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Research Paper

STRENGTH AND ELASTIC PROPERTIES OF AERATED CONCRETE BLOCK MASONRY

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The preliminary studies focused estimating physical and elastic properties of ACB units. These included initial rate of absorption, density and water absorption test etc. The compressive strength, flexural strength and modulus of elasticity of the units were obtained. Later, the studies were extended to obtain the strength and elastic properties of ACB masonry. Here, the focus was compressive strength of prisms and wallettes, flexural strength and shear bond strength. All the details of the studies were reported extensively in this paper.

Keywords: Aerated concrete block (ACB), Initial rate of absorption (IRA), Dry density, Compressive strength, Modulus of Elasticity, Shear strength, Flexural strength.

INTRODUCTION

Masonry is commonly defined as an assemblage of geometrically well-defined masonry units and mortar placed and bond together in a particular disposition using cementitious materials. There are several properties of masonry units and mortar that influence the behaviour of masonry.

Although ACB units possess lot many advantages over conventional large weight masonry, there are certain issues which may perhaps need to be studied in great detail, particularly in the Indian context. Two important among them are;

1. There is scanty information on the strength and elastic properties of ACB units and ACB masonry
2. There are no guidelines available for identifying the design parameters for load bearing ACB masonry and particularly the properties such as masonry efficiency.

An attempt has been made to obtain all the requisite strength and elastic properties of ACB and ACB masonry, through a series of experiments and the same has been presented in this paper. Whereever applicable, the experiments have been conducted as per relevant codes of practice, elsewhere the

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procedure adopted and quoted extensively in literature, have been followed. The following properties were highlighted in this paper;

- Physical properties of ACB such as Initial Rate of Absorption (IRA), water absorption, dry density.
- Compressive strength and stress-strain characteristic of ACB units and ACB masonry.
- Flexural strength of ACB masonry.
- Shear strength of ACB masonry triplets.

TESTS ON AERATED CONCRETE BLOCKS

Here, an attempt has been made to compile the information on the absorption characteristics, wet compressive strength and density of aerated concrete blocks and strength and elastic properties of aerated concrete block masonry.

Initial Rate of Absorption

Initial rate of absorption test was conducted, in accordance with ASTM C-67 (1995). The specimen was kept in a tray containing distilled water up to a depth of 25 mm from the bottom of the tray for 60 s. Later, the specimen was removed from the tray and weighed, thus the initial rate of absorption is obtained by using the formula 1 given below and the results were presented in Table 1. It can be noted that the range of IRA values is quite similar to that of any common type of masonry unit.

$$IRA = \frac{\text{Weight After 1 min} - \text{Dry Weight}}{\text{Immersed Area of Sample}} \times 100 - 1$$

Dry Density

This test was carried out on blocks samples collected randomly in and around Bangalore City. IS: 2185-(Part I) (1997) specifications were followed to conduct this test. The results were presented in Table 2. The extremely low density is an interesting result to be noticed.

Table 1: Initial Rate of Absorption of ACB

Specimen No.	IRA ($kg/m^2/min$)	Average IRA ($kg/m^2/min$)	COV
1	1.93	1.85	0.06
2	1.90		
3	1.70		
4	1.70		
5	1.93		
6	1.93		

Table 2: Dry density of ACB

Specimen No.	Dry Density (kg/m^3)	Average Dry Density (kg/m^3)	COV
1	601.50	597.42	0.011
2	589.25		
3	607.50		
4	591.25		
5	596.45		
6	598.60		

Water Absorption

The blocks were tested in accordance with the procedure laid down in IS: 2185 (Part I) (1979). The code specifies two methods to be adopted, by 5 h boiling water test or the 24 h cold water immersion test. The latter method was adopted. Water absorption for blocks should not be greater than 20% by weight up to class 12.5 as per IS: 1077 (1992) specifications. The result of the water absorption test was presented in Table 3. The test clearly indicates the very high water absorption. This is beyond the permissible units of 15 to 20%.

