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"Experimental Analysis of Bond strength of Autoclaved Aerated Concrete Masonry with regards to Mortar Ratio and Mortar Thickness"

by

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Experimental Analysis of Bond strength of Autoclaved Aerated Concrete Masonry with regards to Mortar Ratio and Mortar Thickness"** submitted by Raghav Tandon (PUL074MSTIM011) in partial fulfillment of the requirements for the degree of Master of Science in Technology and Innovation Management.

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ABSTRACT

Autoclaved aerated concrete (AAC) blocks are commonly used for masonry walls. It is essential to assess the bond strength of the block-mortar interface for the AAC masonry walls in order to assess its tensile and shear bond strength under various mortar combination. This research investigates the bond strength of AAC block mortar interface made up of a) polymer modified mortars (PMM) and b) ordinary cement sand mortar of 1:4 and 1:6 mix of thickness 10mm,15mm and 20 mm respectively. A thin cement slurry coating was applied before placing the cement sand mortar in the masonry. For all types of interface, shear bond strength of masonry was studied using a triplet test, while the tensile bond strength was determined through a cross-couplet test. Among the cement sand mortar used in this study, cement sand mortar of ratio 1:4 and thickness 15mm showed the maximum shear strength of 0.13 MPa with the failure of blocks as the predominant failure while the PMM had shear bond strength of 0.12 MPa with the failure of blocks as the predominant failure type. However, in case of the tensile bond strength testing, PMM showed the tensile bond strength of 0.19 MPa, which was highest among all the test specimens used in this study. Considering both the tensile and shear bond strength of the AAC masonry based on the failure pattern, among all the combinations used in the experiment, either PMM or cement-sand mortar of ratio 1:4 and thickness of 15mm can be chosen for the AAC masonry.

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Raghav Tandon

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LIST OF ABBREVIATIONS

AAC	: Autoclaved Aerated Concrete
RCC	: Reinforced Cement Concrete
UTM	: Universal Testing Machine
SCM	: Sand Cement Mortar
PPC	: Portland Pozzolana Cement
CLC	: Cellular Light Weight Concrete
PPM	: Polymer Modified Mortar

CHAPTER ONE: INTRODUCTION

1.1 Background

Considering the unique thermal properties, high fire resistance and low density, AAC Blocks are being widely used as a construction materials in the residential and contemporary buildings. (Andlsun, 2006; Radhi, 2011). Due to the availability of blocks in large sizes, the AAC Masonry works are easy and rapid. The preparation of AAC is possible through the various range of cementitious materials; however, in common, materials like sand, Portland cement and fly ash are used. Sand is generally added in the mixture to achieve the adequate fineness. In order to provide the cellular composition and structure to the block, small amount of Aluminum powder is also added. Besides, varying the amount of aluminum powder also changes the density of the final block (Aroni et al., 1993; Fudge et al., 2019). Thus, due to the presence of aluminum in the composition, AAC possess porous structure with lightness and insulation properties (Aroni et al., 1993).

Generally, the compressive strength of AAC ranges from 1.5 to 10 MPa while its density ranges between 300 and 1000 kg/m^3. The density and porosity of the AAC block determines the compressive strength of the block. (Alexanderson, 1979) summarized that the increase in porosity and reduction in density results in decrease of the compressive strength. In order to have the adequate bond strength, adequate amount of binding material should be applied at the block interface.

Regardless of the different curing methods applied, thermal conductivity is dependent on the density, material constituents and the water content. The distribution and quantity of pores has great contribution for the prevention of transfer of heat. The lesser is the number of pores in the block, more it becomes better in the prevention of transfer of heat. As per the results obtained from (Narayanan & Ramamurthy, 2000b), increase in 1% increase of moisture by mass resulted in the increase of the thermal conductivity by 42%. Aerated concrete also has good fire resistance thereby reducing the risk of fire spread. This property is aided by the presence of solid-air buffer which contributes in the thermal insulation. As per the (RILEM, 1993), under the comparable conditions, AAC seems to provide good sound proof environment as compared to the dense concrete or mud blocks/bricks.

AAC Block has been evolving as one of the potential alternatives to the clay bricks and so on. There has been a successful history of the use of AAC blocks in different types of environments for all types of building (Wittmann et al., 1983; Concrete & Wittmann, 1992). Different studies have compared the compressive and tensile strength of the mud bricks with AAC. Using slender joint thickness of about 0.5mm or 1mm, the bond strength of the Autoclaved Aerated concrete (AAC) was observed by (Ferretti et.al., 2015). But this study ignored the dynamics of joint thickness on the behaviour of AAC masonry. Different researchers have studied the strength of AAC masonry, but the study seems limited in case of the mortar with variable mixture composition and join thickness.

1.2 Significance of the study

Autoclaved Aerated Concrete (AAC) block masonry can also serve as an alternative in the construction of masonry walls. The dynamics of the interface between the block and the mortar governs the strength of the AAC masonry. This study will observe the tensile and shear bond strength of the AAC masonry using Polymer Modified Mortar (PMM) of 3-4mm thickness and cement sand mortar of 1:4 and 1:6 ratio of thickness 10mm, 15mm and 20mm respectively. This will also help in signifying the relevancy of the use of cement sand mortar and PMM in the AAC masonry. It will be assessed by testing the specimens and understanding the failure patterns under different loading conditions.

1.3 Statement of the Problem

There has been extensive use of red clay brick for the construction purpose in Nepal. However, considering the environmental aspect, the use of kiln and production of red clay brick imposes severe environmental impact thereby degrading the air quality of the environment. The red clay bricks are obtained from the agricultural fields. Similarly, the increasing urbanization has also resulted in the shifting of brick chimneys and also closure away from the human settlement. Thus, the brick chimneys are likely to be removed or stopped from the areas with higher human settlement. Hence, it becomes essential to explore for the potential alternatives of red brick.

It is very much essential for a rapidly growing urbanization to adhere and cope up with the increasing demands. Thus, there is a need of the economic, effective and environment friendly alternative building materials. In this context, AAC Eco-blocks can serve as a potential alternative compared to red clay bricks in the construction market in terms of quality, reliability and environment friendly aspects. In case of Nepal, the use of AAC blocks is in the primitive phase. There lacks sufficient research and relevant studies for the effectiveness of AAC blocks in the construction industry. Similarly, there are very few studies in the local context about the optimum cement sand mortar proportion ratio for the better bond strength. This research aims to study the usability of AAC blocks as per the assessment of Bond Strength varying mortar proportion and mortar thickness.

1.4 Objectives

This study aims to work on following areas:

1.4.1 Main Objective

The main objective of this research is to identify and analyze the shear and tensile bond strength of AAC masonry varying the mortar ratio and mortar thickness.

1.4.2 Specific Objectives

- To determine the shear strength of the masonry triplet
- To determine the tensile strength of the masonry cross-couplet
- To compare the use of PMM with 3-4 mm thickness and cement sand mortar of ratio 1:4, 1:6 with thickness 10mm, 15mm and 20mm.

1.5 Limitation of Study

While carrying out this research, considering the various constraints, following limitations were considered:

- Considering the budget, resources and time constraints, Mortar mix of 1:4 and 1:6 ratio is considered for the study while the Mortar thickness considered was 10mm, 15mm and 20mm for the study.
- Among various tests compressive strength, bulk density, moisture content test was performed.

CHAPTER TWO: LITERATURE REVIEW

2.1 Research Gap

Comparative study on Cellular Light Weight Concrete, fly ash concrete and AAC, was done in 2017, keeping the density constant; which summed up a finding that AAC blocks were better in terms of compressive strength, fly ash concrete were better in terms of water absorption and Cellular Light Weight Concrete and AAC were quite similar and better than fly ash concrete in terms of thermal conductivity (Kurweti et al., 2017). Thus, the use of AAC masonry has also been evolving.

Similarly, for the AAC Masonry, the splitting tensile strength tests was carried out and the failure mechanism were identified by (Małyszko et al., 2017). In case of AAC masonry, there can be number of mortar joints like Polymer modified mortar (PMM) and cement-sand mortar. Different researchers have studied the properties of AAC masonry using different mortar materials. (Thamboo et al., 2013; Thamboo & Dhanasekar, 2015) used a thin layer (2-4mm) of PMM while constructing an AAC masonry. Similarly, (Thamboo & Dhanasekar, 2015) worked on the masonry using thin layer of polymer-based mortar of thickness 2mm. Using a thick cement sand mortar joint, Mallikarjuna (2017) studied the tensile and shear strength of the AAC masonry. Similarly, the examination of the shear, tensile and compressive strengths of AAC masonry using PMM was done by Bhosale et al. (2019). Generally, in practice, cement-sand mortar work is considered in the masonry works with the mortar thickness of range 10-18mm. However, there lacks enough research for the effective thickness of the cement-sand mortar joint in AAC-block masonry. The significance of this study is to observe the tensile and shear strength of the masonry of AAC prepared with PMM of 3mm thickness and 1:4 and 1:6 cement sand mortar mix ratio and thickness of 10mm, 15mm, 20mm mortar joint.

