Experimental Study on Interface Behavior of Masonry Structures

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Abstract— Masonry structures are durable in nature and are resistant to variations in climatic conditions. In Civil Engineering Projects, nowadays the usage of different types of structural blocks (Clay bricks, fly ash bricks and solid blocks) are increasing. Masonry structures accommodate minor earth disturbances and normally will not lead to failure in differential settlement of foundations. This thesis work is an experimental study of Compressive strength, Modulus of elasticity and Poisson's ratio for different mix proportions. Tests were conducted for mix proportions 1:4, 1:5 and 1:6 for masonry prisms. The type of bond used for the experiment is English bond. Dimensions of masonry prisms were 230mmx230mmx 300mm. The specimens prepared were tested on 7th and 28th day of curing. Specimens of 3 each in all mix ratios were tested which made a total of 63 prisms. The results were verified using the model created in ANSYS. The experimental results were compared and plotted which proved that the prism with fly ash brick masonry achieved maximum young's modulus and Poisson's ratio.

Key words: Brick masonry, Material properties, Mortar ratios

I. INTRODUCTION

The bricks are obtained by moulding clay in rectangular blocks of uniform size and then by drying and burning them. It is used extensively as a leading material of construction because of its durability, strength, reliability, low cost, easy availability etc. The bricks have been used all over the world in every class and kind of building. The advantage of brick over stone is its ease of construction and requires comparatively less labor effort for masonry works. It was considered as a suitable load bearing material for various structures. Presently, the building frames are constructed as reinforced concrete frame and then the frames are filled up using bricks. In this project, a study of interface behavior of bricks in masonry structures with different mix proportions was carried out on masonry units of several types such as clay bricks, concrete blocks, line based blocks and stones. -Generally, the choice of masonry was governed by local availability, compressive strength, fire resistance, cost and ease of construction.

The present study, deals with the experimental investigations of the constituent material properties of the brick masonry for different mortar ratios. Burnt clay bricks of standard size were used to determine their individual properties. The stress-strain curve was plotted from the experimental data. The strength of the masonry structure depends on the strength of bonding between the bricks. The interface behaviour between the mortar and brick plays a vital role in enhancing the strength of masonry. Hence, the interface behaviour of masonry was also discussed in this thesis.

II. OBJECTIVE

- To study the various properties of the materials used for the construction.
- To prepare the models of various types of brick masonry prisms.
- To compare the properties for different mix proportion such as 1:4, 1:5 and 1:6.
- To compare the properties after 7 days and 28 days curing.
- To verify the results using ANSYS software.

III. PROPERTIES OF MATERIAL

A. General

Brick masonry exhibits heterogeneous property due to different constituent materials. Hence, it was important to identify the individual properties of brick and mortar to understand the overall bhevaiour of masonry.

B. Brick

A brick is a block or a single unit of a kneaded clay-bearing soil, sand and lime, or concrete material, fire hardened or air dried, used in masonry construction. Lightweight bricks (also called lightweight blocks) are made from expanded clay aggregate. Fired brick are the most numerous types and are laid in courses and numerous patterns known as bonds, collectively known as brickwork, and may be laid in various kinds of mortar to hold the bricks together to make a durable structure. Brick are produced in numerous types, materials, and sizes which vary with region and time period, and are produced in bulk quantities. Three types of brick used in this experimental study are clay brick, fly ash brick and solid block.

C. Cement

Cement is a binder, a substance that sets and hardens and can bind other materials together. The word "cement" traces to the Romans, who used the term opus caementicium to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder. The volcanic ash and pulverized brick additives that were added to the burnt lime to obtain a hydraulic binder were later referred to as cementum, cimentum, cament, and cement. The most important use of cement is the production of mortar and concrete. The cement used to cast specimen was Portland Pozzolana cement manufactured by Ramco.

D. Fine Aggregate

Fine aggregate (sand) is the main constituent of masonry mortars and renders. Sand between 4.75mm and 0.15mm in size is called fine aggregate. It is used for making concrete, mortars and plasters. For economy in construction, as far as possible local sand, fit for the perpendicular use, should be used. Otherwise, transport expense will be a major part of the cost of the sand. Soft sand is the ideal material for making mortar and plaster for brickwork. (As per I.S. 2116-1980)

IV. BLOCK MAKING AND MIX DESIGN

A. General

The specimens or brick masonry prisms were made of 230mm x 230mm x 300mm in dimension from clay, fly ash and solid materials; for a mix proportion of CM 1:4, 1:5 and 1:6. After casting the prisms, they were allowed for 7 days and 28 days curing. Type of bond used for construction of specimen was English bond.

