(a) 1:4 cement mortar

(b) 1:6 cement mortar

The pre-wetting duration of bricks is 20 minutes for 1:4 cement mortar, where as for 1:6 cement mortar is 10 minutes. A mortar joint thickness of 10mm was maintained for all the cases. The prisms were cured for 28 days by keeping in moist condition under wet burlap. 6 prisms were prepared in each case. All prisms were tested in saturated state. The prisms were soaked in water for 48 hours prior to testing to achieve a saturated state. The compressive normal load was applied to the brick triplets such that the compressive stress could be either 0.1 MPa or 0.3 MPa. These values may be considered to be typical of the vertical stress on any horizontal masonry joint.

IV. RESULTS AND DISCUSSION

4.1 Tests on Bricks

Various test conducted on brick specimens collected from two different manufacturing units namely Type-I and Type-II are discussed below.

Table 1 shows the percentage water absorption by its weight. Table 2 shows the Compressive strength test values in dry state along and across the rift. Table 3shows the Compressive strength test values in wet state along and across the grains.

Table 1.Water absorption test

Sl no.	Unit Name	Water Absorption (%)
1	Type-I	17.35
2	Type-II	16.95

From the above values we can note that the water absorbed by the bricks from the Type-II brick manufacturing unit is comparatively lower than the bricks from the Type-I brick manufacturing unit. The maximum water absorption as per IS: 3495-1992 is 20% of its dry weight and hence both the values are within the permissible limits.

Table 2 Compressive strength test in dry state

Unit Name	Along (MPa)	Across (MPa)
Type-I	13.16	10.63
Type-II	11.67	09.30

From the above table we can note that the compressive strength of the bricks from the Type-I brick manufacturing unit is comparatively higher than the bricks from the Type-II brick manufacturing unit.

Table 3 Compressive strength test in wet state

Unit Name	Along (MPa)	Across (MPa)
Type-I	12.95	10.03
Type-II	11.02	09.03

From the above table we can note that the compressive strength of the bricks from the Type-I brick manufacturing unit is comparatively higher than the bricks from the Type-II brick manufacturing unit.

From the above two tables we can conclude that bricks in dry state have higher compressive strength than that of the wet state. We can also conclude that bricks manufactured from Type-I brick manufacturing unit have higher compressive strength than the bricks manufactured from Type-II brick manufacturing unit.

4.2 Tests on Mortars

In the present investigation cement mortars of two different proportions have been selected. Various tests have been conducted on 1:4 cement mortar and 1:6 cement mortar. The results of tests that have been conducted are discussed below.

Table 4 and Table 5gives the details of the flow test and compressive strength test results conducted for 1:4 cement mortar and 1:6 cement mortar. Figure 1 and figure 3 shows the variation of flow of mortar with the water cement ratio and Figure 2 and Figure 4 shows the variation of compression strength of mortar with the water cement ratio for 1:4 cement mortar and 1:6 cement mortar respectively.

From the results it can be observed that the compressive strength increases as the flow vale increases till certain optimum level. If flow value increases above the optimum level, compressive strength decreases. In general the compressive strength will be maximum when the flow value is between 80-100%. The compressive strength decreases for lesser flow values. The flow value depends on the water cement ratio. Lower the water cement ratio lower is the flow value. For the construction of brick masonry in each type of mortar one which has maximum strength has been used. The water cement ratio corresponding to maximum strength that is water cement ratio of 1.0 for 1:4 cement mortar and 1.2 for 1:6 cement mortar has been used for the preparation of mortar.

Table 4. Tests on 1:4 cement mortar

Sl no.	W/C ratio	Flow percentage	Compressive Strength (MPa)
1	0.6	32.90	5.30
2	0.7	40.17	6.12
3	0.8	84.20	8.36
4	0.9	92.32	8.78
5	1.0	97.45	11.22
6	1.1	105.65	7.88
7	1.2	112.23	3.63
8	1.3	119.16	1.23
9	1.4	124.57	1.02

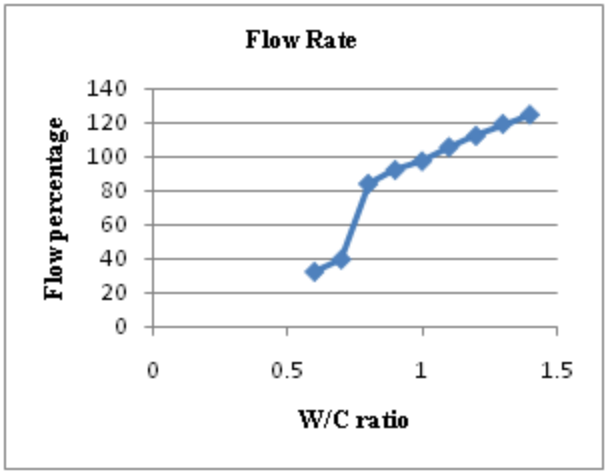

Figure 1 shows the flow rate of 1:4 cement mortar.

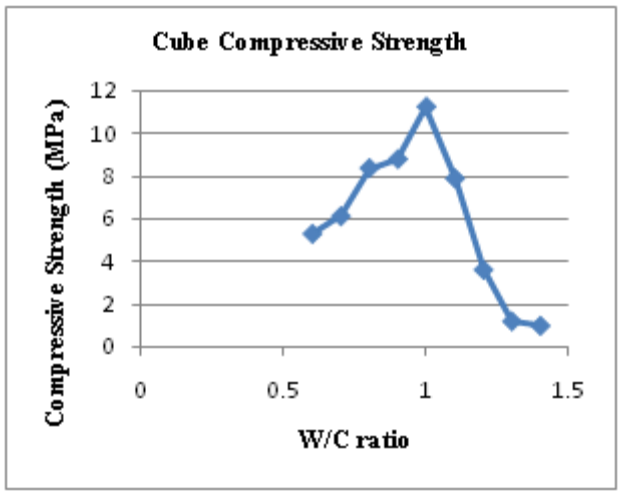

Figure 2 shows the compressive strength of 1:4 cement mortar.