2.2 PMM

The mortar applied in the masonry of AAC block is a polymer-based joining material which provides high bond strength, durability and speed up the construction process. The polymer modified mortar is prepared by adding 300 ml of water to 1 kg of dry mortar mix for better workability. Thamboo & Dhanasekar (2015) studied the characteristics of AAC masonry using PMM of 2mm thickness.

2.3 Mortar Constituents

2.3.1 Cement

Cement used as a binding material is mixed as a powder and combined with other materials. Cement is generally used as a binding material which sets and hardens with other materials. Cement, itself is not sufficient to act as a binder unless it is combined with the aggregates. A mortar is formed when we add cement with sand while the concrete is formed when cement is mixed with coarse aggregate. Portland Pozzolana Cement is generally use in mortar preparation. The content of cement highly affects the strength and performance of the concrete depending upon the hydration of cement including its chemical and physical properties.

2.3.2 Sand

Sand passes through the IS 4.75mm sieve and is also known as fine aggregate. It is generally found in the river.

2.3.3 Water

Water contributes in the hydration and is thus the key component to form a mortar or concrete. It should be clean, potable and free from harmful impurities.

2.3 Laboratory Test

For the material test; different tests like sieve analysis, normal consistency test, bulk density test, moisture content and compressive strength test is performed.

2.3.1 Grading

The particle size distribution of the sand is done via grading test. Grading is done by passing the materials through a series of sieves stacked with bigger opening at the top and progressively smaller opening at the and weighing the materials retained on each sieve. Particle size distribution shows what sizes of particles are present in what proportions. Sieve analysis is needed to be performed to obtain grading of aggregate. A set of IS Sieves of different sizes (0.15mm, 0.3mm, 0.6mm, 1.18mm, 2.36mm and 4.75mm) are used as per requirements.

2.3.2 Compressive Strength Test

It is obtained by keeping the block in the testing machine. The block is then applied with the definite amount of load on the testing machine until it gets broken. The value of load at which the block breaks, is then noted. The area of the block is then measured by measuring its plan area (mm^2). The failure load(N) is then divided by the plan area to give the value of the compressive strength in MPa.

2.3.3 Bulk Density

It is defined as the ratio of weight of a substance to its volume. Bulk density of the block is obtained as per IS 6441 (Part I). First the dimensions of the block are measured and volume is calculated. Then the block is kept in the oven and dried till it achieves appreciable constant mass. Finally, the bulk density is calculated using the following expression: Bulk Density= Weight/Volume.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Design

Our study will be based upon the experiment carried out in the lab and its overall flow is given as:

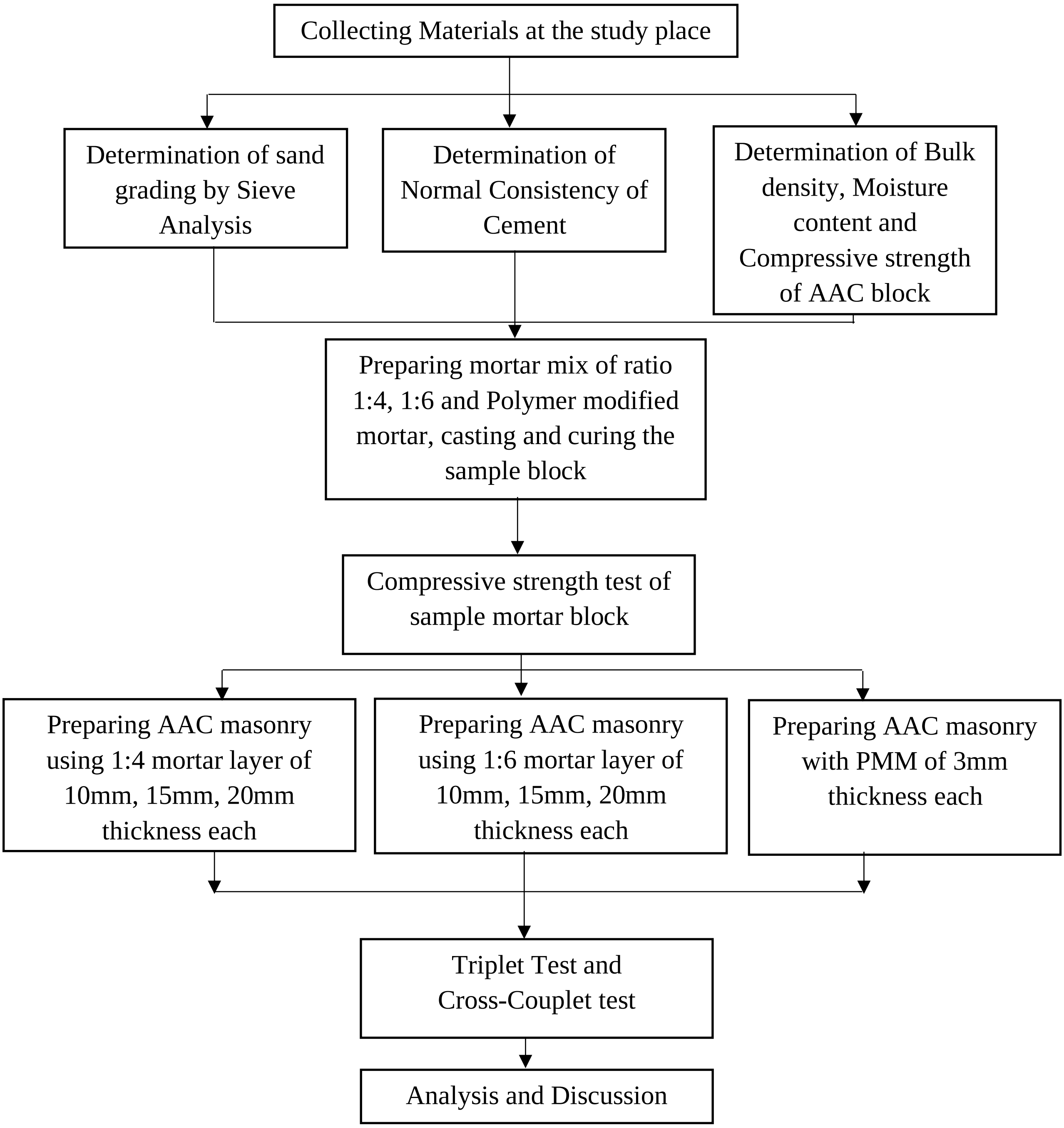


Figure 1 Research Methodology Framework of the Research

3.2 Materials

Materials like AAC Eco Block, PMM, Portland pozzolana cement, sand, and water will be used in the study. And, different equipment's/machines available in Central Material Testing Lab in Institute of Engineering, Pulchowk Campus were used for the experimental works namely-

- Sieve sets as per Indian Standard
- Sieve Shaking Machine
- Oven
- Electronic Balance
- Volumetric Flask
- Vicat Apparatus
- Buckets
- Mould for making cubes of size 70mmx70mmx70mm
- Vibrator
- Curing Tank
- Others

Materials are collected as shown in Annex

3.3 Physical Properties of Materials

It involves in the determination of the properties of sand, cement, and AAC-eco block used in the test. Sand Grading, Normal consistency and compressive strength of cement used is determined.

3.3.1 Properties of Cement.

PPC cement is used for the experimental works. The following properties is tested and determined as mentioned below.

i. Normal Consistency Test

Vicat apparatus with 10mm diameter plunger is used to determine the normal consistency of cement pastes which on penetration about 5-7mm of cement paste from the base of the Vicat mould give the desired proportionate of the water to prepare standard paste of cement in accordance to the IS 4031-4.

Procedure:

1) The desired weight of cement is mixed with the distilled water to make a paste.
2) Gauging is done for 3 to 5minutes and is done starting from the time when the water is added to the cement till the mould gets filled.
3) The Vicat mould is then filled with that paste and is further smoothened in its surface.
4) The plunger is then lowered gently till it kisses the surface of the paste. It is then released quickly to let it sink into the paste.
5) The depth of the penetration of the needle into the paste is noted down.
6) The whole procedure is then continued again by changing the proportion of the water until the penetration is 5-7mm from the base of the Vicat mould.

ii. Compressive Strength Test

It is done in accordance to IS 4031 (Part 6):

1) The appropriate proportion of cement (200g), sand(600g) and water are mixed.

   Water is $\left(\frac{P}{4}+3\right)$ percentage of joint mass of sand and cement.

   Where P is the proportion of water to give a paste of cement with standard consistency as mentioned by IS 4031-4.

3.3.2 Properties of Sand

The sand used to prepare samples is well washed and dried one. Various physical properties of sand are determined as described below:

i. Particle Size Distribution (Grading)

According to IS 2386 (part I)-1963, the sieve of various opening sizes 4.75mm, 2.6mm, 1.18mm, 600-micron, 300 micro, 150 micros will be used in sieve analysis of fine aggregate.

Procedure:

1) The sample is either dried at the standard room conditions or kept at oven with the range of temperature 100$\pm$10 ℃ before weighing.
2) Each sieve is then shaken separately over a dry clean tray for a period of two minutes or more.