Table 3: Water absorption of ACB

Specimen No.	Water Absorption (%)	Average Water Absorption (%)	COV
1	36.97	36.08	0.03
2	35.68		
3	37.26		
4	34.93		
5	35.37		
6	36.32		

Wet Compressive Strength

The compressive strength of the block is the main contributing factor for the strength of masonry. IS: 2185 (Part-I) (1979) specifies the minimum compressive strength for three types of units. They include hallow (load bearing), hallow (non-load bearing) and solid (load bearing). The minimum compressive strength for a non-load bearing unit is 1.2 MPa while that for a load bearing unit, it varies from 1.6 MPa to 5.6 MPa. This test was conducted as per the specification laid in the IS: 3495 (1992). For the ACB units, the wet compressive strength has been presented in Table 4. The compressive strength is indicative of the minimum acceptable value.

Flexural Strength Test

This test was conducted as per the guidelines, given in the reference by Dayaratnam (1987). The test specimen was placed centrally on two roller supports and load was applied through another roller, taking care not to cause local failure, as shown in Plate 1. The transverse load was applied at a uniform rate not exceeding 300 N/min through the central roller seen in the figure. The individual breaking load was recorded and flexural strength was calculated, using pure bending equation. The flexural strength test results were presented in Table 5. As compared to other masonry units, the flexural strength is relatively high especially for blocks having compressive strength in the range of 1.6 MPa to 5.6 MPa.

Table 4: Wet Compressive Strength of ACB

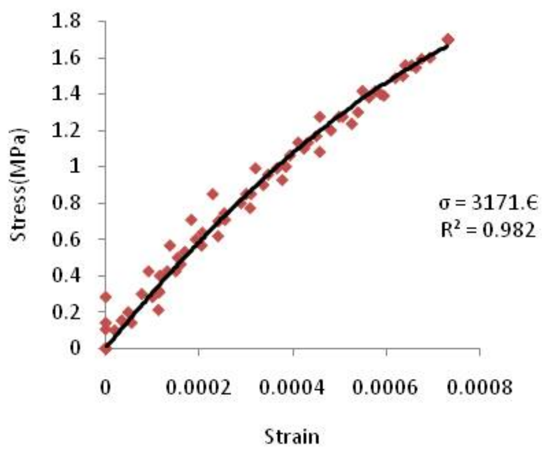
Specimen No.	Wet Compressive Strength (N/mm^2)	Average Wet Compressive Strength (MPa)	COV
1	3.28	3.2	0.10
2	3.31		
3	3.06		
4	2.85		
5	3.75		
6	2.94		

Plate 1: Flexure Strength of ACB

Table 5: Flexural Strength of ACB

Specimen No.	Flexural Strength (N/mm^2)	Average Flexural Strength (MPa)	COV
1	0.56	0.44	0.35
2	0.62		
3	0.50		
4	0.23		
5	0.43		
6	0.29		

Figure 1: Stress-Strain Plot for ACB



Stress-Strain Characteristics

Strain measurements were carried out on the block specimens with a uni-axial compressive load applied parallel to its length in a 600 kN UTM. Plate 2 shows a specimen being monitored for strain measurement under compressive loading. Figure 1 shows the best fit curve obtained from the test conducted on several specimens. The initial tangent modulus of ACB units is very high compared to that of table moulded bricks available in Bangalore. It is however comparable to that of moderate strength conventional concrete blocks.

Plate 2: Set up of a Typical Specimen for Stress-Strain Measurement Under Compressive Load

CHARACTERISTICS OF MORTAR

Mortar is an essential binding material in masonry. The strength of mortar has an important role as it directly influences the bond strength of masonry. There are several types of mortars available for masonry construction. However it has been a common practice in Bangalore, to adopt the use of cement-sand mortar for all masonry construction works. The use of mortar mix of proportion 1:6 with a water cement ratio of 1.2 is normally adopted. In the present study, four tests, viz., the cube compression test, tension test, test to determine flexural strength and test to determine the stress strain characteristics of mortar, were conducted. All the tests were carried out using 53-grade Ordinary Portland Cement. The physical tests on cement and fine aggregate were conducted as per IS: 4031 (2005) and IS: 2386 (2007).