B. Mix Proportion

Mortar type should correlate with the particular masonry unit to be used. The masonry that has a high initial rate of absorption will have greater compatibility with mortar and high water retentiveness. The material properties of mortar that influence the structural performance of masonry are compressive strength, bond strength and elasticity. Since the compressive strength of masonry mortar is less important than the bond strength, workability and water retentive property; the latter properties should be given principal consideration in selection of mortar. In this experimental study, three types of bricks were used, namely clay brick, fly ash brick and solid block. Total numbers of specimens prepared are as mentioned below:

Type of Bricks	Cement Mortar Ratio	No. of Prisms
Clay bricks	1:4	9
	1:5	9
	1:6	9
Fly ash bricks	1:4	9
	1:5	9
	1:6	9
Solid blocks	1:4	3
	1:5	3
	1:6	3
Total		63

C. Casting of Prisms

Brick masonry is a type of construction in which uniform units, which are small enough to be placed with one hand, are laid in courses with mortar joints to form walls. Bricks are kiln baked from various clay and shale mixtures. The chemical and physical characteristics of the ingredients vary considerably. These characteristics and the kiln temperatures combine to produce brick in a variety of colors and harnesses. In some regions, individual pits yield clay or shale which, when ground and moistened, can be formed and baked into durable brick. In other regions, clay or shale from several pits must be mixed. Casting of brick masonry prisms were made of 230mm x 230mm x 300mm in dimension for clay bricks, fly ash bricks and solid blocks in CM 1:4, CM 1:5 and CM 1:6.

Fig. 1: Casting of Clay Brick Prisms

D. Curing Of Prisms

Curing is the process of keeping brick prisms under a specific environmental condition until hydration is relatively complete. Because the cement used in brick prisms requires time to fully hydrate before it acquires strength and hardness, brick prisms must be cured once it has been placed. Good curing is typically considered to use a moist environment which promotes hydration, since increased hydration lowers permeability and increases strength, resulting in a higher quality material. Allowing the brick prisms surface to dry out excessively can result in tensile stresses, which the still-hydrating interior cannot withstand, causing the brick prisms to crack. Also, the amount of heat generated by the chemical process of hydration can be problematic for very large placements. Allowing the brick prisms to freeze in cold climates before the curing is complete will interrupt the hydration process, reducing the brick prisms strength and leading to scaling and other damage or failure. The effects of curing are primarily a function of specimen geometry, the permeability of the concrete, curing length, and curing history.

Fig. 2: Curing of Brick Prisms

V. EXPERIMENTAL INVESTIGATIONS

A. General

Brick masonry exhibits heterogeneous property due to different constituent materials. Hence, it is important to identify the individual properties of brick and mortar to understand the overall behaviour of masonry. Experiments were carried out using the compression testing machine and the Compressive Strength, Modulus of Elasticity and Poison's Ratio were determined.

B. Test Procedure for Compressive Strength Test

Test set up were made to determine the compressive strength of masonry prisms for the mix ratio of CM 1:4, CM

1:5 and CM 1:6 at the end of 7 and 28 day. The dimension of masonry prisms were

- Clay brick prism - 230mmx230mmx300mm
- Fly ash brick prism- 230mmx230mmx300mm
- Solid block prism- 300mmx150mmx450mm

The test was carried out at the end of 7 and 28 days of curing. The prisms were placed between the plates of compression testing machine. The load was applied axially at a uniform rate of until the prisms failure occurred. To determine the compressive strength of masonry prism, the maximum load at failure stage was noted which was divided by its surface area of masonry prism (expressed in N/mm^2). Number of Specimens Tested to determine Compressive Strength is

- Clay Brick Prisms - 9 nos.
- Fly Ash Brick Prisms - 9 nos.
- Solid Blocks - 9 nos.