3) After the completion of sieve analysis, the materials remaining on each sieve is weighed.

3.3.3 Properties of AAC block

The following properties is tested and determined as mentioned below.

i. Bulk Density Test

The bulk density is determined as per IS 6441 (Part I)-1972.

Procedure:

1) The dimension of the block is measured before drying which gives the measurement and will thus provide volume V of the specimen.
2) The specimen is then placed in oven at 110 $\pm$ 5 °C thereby removing its water content. It is then weighed.
3) If the weight of the specimen doesn't change by 0.2 percent even after four hours of drying, then the weight shall be considered constant weight W.

The bulk density γ in g/cm^{3}shall be calculated as:

$\gamma = \frac{W}{V}$ (g/cm^3) where,

W = dry weight in g, and

V = volume in cm^3

ii. Moisture Content Test

The moisture content is determined as per IS 6441 (Part I)-1972.

Procedure:

1) Weight the specimen before drying which is designated as W_1.
2) If the weight of the specimen doesn't change by 0.2 percent even after four hours of drying, then the weight shall be considered constant weight W. Moisture content F is determined as follows:

$$F = \frac{W1-W}{W} x100\ (percent)$$

where,

W_1= Weight of specimen and

W = Weight of dry specimen

iii. Compressive Strength Test (σ_{cu})

The compressive strength test is done in accordance with IS 6441 (Part V)-1972. Procedure:

1) For sample three cubes shall be taken from the specimen which have been tested before.
2) The sample is then kept in the testing machine. A standard load(P) of rate 0.05 – 0.196 N mm^{-2} is applied perpendicular to the cube such that the failure takes place in 30 seconds.

   $\sigma_{cu} = \frac{P}{A}$ N/mm^2

   Here, P is the ultimate load in N and A is the plan area in mm^2.

3.3.4 Determination of Joint Materials Properties

Cement sand mortar was prepared with two ratios of 1:4 and 1:6. For each cement sand mortar mix, the thickness was varied as 10 mm, 15 mm and 20 mm. It was then applied on the AAC block surface to study the bond strength. Cement-water slurry was initially applied on the block surface before applying the cement sand mortar as suggested by Raj et al. (2020).

PMM was prepared by adding 300 ml of water to 1 kg of dry mortar mix in this study. The thickness used for PMM was 3mm in our study.

i. Compressive Strength Test for 1:4 and 1:6 mortar mix

Compressive strength test of cement sand mortar specimen is done as per IS 2250. Procedure:

1) Mortar shall be of materials and proportions of 1:4 and 1:6 cement sand ratio by weight.
2) The dry mix of cement and sand is made initially followed by the addition of different proportion of water until the paste becomes workable,
3) Initially, around half of the mould is filled up the prepared mortar which is then compacted through the tampering. The mould is then completely filled and compacted in similar manner.
4) Mould is then kept at room temperature of 27±2°C for about 1 to 3days and then kept in a curing tank for 28days.

5) Specimen is tested after 3,7 and 28days after the curing.
6) Three specimens are made for each period of time specified.
7) Immediately after removing the specimen from the curing water, it should be tested.
8) The load is then applied into the specimen until the specimen fails. The load at which the specimen fails is then noted.

It can be computed as

Compressive Strength (N/mm^2) =$\frac{Maximum\ load\ at\ failure(N)}{Cross-sectional\ area\ (mm2)}$

3.3.5 Determination of shear and tensile bond Strength

It is done via testing the triplet specimen and cross-couplet masonry specimen. All the samples undergo curing process in wet conditions for about 28 days. Thickness of the mortar joint is varied as 10mm, 15mm and 20mm along with the mortar mix as 1:4 and 1:6 cement sand ratio.

i. Determination of shear bond strength of AAC masonry specimen

Procedure:

1) Using mortar joints as shown in Figure 2, three blocks are combined to prepare the triplet sample.
2) The sample is then provided with a constant load P as shown in figure 2.

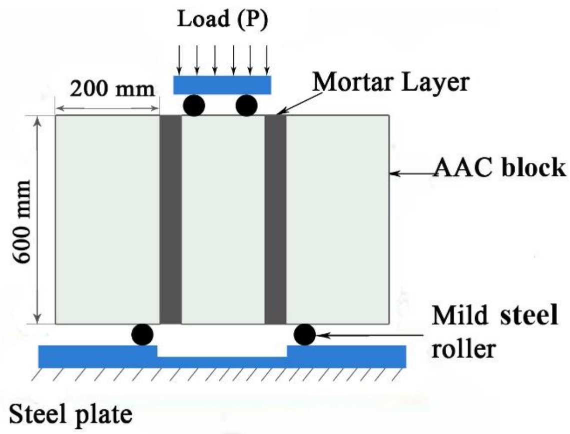


Figure 2 Experimental setup for the determinination of shear bond strength of AAC masonry

3) Formula to compute the shear bond strength is:

$\tau = \left(\frac{Pmax}{2Ac}\right)$

where,

P_{max} is the ultimate load before the failure of sample

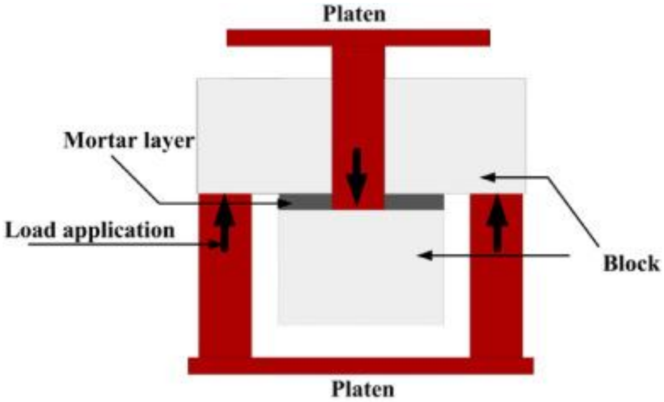
A_c= Contact area of the joint

Following failure patterns were observed: Type A: (Block failure), Type B (Mortar failure), Type C (Interface failure)

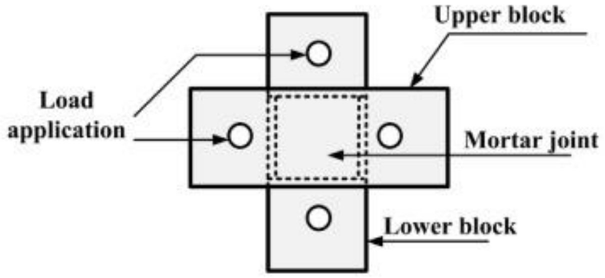
ii. Determination of tensile bond strength of AAC masonry

Procedure:

1) Two blocks were arranged as shown in Figure 3a to prepare the sample.
2) It was then provided with a constant downward load on the consecutive edges of the sample as shown in Fig 3a.



(a)



(b)

Figure 3 Experimental setup for the determination of the tensile bond strength

4) Formula to compute the tensile bond strength is:

$\tau t = \left(\frac{(Pt)max}{A}\right)$

Here, (P_t) max is the ultimate load before the failure of sample and A is the contact area.

Following failure patterns were observed: Type I (Complete failure of interface), Type II (Partial Failure of interface), Type III (Partial block failure), Type IV (complete block failure).

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Property of Sand

For the determination of the particle size, a sieve analysis was performed.

Sample Weight= 300.55gm

Table 1 Sieve Analysis

Size of the sieve (mm)	Weight of sand retained (gm)	Percentage of weight retained (%)	Cumulative percentage of weight retained (%)	Percentage Passing (%)
4.75	19.4	6.46	6.46	93.54
2.36	22.6	7.52	13.98	86.02
1.18	13.87	4.61	18.59	81.59
0.6	106.10	35.30	53.89	46.11
0.3	92.68	30.84	84.73	15.27
0.15	34.22	11.39	96.12	3.88
Pan	11.68	3.88	100	0
Total	300.55	100	273.77	

$$\text{Fineness Modulus} = \frac{Total\ cumulative\ per\ of\ weight\ retained}{100}$$

$$= \frac{273.77}{100}$$

$$= 2.74$$

From the experiment, the value of fineness modulus of sand was observed to be 2.74 which means the average size of particle of given fine aggregate sample was in between 0.3mm to 0.6mm which is of the range of size of sand used in mortar as per IS 2116.