Compressive Strength of Mortar

The compressive strength of mortar mainly depends upon the cement content and water cement ratio. The water cement ratio also governs the workability condition of the mortar mix. The relative moisture content at the time of placing the mix, governs the bond between the masonry unit and mortar. The mortar, when devoid of water, affects the bond and its compressive strength. Masonry mortar needs to be workable and should possess adequate bond with the unit. Hence, mortar with good retentivity property needs to be selected for masonry. The choice of the water cement ratio was based on the flow test to determine the optimum water cement ratio for a particular mortar mix as per IS: 2250 (1981), which specifies a flow of 110mm. Mortar cubes of size 70.6 mm x 70.6 mm x 70.6 mm as per IS: 10080 (1982) were cast for conducting the compression test. The tests were conducted as per IS: 2250 (1981) specifications. The cubes were cured for 28 days before testing in a Universal Testing Machine. It is well known that mortar compressive strength is less related to the masonry strength. However, it remains essential to quantify the mortar strength for complete characterization of any type of masonry be it conventional blocks/ bricks or ACB. Table 6 presents the compressive strength of the mortar used.

Tensile Strength of Mortar

In this test, mortar briquette specimens were cast and cured for 28 days. The briquette specimen had the resemblance of the number "8". The size of the specimen at the web was 25.4 mm x 25.4 mm. The experiment was conducted using the tensile testing machine as per ASTM C 109. The tensile load was applied through a lever arm mechanism, which had a lever arm ratio of 40. The specimen was placed between the clips of the machine, and loaded by using lead metal shots. The specimen was loaded till failure, and the axial tensile strength was determined.

Flexural Strength of Mortar

Specimens of dimension 40mm x 40mm x 160mm were cast and subjected to transverse loading as per specifications of IS: 10078 (1982). The mortar prisms were cast and cured for 28 days prior to testing.

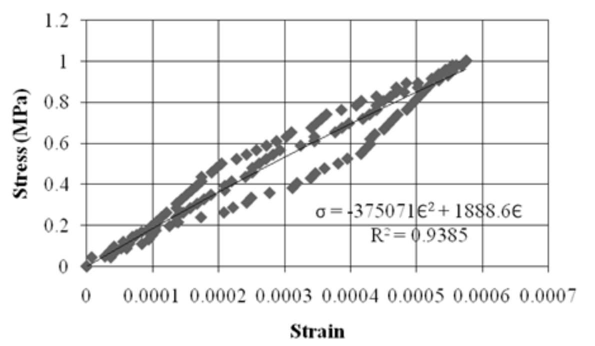
Stress-Strain Characteristics of Mortar

Compression tests were carried out on 70.6 mm size mortar cubes, while the tension tests were carried out on mortar briquettes. The flexure tests were conducted on mortar prism bars of size 40 mm x 40 mm x 160 mm and the stress-strain characteristics were studied using mortar prisms of dimensions 150 mm x 150 mm x 300 mm ((Sarangapani G 1998; Gumaste, 2004)). The results have been presented in Table 6 and a graph of stress versus strain was presented in Figure 3.

Table 6: Test Results of Cement-Sand Mortar Mix 1:6

S. No.	28 days Cube Compressive Strength	Tensile Strength	Flexural Strength (MPa)	Modulus of Elasticity
1	No. tested = 129.2 MPa COV – 20.97%	No. tested=120.82 MPa MPa COV – 29.89%	No. tested=121.85 MPa COV – 17.56%	No. tested=06 E = 1888.60MPa R^2 = 0.94

Figure 2: Stress-Strain Plot of Cement-Sand Mortar Mix (1:6) Prism



STRENGTH AND ELASTIC PROPERTIES OF ACB MASONRY

This section presents the compressive strength, elastic properties of ACB masonry prisms and wallettes, flexural strength of ACB masonry and shear strength of ACB masonry triplets.

Compressive Strength and Modulus of Elasticity of Stack Bonded ACB Masonry Prisms

Perpendicular to Bed Joint

Plate 3 shows the set-up of the ACB masonry prism test loaded normal to bed-joints. The details were presented here under.