Fig. 3: Compressive Strength Test for Brick Masonry Prism

C. Test Procedure for Modulus of Elasticity

Test set up were made to determine the Modulus of Elasticity of masonry prisms for the mix ratio of CM 1:4, CM 1:5 and CM 1:6 at the end of 7 days and 28 days. The dimension of masonry prisms were

- Clay brick prism - 230mmx230mmx300mm
- Fly ash brick prism- 230mmx230mmx300mm
- Solid block prism- 300mmx150mmx450mm

Number of Specimens Tested for Modulus of Elasticity was,

- Clay Brick Prisms - 9 nos.
- Fly Ash Brick Prisms - 9 nos.

The test set was carried out at the end of 7 days and 28 days of curing. The prisms were placed with the frame set up in which a compressometer (dial gauge) was fixed at one lateral direction (X or Z) of the frame in which other three faces of the frame was fitted with adjustable screws with pivot rod at center of the specimen to tighten the frame with masonry prism. The compressometer was centrally pivoted with the prism to observe the lateral movement of prism during axial loading. The dial gauge (least count = .01) was set at the center of prism surface. The load was applied axially at a uniform rate and corresponding readings were noted at equal intervals until the prism failure occurred.

Fig. 4: Test set up for Young's Modulus of Elasticity

D. Test Procedure for Poisson's Ratio

Test set up were made to determine the Poisson's Ratio of masonry prisms for the mix ratio of CM 1:4, CM 1:5 and CM 1:6 at the end of 7 days and 28 days. The dimension of masonry prisms were

- Clay brick prism - 230mmx230mmx300mm
- Fly ash brick prism- 230mmx230mmx300mm
- Solid block prism- 300mmx150mmx450mm

Number of Specimens Tested for Poison's Ratio was

- Clay Brick Prisms - 9 nos.
- Fly Ash Brick Prisms - 9 nos.

The tests were carried out at the end of 7 days and 28 days on the brick prisms on a compression testing machine. The dial gauges were placed at three directions X, Y, Z respectively, since X and Z were two lateral directions and Y was the linear direction. Two compressometer were fixed to record the lateral movement of the prism and also for longitudinal movement at Y direction. The set up was ready to apply load and the load was applied gradually. Set the dial gauges to zero (LC =0.01) and the rod was pivoted at the center of the prism surface. The readings were taken at all three directions from the corresponding dial gauges at different loadings. The set up was shown in fig 5.

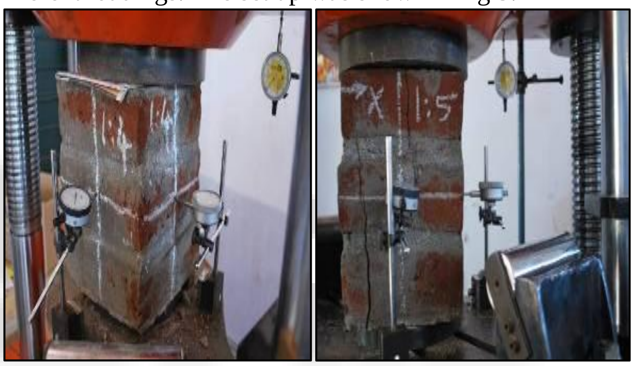

Fig. 5: Test set up for Poisson's Ratio (Clay Brick Prism)

VI. EXPERIMENTAL RESULTS

A. General

In this chapter, discussion of results of compressive strength, modulus of elasticity and poison's ratio tests are compared for different mix proportions such as 1:4, 1:5 and 1:6 for masonry prisms.

B. Results for Compressive Strength

The maximum load that the burnt clay brick can withstand was determined using the compressive strength test as per IS 3495 (Part 2): 1992. The compressive strength of brick depends upon the composition of clay, method of brick manufacturing and degree of firing. The test was carried out using the compression testing machine of 300 tones capacity. The test was progressed with a constant rate of loading of 2.5kN. The frog of the brick was filled with mortar and the level of bed surface was also ensured before testing. Test set up were made to determine the compressive strength of masonry prisms for the mix ratio of CM 1:4, CM 1:5 and CM 1:6. The test was carried out at the end of 7 and 28 days of curing. The prisms were placed between the plates of compression testing machine. The load was applied axially at a uniform rate of until the prisms failure occurred. To determine the compressive strength of masonry prism the maximum load at failure stage was noted which was divided by its surface area of masonry prism, expressed in N/mm².