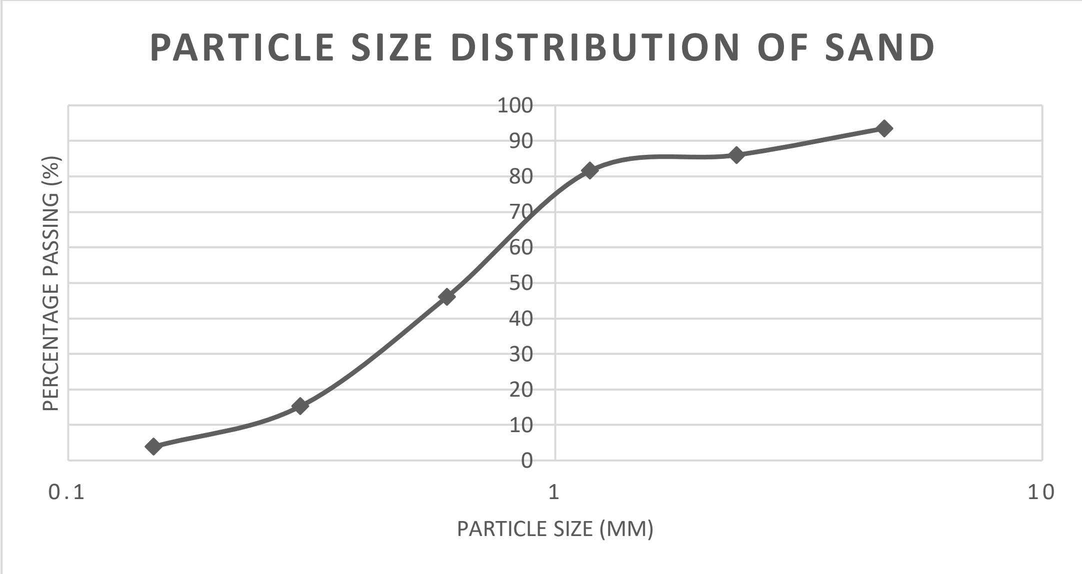


Figure 4 Particle Size Distribution of Sand

4.2 Bulk Density of AAC Block

The dimensions of the block and volume was measured and calculated as shown in the table below before and after drying.

Table 2 Result of Bulk Density of AAC Block

Weight before drying(kg)	Length (cm)	Breadth (cm)	Thickness (cm)	Volume (cm^3)	Weight after drying(kg)	Bulk Density (g/cm^3)
8.18	59.93	19.80	9.83	11669.09	5.98	0.51

The block was kept in the oven for drying until constant weight was obtained. Bulk density calculated after the block was removed from the oven.

The bulk density γ in g/cm^3 calculated as:

$\gamma = \frac{W}{V}$ (g/cm^3) where,

W = dry weight in g, and

V = volume in cm^3

Thus the average Bulk density of AAC Block was found to be 0.51 g/cm^3. Different researchers like (Duwadi, 2019) in the local context have also obtained results in the similar range.

4.3 Moisture Content of AAC Block

Before and after drying of the AAC block, the weight was measured and its value is shown the table below.

Table 3 Result of Moisture Content of AAC Block

Weight before drying- W_1(kg)	Weight after drying- W(kg)	Moisture Content F (%)
8.18	5.98	37.17

Moisture content will be calculated after the block is taken out from the oven. The block will be kept in the oven for drying until a constant weight is obtained.

Moisture content F:

$$F = \frac{W1-W}{W} x100\ (percent)$$

where,

W_1 is the weight before drying (kg), and W is the weight after drying (kg).

Thus the average Moisture Content of AAC Block was found to be 37.17 %.

(Duwadi, 2019) computed the moisture content to be 17.43% which seems less as compared to our experiment. It is due to the presence of the damp conditions in our experimental lab where the AAC block was stored.

4.4 Compressive Strength of AAC Block

It was calculated as shown in the table below:

Table 4 Result of the test

Weight (Kg)	Area (mm^2)	Thickness (mm)	Ultimate Load (P)- KN	Compressive Strength (N/mm^2)
2.08	39138.00	99.33	125.00	3.19

The compressive strength $\sigma_{cu} = \frac{P}{A}$ MPa

Here, P is the ultimate load (N) while A is the contact area (mm^2)

Hence, the value was observed to be 3.19 N/mm^2 or 3.19MPa which is in line with the results obtained from the experiments of (Chaipanich and Chindaprasirt 2015; Duwadi, 2019).

4.5 Normal Consistency Test of Cement

300g of cement is taken for the normal consistency test as per IS4031-4 Table:1. Varying proportionate of water as a percentage by weight of cement was added and corresponding depth of plunger penetration from the bottom of the Vicat mould was noted as shown in the table below:

Table 5 Depth of plunger penetration with respect to amount of water

Percentage of water (Pt%)	Weight of cement -g	Amount of water (ml)	Depth of penetration
30%	300	90	0
28%	300	84	8
29%	300	87	7

From the test, the normal consistency was obtained to be 29% which is also relevant with the results obtained from (Kumar, 2016) that was found in the range of 32%.

4.6 Compressive strength of mortar

4.6.1 Compressive strength of cement sand Mortar (1:4 and 1:6)

For the cement sand mortar proportion of 1:4 and 1:6, compressive strength was observed after curing the sample for 3, 7 and 28 days respectively.

Compressive Strength (N/mm^2) $= \frac{Maximum\ load\ at\ failure (N)}{Cross{-}sectional\ area\ (mm2)}$

<u>Sample tested after 3days of curing:</u>

Table 6 Result of Compressive Strength Test after 3 days of curing

Mortar Ratio	Weight -Kg	Water cement ratio (w/c)	Area (mm^2)	Ultimate Load (N)	Compressive Strength (MPa)
1:4	0.78	0.67	4900.00	38000.00	7.76
1:6	0.74	0.91	4900.00	12666.67	2.59

Thus, the average compressive strength of mortar after 3days of curing is:

Mortar 1:4 = 7.76 N/mm^2

Mortar 1:6 = 2.59 N/mm^2

Sample tested after 7days of curing:

Table 7 Result of the test after 7 days

Mortar Ratio	Weight - Kg	Water cement ratio (w/c)	Area (mm^2)	Ultimate Load (N)	Compressive Strength (MPa)
1:4	0.78	0.67	4900.00	58000.0	11.84
1:6	0.75	0.91	4900.00	23333.33	4.76

Thus, the average compressive strength of mortar after 7days of curing is:

Mortar 1:4 = 11.84 N/mm^2

Mortar 1:6 = 4.76 N/mm^2

Sample tested after 28days of curing:

Table 8 Result of test after 28 days

Mortar Ratio	Weight - Kg	Water cement ratio (w/c)	Area (mm^2)	Ultimate Load (N)	Compressive Strength (MPa)
1:4	0.78	0.67	4900.00	73333.33	14.97
1:6	0.75	0.91	4900.00	42500.00	8.67

Thus, the average compressive strength of mortar after 28days of curing is:

Mortar 1:4 = 14.97 N/mm^2

Mortar 1:6 = 8.67 N/mm^2

The results from the (Raj et al., 2020a) computed the compressive strength of the mortar (after 28 days of curing) to be 18.3 MPa and 9.4 MPa for Mortar 1:4 and Mortar 1:6 respectively.

4.6.2 Compressive Strength of Polymer Modified Mortar (PMM)

Compressive strength test of the PMM was done for 3 and 28 days respectively.

The compressive strength was calculated as follows:

Compressive Strength (N/mm^2) =$\frac{Maximum\ load\ at\ failure (N)}{Cross{-}sectional\ area\ (mm2)}$

Sample tested after 3days of curing:

Table 9 Result of Compressive Strength of PMM after 3 days of curing

Weight - Kg	Water cement ratio (w/c)	Area (mm^2)	Ultimate Load (N)	Compressive Strength (MPa)
0.65	0.33	4900.00	6125.00	1.25

Thus, the average compressive strength of PMM after 3days of curing is 1.25 N/mm^2

Sample tested after 28days of curing:

Table 10 Result of Compressive Strength of PMM after 28 days of curing

Weight - Kg	Water cement ratio (w/c)	Area (mm^2)	Ultimate Load (N)	Compressive Strength (MPa)
0.65	0.33	4900.00	56666.67	11.56

Thus, the average compressive strength of PMM after 28days of curing is 11.56 N/mm^2. The results from the (Raj et al., 2020a) computed the compressive strength of PMM mortar (after 28 days of curing) to be 6.34 N/mm^2.