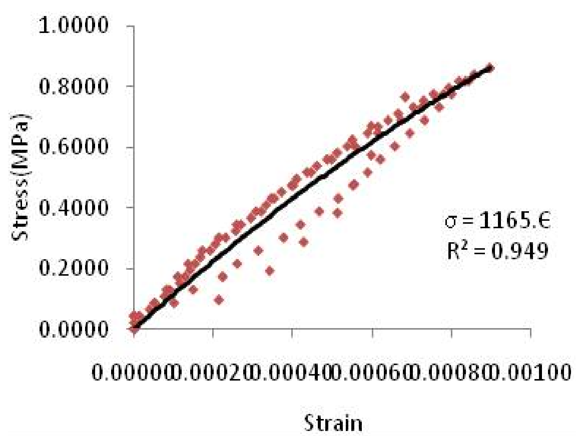
Plate 3: Set up of a Typical Specimen Loaded Perpendicular to Bed Joint

In this test total six specimens were tested. The average dimension of the specimen tested was 200 mm length, 200 mm in width and 624 mm in height. A digital dial gauge having a gauge length of 150 mm was mounted on to the specimen to record the deformations. The results are presented in the Table 7 and also plot of stress v/s strain was presented in Figure 3.

Table 7: Compressive Strength of ACB Masonry Prisms

Specimen No.	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^2)	Corrected Compressive Strength (N/mm^2)	COV
1	0.75	1.25	1.643	0.253
2	1.00			
3	1.30			
4	1.63			
5	1.41			
6	1.38			

Figure 3: Stress-Strain plot for ACB masonry prisms (perpendicular to bed joint)



Parallel to Bed Joint

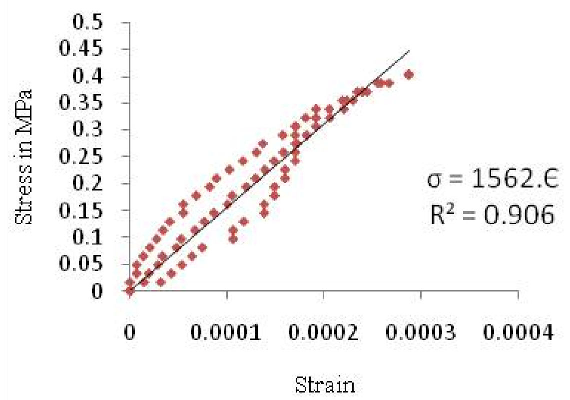
In this test also total six specimens were tested. The average dimension of the specimen tested was 200 mm length, 200 mm in width and 624mm in height. A digital dial gauge having a gauge length of 150mm was mounted on to the specimen to record the deformations. The Plate 4 shows the setup of the ACB masonry prism test loaded parallel to bed joints. The details were shown in Table 8 and also in Figure 4.

Plate 4: Set up of a typical specimen loaded parallel to bed joint

Table 8: Compressive Strength of ACB Masonry Prisms

Specimen No.	Compressive Strength (N/mm^2)	Average Compressive Strength (MPa)	Corrected Compressive Strength (MPa)	COV
1	1.78	1.66	2.181	0.114
2	1.87			
3	1.32			
4	1.68			
5	1.70			
6	1.59			

Figure 4: Stress-strain plot for ACB masonry prisms (parallel to bed joint)



Compressive Strength and Modulus of Elasticity of ACB Masonry Wallettes

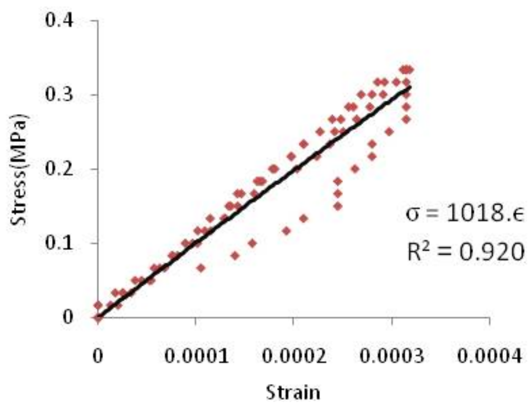
Here again total six specimens were tested. The average dimension of the specimen tested was 600 mm length, 200 mm in width and 624 mm in height. A digital dial gauge having a gauge length of 150 mm was mounted on to the specimen to record the deformations as shown in plate 5. The results were presented in the Table 9 and also in Figure 5.