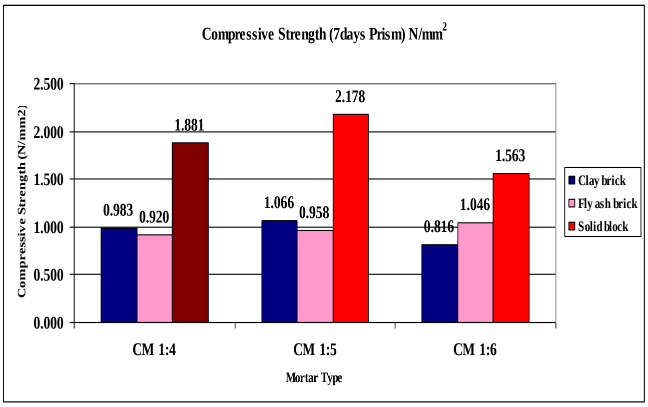

Fig. 6: Compression Strength for Bricks

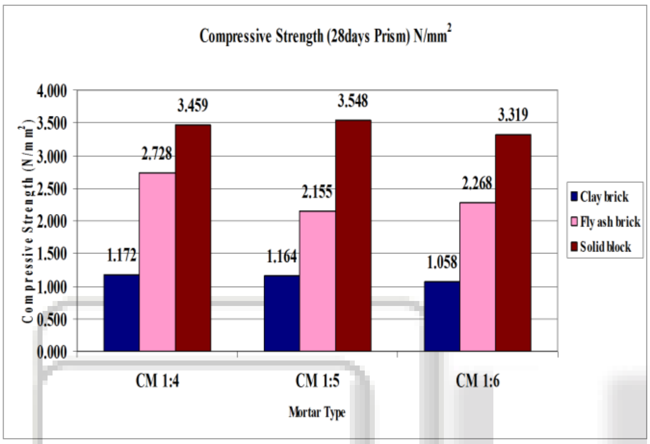

Fig. 7: Compression Strength for Bricks

In this study, the compressive strength of Solid block prism of CM 1: 4 showed 26.8% higher value than Fly ash brick and 195% higher than clay brick prism for 28days. The compressive strength of Solid block prism of CM 1: 5 was 64.60% higher than Fly ash brick and 204% higher than clay brick prism for 28days. Similarly, the compressive strength of Solid block prism of CM 1: 6 was 46% higher than Fly ash brick and 213% higher than clay brick prism for 28days. By comparing the test results, the solid block prisms were found to give higher compressive strength when compare to other masonry prisms.

C. Results for Modulus of Elasticity

The test set up was made to determine the Modulus of Elasticity of masonry prisms for the mix ratio of CM 1:4, CM 1:5 and CM 1:6. The test was carried out at the end of 7 and 28 days of curing. The prisms were placed with the frame set up in which a compressometer (dial gauge) was fixed at one lateral direction (X or Z) of the frame in which other three faces of the frame was fitted with adjustable screws with pivot rod at center of the specimen to tighten the frame with masonry prism. The compressometer was centrally pivoted with the prism to observe the lateral movement of prism during axial loading. Set the dial gauge (least count = .01) at the center of prism surface. The load was applied axially at a uniform rate and corresponding readings were noted at equal intervals until the prism failure occurred.

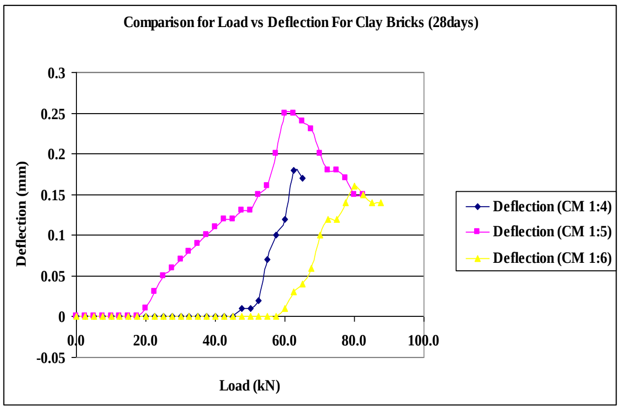

Fig. 8: Load vs. Deflection Curve Clay Brick Masonry Prism (28days)