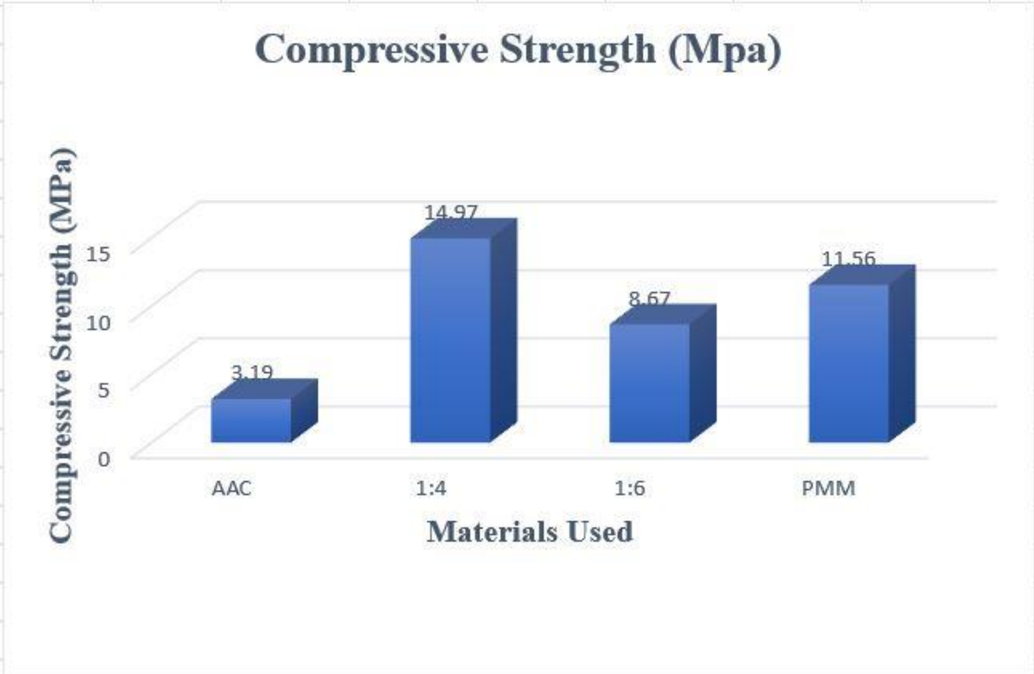


Figure 5 Compressive Strength of Materials Used

As AAC block is a light weight, porous, low density maetrial, we can see that its compressive strength is comparatively less than the compressice strength of the joint materials used i.e cement sand mortar of ratio 1:4 and 1:6 and PMM as shown in the figure 5 above.

4.7 Shear bond strength of AAC masonry

The triplet sample was tested after curing for 28days and varying the mortar thickness as 10mm, 15mm and 20mm for 1:4 and 1:6 cement sand mortar and also by using adhesive as joint material.

Table 11 Result of Triplet test of AAC Masonry

Mortar	Thickness (mm)	Cross Sectional Area (mm^2)	Load (Kg)	Shear Bond Strength (N/mm^2)	Failure Type
1:4	10	59000.67	1073.33	0.09	1 in Type A, 2 in Type C
	15	59090.45	1510.00	0.13	2 in Type A, 1 in Type C
	20	58856.89	750.00	0.06	1 in Type A, 2 in Type C
1:6	10	59256.33	1076.67	0.09	2 in Type B, 1 in Type C
	15	59234.44	1013.33	0.09	1 in Type A, 2 in Type B
	20	58934.33	976.67	0.08	2 in Type B, 1 in Type C
PMM	2-3	59278.33	1385.00	0.12	2 in Type A, 1 in Type C

There lacks enough research to compare shear bond strength of the masonry by varying mortar joint thickness. Hence, the observations from this experiment will be a baseline for the future research.

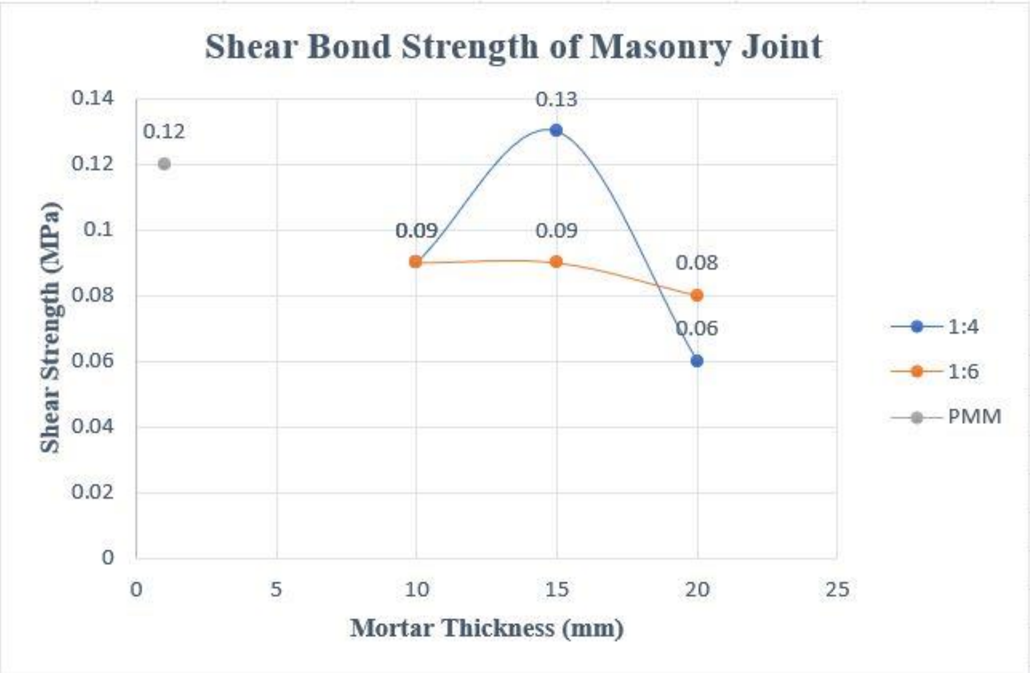


Figure 6 Shear bond strength of AAC masonry

From the above test results (as shown in Figure 6), the values of the shear bond strength using 1:4 and 1:6 cement-sand mortar mix were found to be in the range of 0.06-0.13 MPa while the AAC masonry with PMM had the shear bond strength of value 0.12 MPa. For the cement sand mortar mix of 1:6, the majority of the failure pattern exhibited was either type B or type C or both. However, in case of cement sand mortar mix of 1:4 ratio, joint with 15 mm mortar thickness exhibited highest shear bond strength of 0.13 MPa with failure type A being pre-dominant.

Hence, cement-sand mortar of ratio 1:4 with mortar joint thickness 15 mm seems to be the better option for the shear bond strength among all the mortar joint samples used in our study.

4.8 Tensial bond strength of AAC masonry

The cross-couplet masonry specimen after curing for 28days and varying the mortar thickness as 10mm, 15mm and 20mm for 1:4 and 1:6 cement sand mortar and also by using adhesive as joint material was tested.

Table 12 Result of Cross-couplet test of AAC masonry

Mortar	Thickness (mm)	Cross Sectional Area (mm^2)	Load (Kg)	Tensile Bond Strength (N/mm^2)	Failure Mode
1:4	10	33000.00	96.67	0.03	3 in Type IV
	15	36666.67	140.00	0.04	3 in Type IV
	20	34833.33	116.67	0.03	3 in Type IV
1:6	10	34866.67	73.33	0.02	3 in Type IV
	15	33600.00	106.67	0.03	3 in Type IV
	20	34233.33	83.33	0.02	2 in Type II, 1 in Type IV
PMM	2-3	26812.00	170.00	0.19	3 in Type IV

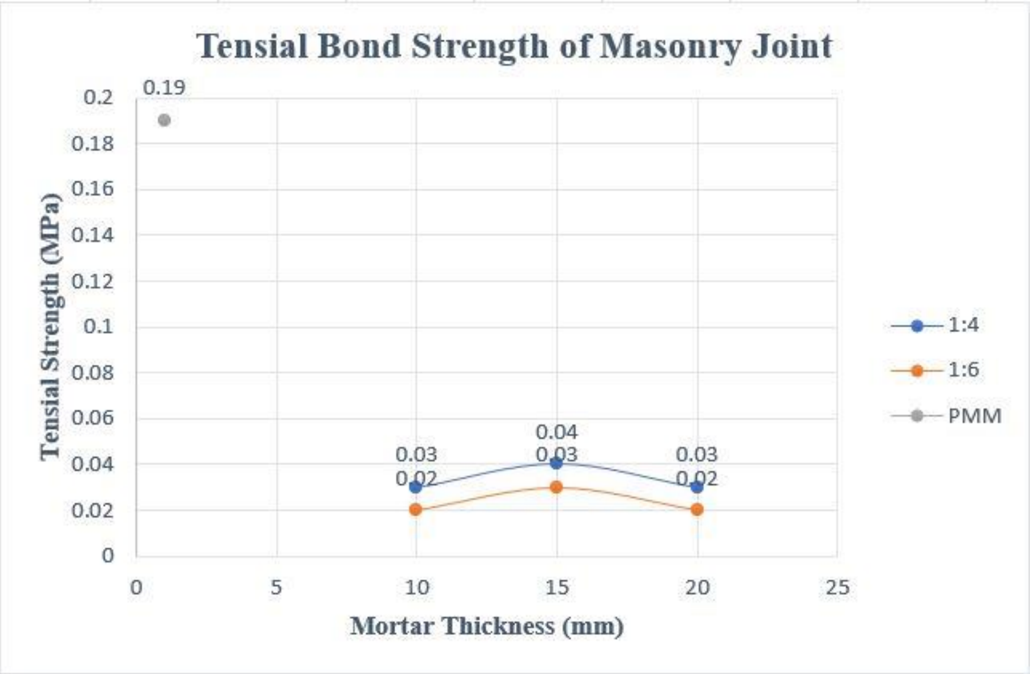


Figure 7 Tensial Bond Strength of Masonry Joint

From the cross-couplet test results (Fig 7), the tensile bond strength of AAC block masonry were found in the range of 0.02- 0.19 MPa. Masonry from PMM had the tensile strength of 0.19MPa with predominant Type IV failure.