Plate 5: Set up of a typical wallette

Table 9: Compressive Strength of ACB Masonry Prisms

Specimen No.	Compressive Strength (N/mm^2)	Average Compressive Strength (MPa)	Corrected Compressive Strength (MPa)	COV
1	0.55	0.80	1.051	0.195
2	0.96			
3	0.95			
4	0.70			
5	0.81			
6	0.82			

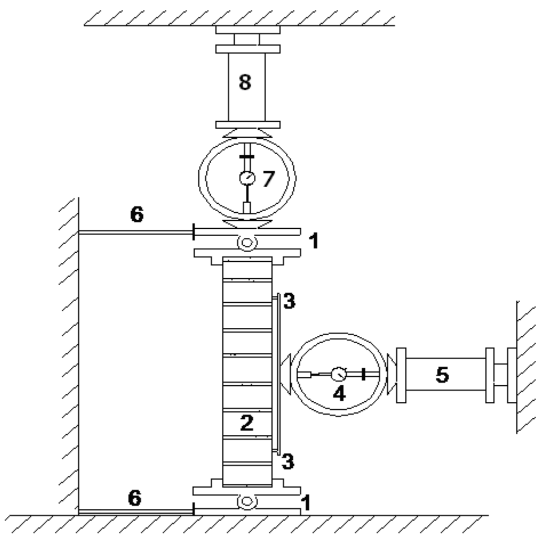
Figure 5: Stress-Strain plot for ACB masonry Wallette



Flexural Test for Aerated Concrete Blocks Prisms

The code of practice BS: 5628 (1992) describes the testing of small brick/block specimens (wallettes) under four-point loading as a standard test for determination of the flexural bond strength of masonry bed joints. The test provides an index of wall strength derived from its flexural performance. The schematic diagram showing the details of the test set-up was indicated in Figure 6.

Figure 6: Schematic Diagram Showing Details of the Test Set-Up for Flexure



1. Hinge
2. Specimen
3. Two Point Loading
4. Proving Ring (for lateral load)
5. Jack (for lateral load)
6. Props
7. Proving ring (for compression load)
8. Jack (for compression load)

Tests to determine the flexural strength of masonry were carried out on a rigid loading frame of 2000 kN capacity. Accessories such as the jacks, proving rings and props were used to make all the necessary measurements required for testing the specimens. Three ACB masonry prisms were cast for the flexure test. The dimensions of the prisms were 400 mm x 100 mm x 840 mm. All the specimens were tested with flexural stress developing normal-to-bed-joints under the application of normal stress level of 0.05 MPa. Two proving rings and two hydraulic jacks were used to conduct the experiment. One set of proving ring and hydraulic jack was required to keep the normal stress level constant. The second set was required to apply the lateral load. This load was applied gradually and at the same time the normal stress level was also monitored. The experiment was conducted till the specimen reached the failure load and the final reading on the proving ring was noted down. Plate 6 shows the ACB masonry prism under flexure test. The results are presented in the Table 10.

Shear Strength Test

The strength in shear for masonry is usually assessed by testing a masonry specimen. In general, two type of masonry specimen can be considered namely: masonry triplets and masonry couplets. In the present study masonry triplet were used for testing. The triplets were made up of three aerated concrete blocks of size (200 mm x 100 mm x 100 mm). The triplet specimens were tested on compression testing machine. The triplet was made-up of three aerated concrete blocks arranged in such a manner that the block in centre was projected by a thickness equal to one mortar joint from the other two blocks as shown in Plate 7. The specimen was placed under UTM, one steel plate was kept below the specimen and one above the specimen so that the load applied is distributed uniformly. The load was applied axially at a uniform rate of 14 N/mm² per minute till failure occurred and the maximum load at failure was noted, thus the ultimate shear strength of the specimen was obtained by using an expression given below:

$$\text{Shear Strength} = \frac{P}{(2 \times b \times d)}$$

Plate 6: Test Set-Up of ACB Masonry Prism for Flexure Test

Table 10: Flexural Bond Stress of ACB Masonry Prisms					
S. No	Proving Ring Reading in (N)	Bending Moment in (N-mm)	Flexural Bond Stress in (N/mm^2)	Average Flexural Bond Stress in (MPa)	COV
1	1250	90625	0.136	0.131	0.085
2	1200	87000	0.131		
3	1000	72500	0.109		
4	1280	92800	0.139		
5	1220	88450	0.133		
6	1260	91350	0.137		

Plate 7: Triplets Shear Strength test set-up

Table 11: Shear Strength of ACB Triplets

Specimen No.	Shear Strength (N/mm²)	Average Shear Strength (N/mm²)	COV
1	0.11	0.13	0.097
2	0.14		
3	0.12		
4	0.13		
5	0.14		
6	0.12		

The results are presented in the Table 11.