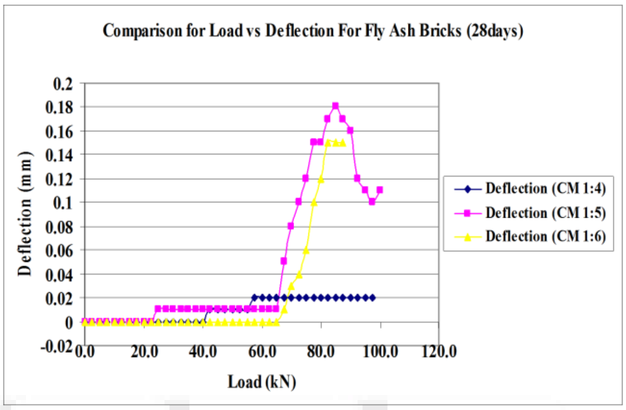

Fig. 9: Load vs. Deflection Curve Fly Ash Brick Masonry Prism (28days)

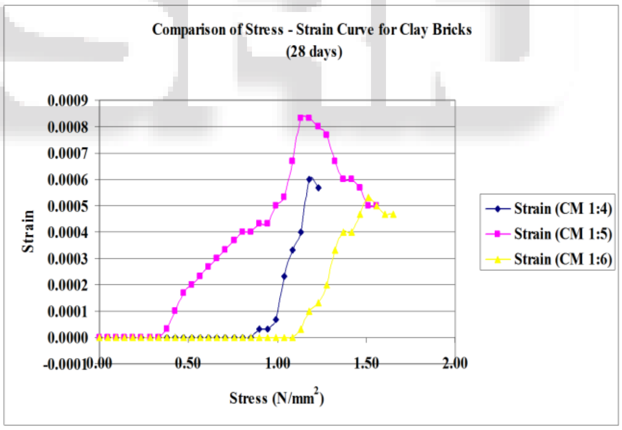

Fig. 10: Stress Strain for Clay Brick Masonry Prism (28days)

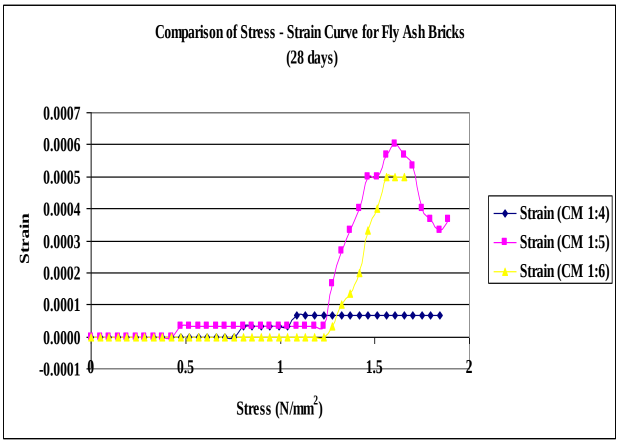

Fig. 11: Stress Strain for Fly Ash Brick Masonry Prism (28days)

Based on the experimental data, the graph was plotted between the stress and strain as shown in figure 6.5 and 6.6. The average Young's Modulus or Modulus of Elasticity of Clay Brick prism CM 1: 4 was 874.22 N/mm^2 and that for Fly ash brick prism of CM 1: 4 was found to be 408.89 N/mm^2. The average Modulus of Elasticity of Clay Brick prism CM 1: 5 was 437.975 N/mm^2 where as that of Fly ash brick prism of CM 1: 5 was 476 N/mm^2. The average Modulus of Elasticity of Clay Brick prism of CM 1: 6 was 529.975 N/mm^2 and that of Fly ash brick prism of CM 1: 6 was 319.82 N/mm^2. The brick prism with mortar ratio of 1:4 exhibited higher Young's Modulus Elasticity than other two mortar ratios. This shows that the mortar ratio played an important role in the determination of Young's Modulus or Modulus of Elasticity of the brick masonry.