However, the tensile bond strength of the cross-couplet using the cement-sand mortar of ratio 1:6 with 20 mm thickness exhibited predominant Type II failure. All other combination of cement sand mortar had the Type IV failure. Thus, any of the above cement-sand mortar combination except 1:6 mortar ratio of 20mm thickness can be preferred.

Since, most of the AAC masonry showed Type IV failure, it exhibited that the tensile strength of the AAC masonry joint is higher than the tensile strength of the block itself. Thus, all the possible mortar combination (except cement sand mortar 1:6, 20 mm thickness) can be recommended.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The tensile bond and shear bond strength of the AAC masonry was observed in the experiment.

- 1:4 mortar mix of thickness 15mm has shown the maximum shear strength of 0.13MPa with PMM mortar not far away with 0.12MPa. In both this mortar mix, failure of block was the predominant failure type.
- The tensile strength of PMM was found to be 0.19MPa, which is the highest among all type of mortar mix. Among the cement sand mortar, 1:4 mortar mix of 15mm thickness has shown the highest strength of 0.04MPa
- Considering both the tensile and shear bond strengths of the AAC masonry as well as the failure pattern, among all the combinations used in this experiment, either PMM or cement-sand mortar of ratio 1:4 and thickness of 15 mm can be used for the AAC masonry.

5.2 Recommendations

- Sample of AAC wall can be made and tested for uniaxial compression and three point bending as done by (Ferretti et al., 2015) and results can be compared to the results of this experiment.
- Same experiments can be done with brick and using the mortar mix as used in this experiment and compare the results.
- Cost analysis of this experiment can be done to choose the best option with respect to the cost and strength also.

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PUBLICATION

Tandon, R., Maharjan, S., and Gautam, S. (2021). Comparison of the Bond Strength using different Mortar Mix and Thickness in an Autoclaved Aerated Concrete (AAC) masonry. *Journal of Engineering Issues and Solutions (JoEIS)* (ISSN: 2091-0592) (Accepted).

ANNEX I: Data of Lab test results

Table 13 Test for Bulk Density of AAC Block

Sample	Weight before drying(kg)	Length (cm)	Breadth (cm)	Thickness (cm)	Volume (cm^3)	Weight after drying(kg)	Bulk Density (g/cm^3)
S1	8.034	59.900	19.900	9.800	11681.698	6.158	0.527
S2	8.628	60.000	19.800	9.900	11761.200	6.380	0.542
S3	7.888	59.900	19.700	9.800	11564.294	5.410	0.468

Table 14 Test for Moisture Content of AAC Block

Sample	Weight before drying- W_1(kg)	Weight after drying- W(kg)	Moisture Content F (%)
Sample-1	8.034	6.158	30.464
Sample-2	8.628	6.380	35.235
Sample-3	7.888	5.410	45.804

Table 15 Test for Compressive Strength of AAC Block

Sample	Cubes	Weight (Kg)	Area (mm^2)	Thickness (mm)	Ultimate Load (L)-KN	Compressive Strength (N/mm^2)
Sample-1	1	2.098	39204	99	115	2.933
	2	2.030	39203	100	100	2.551
	3	1.924	39006	99	100	2.564
Sample-2	1	2.128	39204	99	145	3.699
	2	2.134	39402	100	140	3.553
	3	2.148	38809	99	150	3.865

Table 16 Test for Compressive Strength of cement sand mortar after 3 days of curing

Mortar Ratio	Sample	Weight - Kg	Water cement ratio (w/c)	Cross-sectional area (mm^2)	Maximum Load (N)	Compressive Strength (N/mm^2)
1:4	S1	0.784	0.671	4900	36000	7.347
	S2	0.784	0.671	4900	42000	8.571
	S3	0.770	0.671	4900	36000	7.347
1:6	S1	0.738	0.910	4900	14000	2.857
	S2	0.743	0.910	4900	12000	2.449
	S3	0.753	0.910	4900	12000	2.449

Table 17 Test for Compressive Strength of cement sand mortar after 7 days of curing

Mortar Ratio	Sample	Weight - Kg	Water cement ratio (w/c)	Cross-sectional area (mm^2)	Maximum Load (N)	Compressive Strength (N/mm^2)
1:4	S1	0.762	0.671	4900	50000	10.204
	S2	0.798	0.671	4900	60000	12.245
	S3	0.788	0.671	4900	64000	13.061
1:6	S1	0.745	0.910	4900	20000	4.082
	S2	0.732	0.910	4900	24000	4.898
	S3	0.758	0.910	4900	26000	5.306

Table 18 Test for Compressive Strength of cement sand mortar after 28 days of curing

Mortar Ratio	Sample	Weight - Kg	Water cement ratio (w/c)	Cross-sectional area (mm^2)	Maximum Load (N)	Compressive Strength (N/mm^2)
1:4	S1	0.791	0.671	4900	62500	12.755
	S2	0.791	0.671	4900	100000	20.408

	S3	0.749	0.671	4900	57500	11.735
1:6	S1	0.741	0.910	4900	42500	8.673
	S2	0.755	0.910	4900	42500	8.673
	S3	0.758	0.910	4900	42500	8.673

Table 19 Test for Compressive Strength of PMM after 3 days of curing

Sample	Weight - Kg	Water cement ratio (w/c)	Cross-sectional area (mm^2)	Maximum Load (N)	Compressive Strength (N/mm^2)
S1	0.650	0.330	4900	6125	1.250
S2	0.635	0.330	4900	6125	1.250
S3	0.653	0.330	4900	6125	1.250

Table 20 Test for Compressive Strength of PMM after 28 days of curing

Sample	Weight - Kg	Water cement ratio (w/c)	Cross-sectional area (mm^2)	Maximum Load (N)	Compressive Strength (N/mm^2)
S1	0.659	0.330	4900	55000	11.224
S2	0.651	0.330	4900	57500	11.735
S3	0.652	0.330	4900	55000	11.224
S4	0.661	0.330	4900	57500	11.735
S5	0.647	0.330	4900	50000	10.204
S6	0.657	0.330	4900	65000	13.265

Table 21 Triplet test of AAC masonry

Mortar	Thickness (mm)	Sample	Cross Sectional Area (mm^2)	Load (Kg)	Shear Bond Strength (N/mm^2)	Average Shear Bond Strength (N/mm^2)	Failure Type
1:4	10	1	58934.33	670	0.06	0.09	Joint Failure
		2	59100.67	1500	0.13		Joint Failure
		3	58967.00	1050	0.09		Block Failure
	15	1	59069.00	2070	0.18	0.13	Block Failure
		2	58901.67	680	0.06		Block Failure

		3	59300.67	1780	0.15		Joint Failure
	20	1	58767.33	530	0.05	0.06	Joint Failure
		2	58901.67	650	0.06		Joint Failure
		3	58901.67	1070	0.09		Block Failure
1:6	10	1	59301.00	1080	0.09	0.09	Mortar Failure
		2	59167.00	1050	0.09		Joint Failure
		3	59301.00	1100	0.09		Mortar Failure
	15	1	59268.33	1100	0.09	0.09	Block Failure
		2	59267.67	890	0.08		Joint Failure
		3	59167.33	1050	0.09		Mortar Failure
	20	1	58702.00	990	0.08	0.08	Mortar Failure
		2	58967.00	890	0.08		Mortar Failure
		3	59134.00	1050	0.09		Joint Failure
PMM	2-3	1	59534.00	1240	0.10	0.12	Block Failure
		2	59167.00	1530	0.13		Block Failure
		3	59134.00	1385	0.12		Joint Failure

Table 22 Cross-couplet test of AAC masonry

Mortar	Thickness (mm)	Sample	Cross Sectional Area (mm^2)	Load (Kg)	Tensile Bond Strength (N/mm^2)	Average	Failure Mode
1:4	10	1	32400	80	0.02	0.03	Block Failure
		2	34200	50	0.01		Block Failure
		3	32400	160	0.05		Block Failure
	15	1	36000	140	0.04	0.04	Block Failure
		2	38000	150	0.04		Block Failure
		3	36000	130	0.04		Block Failure
	20	1	36100	170	0.05	0.03	Block Failure
		2	34200	70	0.02		Block Failure
		3	34200	110	0.03		Block Failure
1:6	10	1	32400	50	0.02	0.02	Block Failure
		2	38000	80	0.02		Block Failure
		3	34200	90	0.03		Block Failure
	15	1	32400	120	0.04	0.03	Block Failure
		2	34200	110	0.03		Block Failure
		3	34200	90	0.03		Block Failure
	20	1	36100	90	0.02	0.02	Partial Block Mortar Interface Failure
		2	32400	80	0.02		Partial Block Mortar Interface Failure
		3	34200	80	0.02		Block Failure
PMM		1	39800	200	0.05	0.19	Block Failure