COMPARISON OF RESULTS AND DISCUSSION

As mentioned earlier, there has been rather scanty information on the physical and elastic properties of ACB and ACB masonry. The present investigation has endeavored to study all such properties. Having obtained the results, it would now be interesting and useful to compare the results with that of conventional masonry. Very recently Mangala Keshava (2012) has carried out an extensive study on the physical and elastic properties of a variety of masonry available in and around Bangalore (South India). The results obtained by her have been used to compare with the investigations carried out in the present study.

Legend:

ACB: Aerated Concrete Block

TMB: Table moulded brick

WCB: Wire cut brick

SCB: Solid concrete block (150 mm and 200 mm thick)

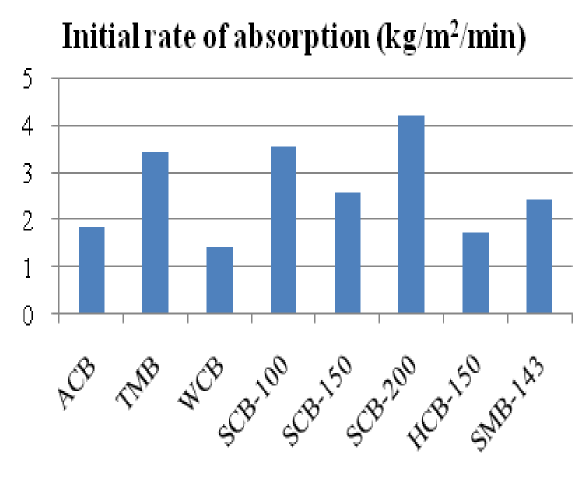
HCB: Hollow concrete block (150 mm thick)

SMB: Stabilized mud blocks, 8% cement (143 mm thick)

Initial Rate of Absorption (IRA)

Figure 7 gives a similar comparison of IRA values of a variety of blocks. Here the IRA values of ACB units are within the range of conventional blocks. It is interesting to note that solid concrete blocks possess more IRA since

Figure 7: Comparison of IRA Values of Different Types of Units

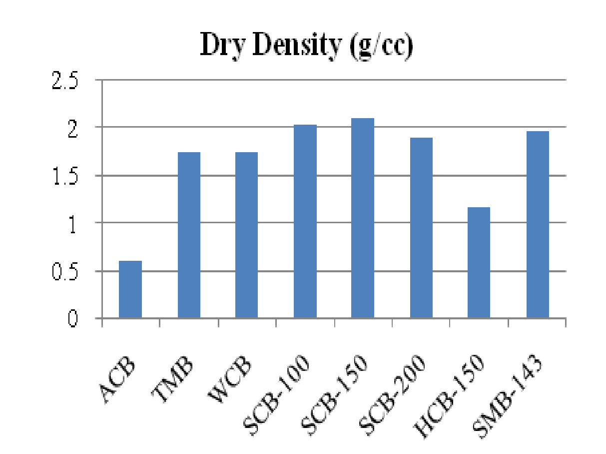


they are generally manufactured using bigger sized fine aggregates and thus tend to have more pores. These pores may enhance the capillary action and thus leading to higher IRA. On the other hand ACB possesses fine discontinuous pores and blocks the movement of water through the body and hence the low IRA values.

Block Density

Figure 8 gives a comparison of the block density of a variety of masonry units. It is quite apparent that ACB has the least density when compared to any other type of unit. Indeed the extremely low density is extremely favorable to structures due to the great reduction in self weight and thus may result in lower structural costs.

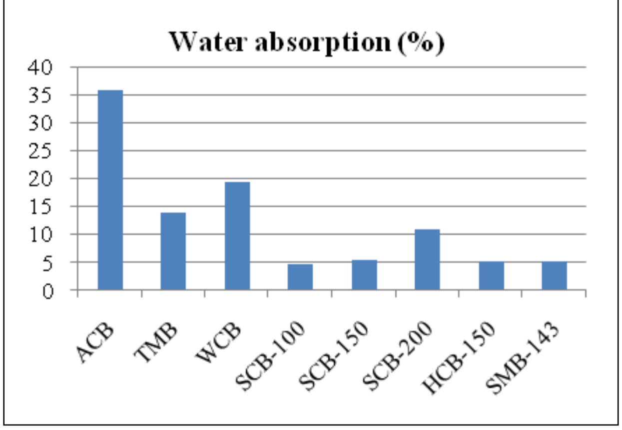
Figure 8: Comparison of Dry Density of Different Types of Units



Water Absorption

Figure 9 presents a comparison of water absorption of a variety of units. The water absorption is extremely high, indeed more than what the IS code specify. This aspect is detremental to the performance in terms of durability. Perhaps there is a need to look into this aspect in great detail, otherwise the low density benefit will be offset by the unwanted need to protect it by water ingression.