D. Results for Poisson's Ratio

Test set up were made to determine the Poisson's Ratio of masonry prisms for the mix ratio of CM 1:4, CM 1:5 and CM 1:6. The tests were carried out at the end of 7 days and 28 days on the brick prisms on a compression testing machine. The dial gauges were placed at three directions X, Y, Z respectively, since X and Z were two lateral directions and Y was the linear direction. Two compressometer were fixed to record the lateral movement of the prism and also for longitudinal movement at Y direction. The set up was ready to apply load and the load was applied gradually. Set the dial gauges to zero (LC =0.01) and the rod was pivoted at the center of the prism surface. The readings were taken at all three directions from the corresponding dial gauges at different loadings.

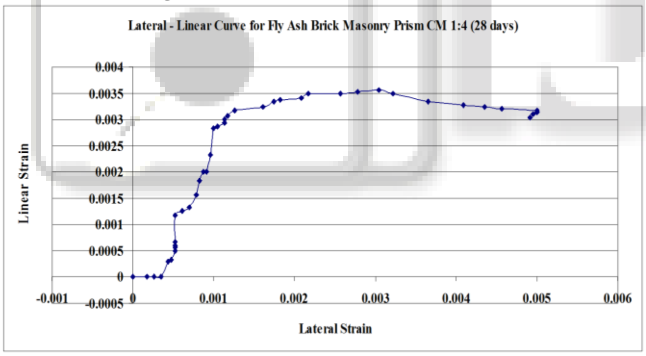

Fig. 12: Lateral vs. Linear Strain for Fly Ash Brick Prism CM 1:4 (28days)

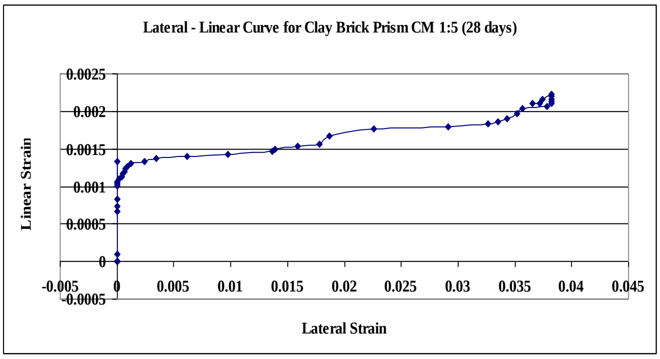

Fig. 13: Lateral vs. Linear Strain for Clay Brick Prism CM 1:5 (28days)

Using the experimental data, the graph was plotted between the Lateral Strain and Linear Strain as shown in the above Figure. The average value of Poisson's Ratio of Clay Brick prism of CM 1: 4 were 0.210 and that of Fly ash brick prism of CM 1: 4 was 0.683. Similarly, the average Poisson's Ratio of Clay Brick prism of CM 1: 5 was 0.319 and for Fly ash brick prism of CM 1: 5 was 0.074. Also, the average Poisson's Ratio of Clay Brick prism of CM 1: 6 was 0.610 and for Fly ash brick prism of CM 1: 6 was 0.158.

VII. FINITE ELEMENT MODELLING

A. General

Masonry is a composite material with the building brick units and the mortar as the joining material, which are bonded together. The basic mechanical properties of the masonry are strongly influenced by the mechanical properties of its constituents namely, brick and mortar. Utilizing the material properties obtained from the experiments and using actual geometric details of both components and joints, the behaviour of the brick masonry was numerically analysed using ANSYS. There was a need for developing a comprehensive finite element model, and numerical analysis method was used since it became more popular in solving numerous engineering problems. The finite element model was developed to understand the behaviour of the brick masonry walls. A three dimensional linear finite element model was developed to determine the strength, lateral displacement and the stress distribution throughout the masonry wall. As we know, the masonry itself is a composite material that consists of two materials depending upon the properties of the masonry unit and the mortar. Three approaches towards its numerical representation depending upon the level of accuracy and simplicity desired. They are (i) micro level modelling (ii) Meso level modelling and (iii) macro level modelling. The brick masonry prism of size 230mm x 230mm x 300mm was considered. The finite element model was used to understand the Experimental results.