Table 5. Tests on 1:6 cement mortar

Sl no.	W/C ratio	Flow percentage	Compressive Strength (MPa)
1	0.6	44.46	3.27
2	0.7	52.38	4.69
3	0.8	66.43	5.72
4	0.9	72.19	6.73
5	1.0	77.58	6.94
6	1.1	84.72	7.76
7	1.2	92.52	8.98
8	1.3	105.39	4.28
9	1.4	112.42	2.04

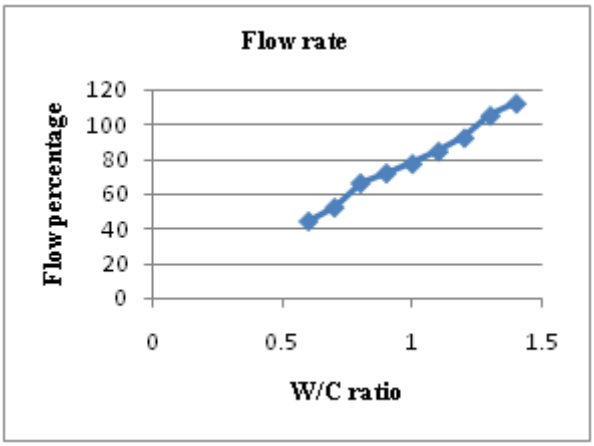

Figure 3 shows the flow rate of 1:6 cement mortar.

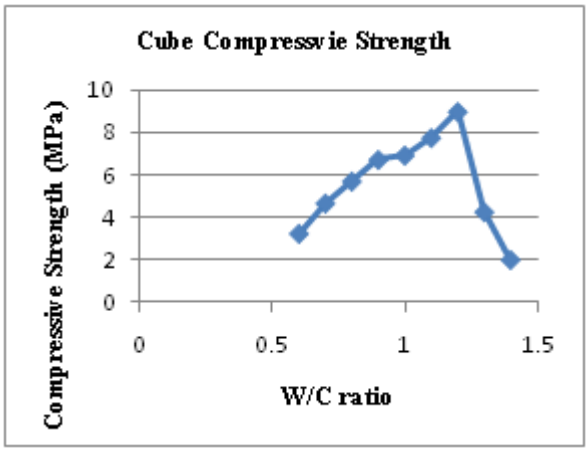

Figure 4 shows the compressive strength of 1:6 cement mortar.

4.3 TESTS ON MASONRY

Several tests have been conducted on brick masonry by using 1:4 cement mortar and 1:6 cement mortar. The results of the tests have been listed below.

4.31 Masonry Prism Compressive Strength Test

The test program consisting of determining the compressive strength of brick masonry using different types of mortars.

Table 6 and Table 7 shows the prism compressive strength of 1:4 cement mortars and 1:6 cement mortar of Punja brick manufacturing unit and Ganesh brick manufacturing unit.

From the test results it is observed that compressive strength of brick masonry constructed using Ganesh brick manufacturing unit is greater than the Punja brick manufacturing unit and hence it is more preferable to select Ganesh brick manufacturing unit.

Table 6. Results of prism compressive strength for mix proportion 1:4

Unit Name	Load (kN)	Compressive Strength (MPa)
Type-I	70.2	3.19
Type-II	85.1	3.89

Table7 Results of prism compressive strength for mix proportion 1:6

Unit Name	Load (kN)	Compressive Strength (MPa)
Type-I	67.6	3.07
Type-II	70.7	3.22

From above two tables we can observe that cement mortar mix of 1:4 gives better result than that of the cement mortar mix of 1:6.

4.32 Shear Bond Strength test

The test program consisting of determining the shear bond strength of brick masonry using different types of mortars.

Table 8 and Table 9 shows the shear bond strength of 1:4 cement mortars and 1:6 cement mortar of Type- I manufacturing unit and Type-II manufacturing unit. Shear bond strength of the brick mortar joint ranges from 0.04 MPa to 0.36 MPa for different mortars. Leaner the mix lesser is the shear strength.

From the test results it is observed that shear bond strength of brick masonry constructed using Type- I brick manufacturing unit is greater than the Type-II brick manufacturing unit and hence it is more preferable to select Type-I brick manufacturing unit.

Table 8. Results of shear bond strength for mix proportion 1:4

Unit Name	Load (kN)	Shear Bond Strength (MPa)
Type-I	23	0.312
Type-II	24	0.322

Table 9. Results of shear bond strength for mix proportion 1:6

Unit Name	Load (kN)	Shear Bond Strength (MPa)
Type-I	21	0.282
Type-II	22	0.287

V. CONCLUSIONS

1. The compressive strength of masonry has a definite relation with the characteristics of masonry materials.
2. The compressive strength of the masonry increases with increase in the strength of the brick, which also increases the bond strength.
3. The strength of the brick is more when kept along the rift than across the rift.
4. Compressive strength of bricks collected from Type-I Manufacturing Unit is 13.16MPa and Type-II Brick Manufacturing Unit 11.67MPa.
5. Water absorption of bricks collected from Type-IBrick Manufacturing Unit is 17.35% and Type-II Brick Manufacturing Unit is 16.95%.
6. Mortar with good workability (flow between 80 - 100%) shall be chosen for the construction of masonry.
7. Wet strength of bricks is around 12.9 MPa which is 2% less than that of dry strength of the brick.
8. Soaking period of bricks should be between 20 - 25 minutes to achieve moisture content of 17% of dry weight.

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