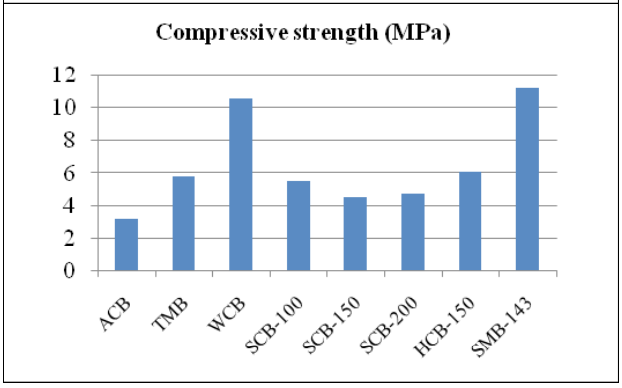
Figure 9: Comparison of Water Absorption of Different Types of Units



Wet Compressive Strength

A similar comparison for compressive strength is presented in Figure 10. Aerated concrete block units has the least compressive strength when compared to any other type of masonry unit. However, it meets the minimum requirement.

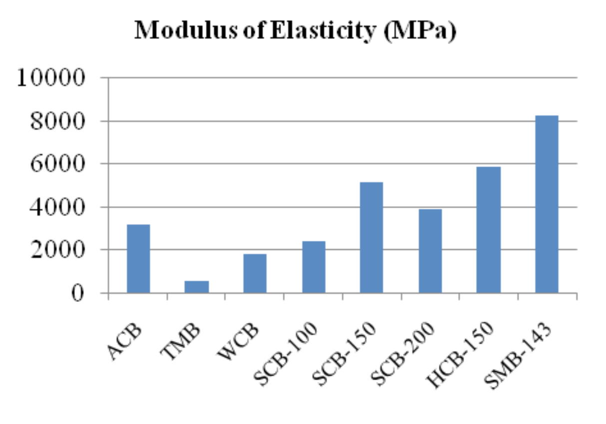
Figure 10: Comparison of Wet Compressive Strength of Different Types of Units



Modulus of Elasticity

It is extremely interesting to note that, although the compressive strength is low, the modulus of elasticity is very high compared to the common table moulded bricks has been presented in Figure 11. Indeed, the value is higher than that of wire cut bricks and Solid concrete blocks as well. This would lead to benefit in the limiting deflection due to lateral loads.

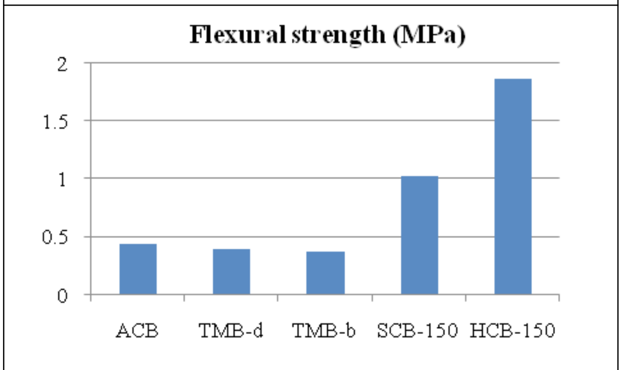
Figure 11: Comparison of Modulus of Elasticity of Different Types of Units



Flexural Strength

The flexural strength of ACB units are favourable for structural purposes. Figure 12, shows the comparison of flexural strength and suggestive of the benefit of ACB as compared to table moulded bricks. However, it is here that hollow and solid concrete blocks perform much better.