		2	37026	140	0.04		Block Failure
		3	3610	170	0.47		Block Failure

ANNEX II: Pictures

Figure 8 StockPiling of AAC Samples

Figure 9 Measurement of the sample

Figure 10 Weighing of AAC before drying

Figure 11 Drying of AAC Block

Figure 12 Materials Collection

Figure 13 Sieve Analysis

Figure 14 Weighing of Sieve Sample

Figure 15 Compression Test of AAC Block

Figure 16 Normal Consistency Test of Cement

Figure 17 Mortar Cube Samples

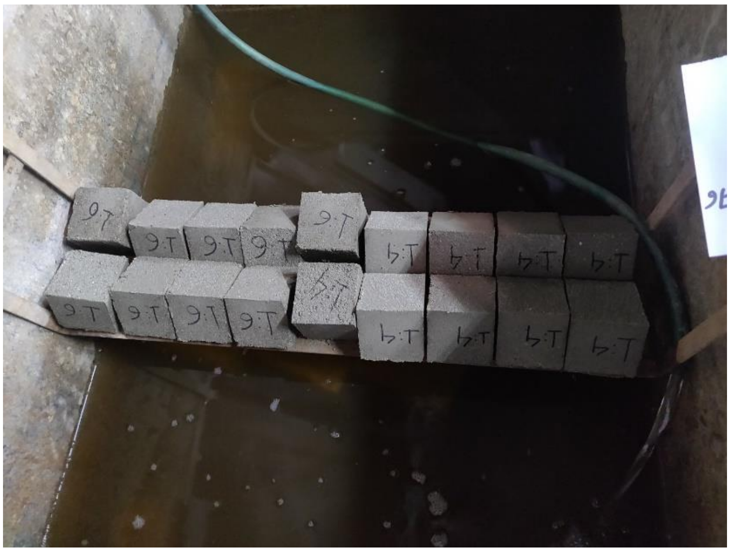

Figure 18 Curing of Mortar Cubes

Figure 19 Preparation of Triplet Samples

Figure 20 Preparation of Cross-Couplet Samples

Figure 21 Triplet Samples

Figure 22 Cross-couplet Samples

Figure 23 Shear Strength Test of Triplet Sample

Figure 24 Tensial Strength Test of Cross-couplet Sample

Figure 25 Complete Tensial Failure of Block (Type IV)

Figure 26 Partial block-mortar interface failure (Type II)

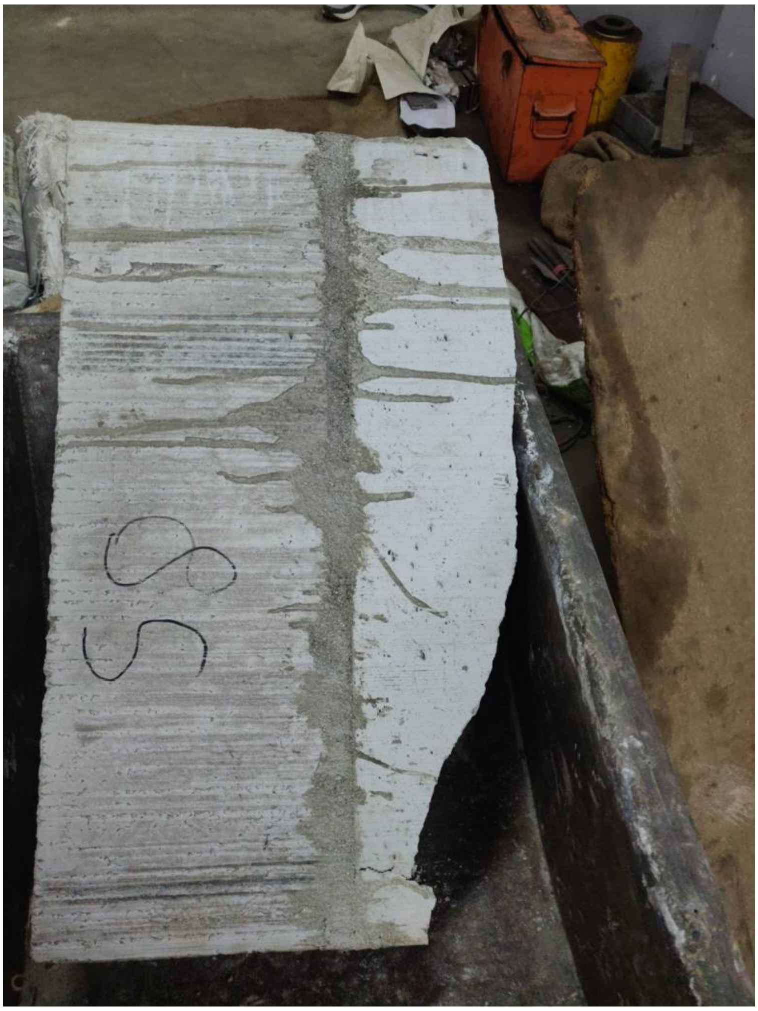

Figure 27 Failure of block (Type A)

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Comparison of the Shear and Tensile bond strength using different mortar mix and thickness in an Autoclaved Aerated Concrete (AAC) masonry

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Abstract:

Autoclaved aerated concrete (AAC) blocks are commonly used for masonry walls. It is essential to assess the bond strength of the block-mortar interface for the AAC masonry walls in order to assess its tensile and shear bond strength under various mortar combination. This research investigates the bond strength of AAC block mortar interface made up of a) polymer modified mortars (PMM) and b) ordinary cement sand mortar of 1:4 and 1:6 mix of thickness 10mm,15mm and 20 mm respectively. A thin cement slurry coating was applied on the block surface before placing the cement sand mortar in the masonry. For all types of interface, shear bond strength of masonry was studied using a triplet test, while the tensile bond strength was determined through a cross-couplet test. Among the cement sand mortar used in this study, cement sand mortar of ratio 1:4 and thickness 15mm showed the maximum shear strength of 0.13 MPa with the failure of blocks as the predominant failure while the PMM had shear bond strength of 0.12 MPa with the failure of blocks as the predominant failure type. However, in case of the tensile bond strength testing, PMM showed the tensile bond strength of 0.19 MPa, which was highest among all the test specimens used in this study. Considering both the tensile and shear bond strength of the AAC masonry based on the failure pattern, among all the combinations used in the experiment, either PMM or cement-sand mortar of ratio 1:4 and thickness of 15mm can be chosen for the AAC masonry.

Keywords: AAC blocks, cement sand mortar, PMM, failure pattern, shear bond strength, tensile bond strength, polymer modified mortar

1. Introduction:

AAC block masonry is one of the most widely used construction materials for the residential and contemporary building considering its unique thermal properties, low density and high fire resistance (Andlsun, 2006; Radhi, 2011). It has been evolving as a potential alternative to the clay as well as fly ash bricks. There has been a successful history of the use of AAC blocks in different types of environments for all types of building (Wittmann et al., 1983; Concrete & Wittmann, 1992). Similarly, the availability of blocks in large sizes makes the construction works of AAC blocks masonry easy and rapid. The preparation of AAC is possible through the wide range of cementitious materials; however, in common, Portland cement, fly ash and sand are used. Hamad (2014) suggested the addition of sand can contribute to achieve adequate fineness. Besides, a small amount of aluminum powder is also added in the mix to give the cellular structure of the block and on varying the amount of aluminum powder changes the density of the final block (Aroni et al., 1993; Fudge et al., 2019). AAC possesses porous structure with lightness and insulation properties due to the presence of aluminum paste in the composition; thereby making it a substantially different product as compared to the other light weight concrete materials (Aroni et al., 1993).

The compressive strength of AAC ranges from 1.5 to 10 MPa while its density varies from 300 to 1000 kg/m^3. The density and porosity of the AAC block determines the compressive strength of the block. Alexanderson (1979) summarized that the increase in porosity and decrease in density results in the decrease of compressive strength. The splitting tensile strength tests was carried out and the failure mechanism were identified by the Małyszko et al. (2017). For the adequate bond strength, there should be sufficient amount of cementitious material at the interface between the blocks. Different types of mortar joints such as cement-sand mortar and PMM are used. For instance, a thin layer (2-4mm) of PMM has been used in constructing AAC masonry (Thamboo et al., 2013; Thamboo & Dhanasekar, 2015). Thamboo & Dhanasekar (2015) worked on the concrete masonry using thin layer of polymer-based mortar of thickness 2mm. Ferretti et al. (2015) used thin cementitious gray glue joints of 1.5mm thickness in the AAC Masonry and studied the compressive and flexural strengths of the AAC masonry. Mallikarjuna (2017) studied the bond strength of AAC masonry using thick sand-cement mortar joints. Similarly, Ferretti et al. (2015) investigated the compressive and flexural strength of AAC masonry focusing the thin glue joints of thickness 0.5 to 1 mm, neglecting the effect of joint strength on the overall performance of AAC masonry. Bhosale et al. (2019) examined the bond strengths and compressive strengths of AAC masonry using polymer-based mortar of 2-5 mm thickness. Generally, in practice, cement-sand mortar thickness varies from 10-18 mm (IS:2250-1981 Reaffiremed 2000, 1981). However, little research exists on the optimum thickness of the cement-sand mortar joint in AAC-block masonry. The aim of this research is to identify the bond strength of the AAC masonry by using 1:4 and 1:6 cement sand mortar mix ratios with various thicknesses of 10 mm, 15 mm and 20mm.