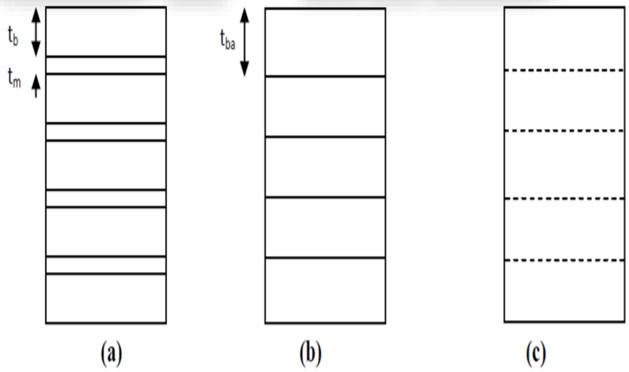

Fig 14 – (a) Micro level modelling (b) Meso level modelling(c) Macro level modelling

B. Formulation of the Model

Masonry strength was dependent upon the characteristics of the masonry unit, the mortar and the bond between them. Empirical formula as well as analytical and finite element model has been developed to predict the structural behaviour of the masonry. When the masonry was under compression, the masonry unit and the mortar will be under multi-axial state of stress. Hence, the present investigation had an attempt to develop a finite element model to predict the compressive strength of the masonry prism subjected to concentric compressive loading while using some failure theories developed for brittle materials under multi-axial state of stress. The finite element model was validated by comparing the predicted values with those obtained from the controlled experimental results. In the present study, the models with two different material assumptions were presented; one, masonry as a composite material consist of brick unit and mortar joint only ; two, consider that both phases of the material were replaced with an equivalent material property, assuming it to be a homogenized material. Brick unit was modelled using SOLID 185, which was an eight-node isoperimetric brick element type with three degrees of freedom; translations in the nodal along x, y and z directions respectively as shown in Fig 15

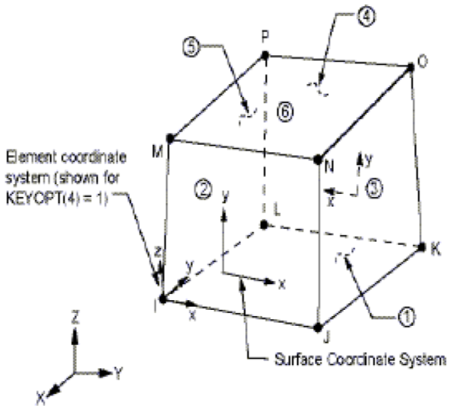

Fig. 15: Solid 185, 3D solid element type

C. Macro Level Modelling of the Brick Masonry

In this analysis, the brick masonry was made from two different materials of the clay bricks and the mortar had been replaced by an equivalent homogenous material. The macro-models were based on the use of constitutive laws for the masonry material; i.e. the stress-strain relationships adopted for the structural analysis were derived by performing tests on masonry, without distinguishing the bricks and the mortar behaviour.

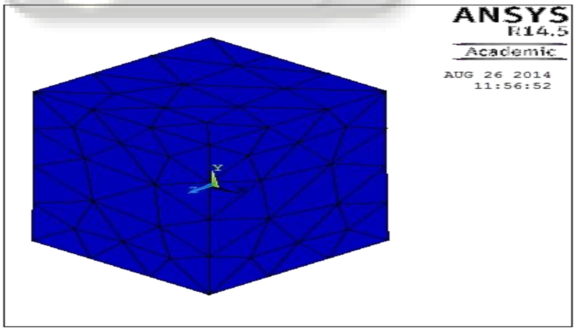

Fig. 16: Macro level modeling of brick masonry prism

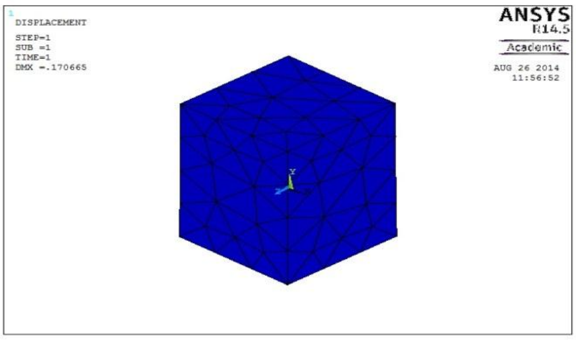

Fig. 17: Deflection of Clay Brick Masonry Prism CM 1:4 (28days)