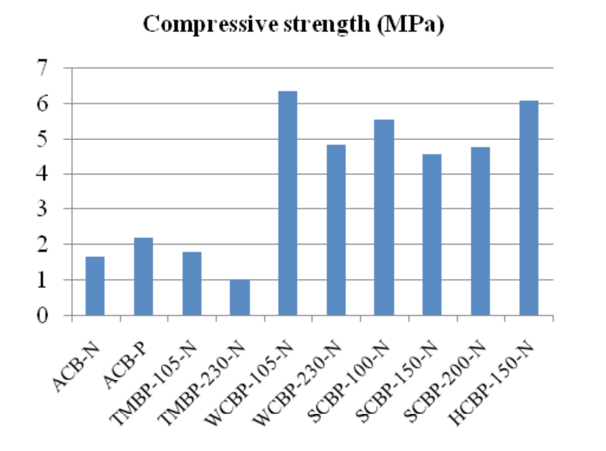
Figure 12: Comparison of Flexural Strength of Different Types of Units



Compressive Strength of Masonry Prism

A comparison of the compressive strength of a variety of masonry prisms, using identical mortar (CM 1:6), has been presented in Figure 13. It can be noted that the relative performance of ACB is not so good.

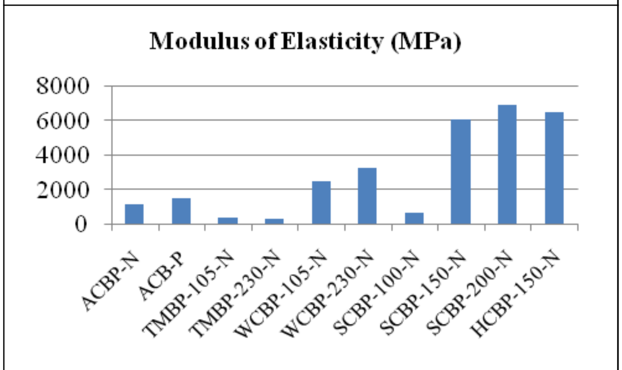
Figure 13: Comparison of Compressive Strength of Different Types of Masonry Prisms



Modulus of Elasticity of Masonry Prisms

Figure 14 presents the comparison of modulus of elasticity of a variety of masonry prisms. These were based on the compression tests conducted on the prisms. Interesting point to be noted is that, although the modulus of ACB unit is relatively high when compared to TMB,

Figure 14: Comparison of Modulus of Elasticity of Different Types of Masonry Prisms



there is a larger percentage reduction in modulus when used for masonry. It clearly indicates the influence of mortar. Perhaps there is a need for a special type of mortar for ACB and which is on the verge of being available in the market soon.

CONCLUSION

1) Solid concrete blocks possess more Initial rate of absorption since they are generally manufactured using bigger sized fine aggregates and thus tend to have more pores. These pores may enhance the capillary action and thus leading to higher Initial rate of absorption. On the other hand Aerated concrete blocks possesses fine discontinuous pores and blocks the movement of water through the body and therefore is seen to possess low Initial rate of absorption values.

2) Aerated concrete block has the least density when compared to any other type of masonry unit. Indeed the extremely low density is extremely favorable to structures due to the great reduction in self weight and thus may result in lower structural costs.

3) The water absorption is extremely high, indeed more than what the IS code specify. This aspect is detremental to the performance in terms of durability. Perhaps there is a need for the manufacturers to look into this aspect in great detail; otherwise the low density benefit will be offset by the unwanted need to protect it by water ingression.

4) Aerated concrete block units has the least compressive strength when compared to any other type of masonry unit. It is not favorable.

5) It is extremely interesting to note that, although the compressive strength is low, the modulus of elasticity is very high compared to the common table moulded bricks and solid concrete blocks. This may find special benefit in the limiting deflection due to lateral loads.

6) The flexural strength of aerated concrete block units is favourable for structural purposes. Flexural strength is suggestive of the benefit of Aerated concrete block as compared to table moulded bricks. However, it is here that hollow and solid concrete blocks perform much better.

7) Compressive strength of ACB masonry prism can be noted that the relative performance is not so good.

8) These were based on the compression tests conducted on the prisms. Interesting point to be noted is that, although the modulus of ACB unit is relatively high when compared to TMB, there is a larger percentage reduction in modulus when used for masonry. It clearly indicates the influence of mortar. Perhaps there is a need for a special type of mortar for ACB and which is on the verge of being available in the market soon.

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