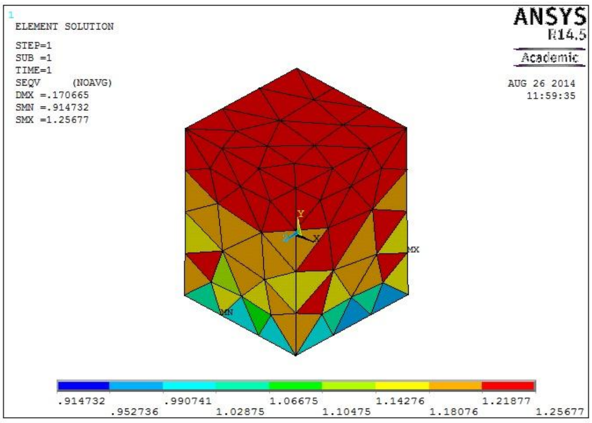

Fig. 18: von mises stress of Clay Brick Masonry Prism CM 1:4 (28days)

The ANSYS modeling was compared with the test results and the behavior had been observed. The masonry sustained damage in the form of cracks in the early stage of loading as the mortar break at the low level of the load compared to the brick units. The micro-modeling created was compared with the experimental results obtained and then the load and deflection behavior of the unreinforced clay brick masonry prism was predicted using finite element modeling and verified with the experimental data. The comparison of the predicted values of masonry compressive strength obtained from ANSYS and from with the experimental results are as shown in Fig 19.

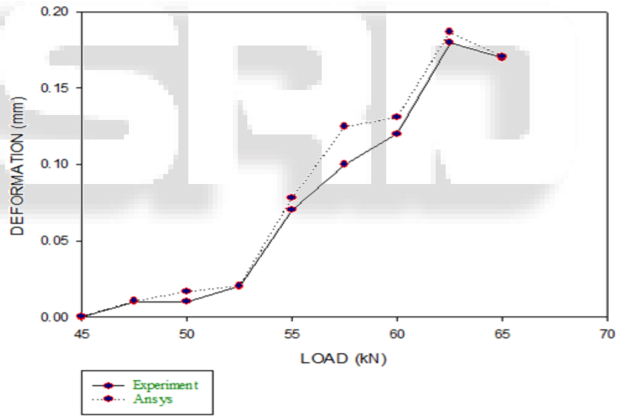

Fig. 19: Load vs. Deflection Curve Fly Ash Brick Masonry Prism (28days)

The result obtained from the software and experiment converged to be same and thus the results were verified.

VIII. SUMMARY

1) Compressive strength of Solid block prism of CM 1: 4 was 26.8% higher than Fly ash brick and 195% higher than clay brick prism for 28days.
2) Compressive strength of Solid block prism of CM 1: 5 was 64.60% higher than Fly ash brick and 204% higher than clay brick prism for 28days.
3) Compressive strength of Solid block prism of CM 1: 6 was 46% higher than Fly ash brick and 213% higher than clay brick prism for 28days.
4) Young's Modulus Elasticity of Clay Brick prism of CM 1: 4 was 874.22 N/mm^2 and for Fly ash brick prism of CM 1: 4 was 408.89 N/mm^2.

5) Young's Modulus Elasticity of Clay Brick prism of CM 1: 5 was 437.975 N/mm^2 and for Fly ash brick prism of CM 1: 5 was 476 N/mm^2.
6) Young's Modulus Elasticity of Clay Brick prism of CM 1: 6 was 529.975 N/mm^2 and for Fly ash brick prism of CM 1: 6 was 319.82 N/mm^2.
7) Poisson's Ratio of Clay Brick prism of CM 1: 4 was 0.210 and for Fly ash brick prism of CM 1: 4 was 0.683.
8) Poisson's Ratio of Clay Brick prism of CM 1: 5 were 0.319 and for Fly ash brick prism of CM 1: 5 was 0.074.
9) Poisson's Ratio of Clay Brick prism of CM 1: 6 were 0.610 and for Fly ash brick prism of CM 1: 6 was 0.158.

IX. CONCLUSIONS

- By comparing the test results, the solid block prisms were found to give higher compressive strength when compared to other masonry prisms.
- The experimental results of fly ash brick masonry proved that it had achieved maximum compressive strength and young's modulus, when compared to clay brick masonry prisms.
- Result obtained from the software and experiment converged to be same.

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