2. Materials and methods

2.1 Sample

In this study, 108 AAC eco-blocks of dimension 600 mm x 200 mm x 100 mm of a single lot were collected from a local industry. The specimens were brought to the Central Material Testing Laboratory of Institute of Engineering, Tribhuvan University for testing. Three blocks were tested for compressive strength, 63 blocks were tested for shear strength and 42 blocks were tested for tensile strength.

2.2 Joint materials

Before starting the evaluation of shear and tensile bond strength of the AAC masonry, properties of the cement, sand, and AAC-eco blocks used in the test were determined. Vicat apparatus with a 10 mm diameter plunger was used to determine the normal consistency of cement paste in accordance with IS 4031 - 4 (2005). Similarly, particle size distribution (grading) of sand was analyzed in accordance with IS 2386- Part I (1963). For the study of the bond strength of AAC masonry, two types of joint materials were used in our study: they are, PMM and cement-sand mortar (CSM).

PMM are the composites prepared by using polymer with the cement and aggregates. A thin layer PMM of thickness 2-3 mm is generally used in the AAC block masonry (Thamboo & Dhanasekar, 2015). PMM was prepared by adding 300 ml of water to 1 kg of dry mortar mix in this study.

Cement sand mortar was prepared with two ratios of 1:4 and 1:6. For each cement sand mortar mix, the thickness was varied as 10 mm, 15 mm and 20 mm. It was then applied on the AAC block surface to study the bond strength. Cement-water slurry was initially applied on the block surface before applying the cement sand mortar as suggested by Raj et al. (2020).

2.3 Methods

The overall study was carried out to investigate the bond strength of AAC masonry with regards to the PMM mortar with 3 mm thickness and cement sand mortar ratios of 1:4 and1:6 with varying thickness of 10 mm, 15 mm and 20 mm. The overall method can be represented in the Figure 1.

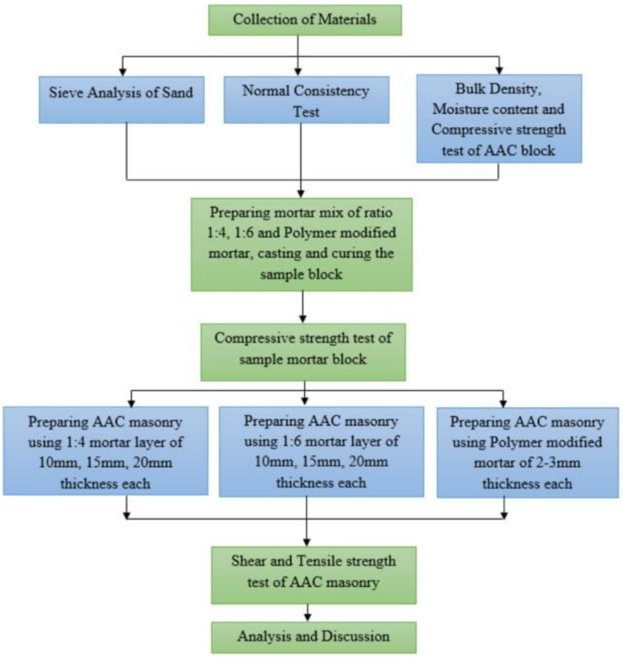


Figure 1 Overall flow of the study

2.3.1 Properties of AAC blocks

The physical properties like bulk density, and moisture content of the AAC blocks were investigated in accordance with IS 6441 (2001). The testing procedure for the bond strength were carried out as per ASTM (1991).

The test for compressive strength of AAC blocks was carried out from the blocks which were used to test the bulk density and moisture content. The test was carried out in accordance to IS 6441 (2001) and 3 sample blocks were used for the test. The samples were cut into three equal pieces such that each cut piece had the dimension of 200 mm x 200mm x 100mm. Then the compressive strength of total 9 pieces of AAC obtained from 3 samples were calculated by dividing the peak load with the area normal to the load.

2.3.2 Properties of joint materials

Normal consistency of cement paste was determined using Vicat apparatus in accordance with IS 4031 - 4 (2005). Similarly, particle size distribution (grading) of sand was analyzed in accordance with IS 2386- Part I (1963). Compressive strength of cement sand mortar of ratio 1:4 and 1:6 and PMM was determined in accordance with IS:2250 (1981 Reaffiremed 2000, 1981).

2.3.3 Test for tensile bond strength of AAC masonry

The cross-couplet specimen was prepared using AAC blocks and mortar bed joints. The specimen preparation and the testing procedure for the tensile bond strength were carried out as per ASTM (1991). The test was carried out in accordance with the procedures followed by Alecci et al. (2013) and Mallikarjuna (2017) as shown in Figure 2.

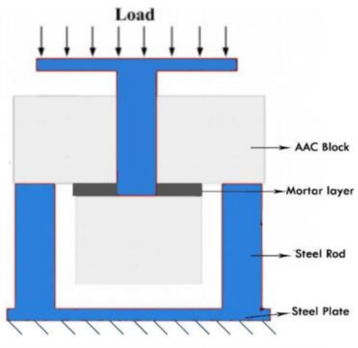


Figure 2 Setup for AAC tensile bond strength

Using a cross-couplet test, tensile bond strength of AAC block and mortar interface was determined as shown in Figure 2. The tensile bond strength was computed corresponding to the peak load at failure which is given by $\tau_t = \left(\frac{(Pt)max}{A}\right)$.

where τ_t is the tensile bond strength, $(P_t)_{max}$ is the Peak load recorded at failure and A is the contact area between the two blocks joined by mortar layer.

The failure of the block-mortar interface can take place in any of the following four patterns: complete block-mortar interface failure (Type I), partial block-mortar interface failure (Type II), partial tensile failure of the block (Type III), complete tensile failure of block (Type IV).

2.3.4 Test for shear bond strength of AAC masonry

Using a triplet test, the shear bond strength of the AAC block and mortar interface was determined as shown in Figure 3. The shear bond strength is given by $\tau = \left(\frac{P_{max}}{2A_c}\right)$

where P_{max} is peak shear load recorded at failure & A_c is the contact area of the joint.

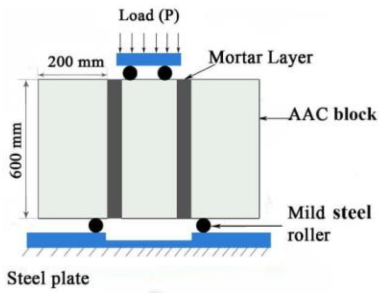


Figure 3 Setup of AAC shear strength test

The failure of the block– mortar interface using triplet test can take place in any one of the following patterns including: failure of block (Type A); failure of mortar (Type-B); failure of block-mortar interface (Type C).

3. Results and discussion

The physical properties of AAC block (bulk density, moisture content and compressive strength), and the properties of the joint materials were observed initially. It was then followed by the determination of shear and tensile bond strength of the AAC masonry using PMM. Similarly, results for the AAC masonry with cement sand mortar of ratios 1:4 and 1:6 and of thickness 10 mm, 15 mm and 20 mm were observed as discussed below:

3.1 Physical properties of AAC block

From the experiment, average value of bulk density of the AAC blocks were observed to be 0.51g/cm^3 as shown in Table 1. Similarly, moisture content of the AAC blocks were observed to be 37.17% as shown in Table 2. During the compressive strength test, the compressive load was applied with a loading rate of 0.05 - 0.196N/mm^2 until the sample couldn't take more load.

Thus, the compressive strength of AAC block sample was observed to be 3.19 MPa as shown in Table 3.

Table 1 Result of bulk density of AAC block

Weight before drying (kg)	Length of block (cm)	Breadth of block (cm)	Thickness of block (cm)	Volume of block (cm^3)	Weight after drying (kg)	Bulk density (g/cm^3)
8.18	59.93	19.80	9.83	11669.09	5.98	0.51

Table 2 Result of moisture content of AAC block

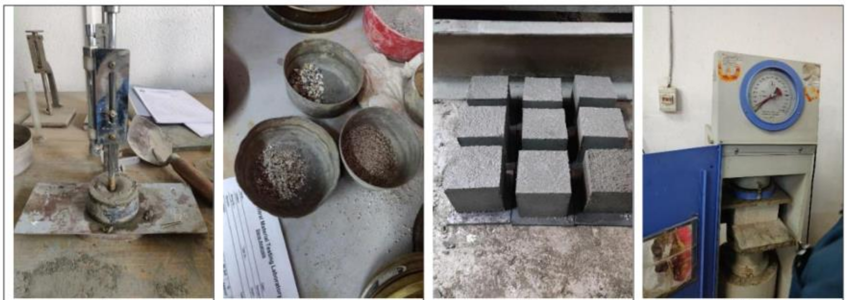
Weight of block before drying- W_1(kg)	Weight of block after drying- W(kg)	Moisture content F (%)
8.18	5.98	37.17

Table 3 Result of compressive strength test of AAC block

Weight of block (Kg)	Area of block (mm^2)	Thickness of block (mm)	Ultimate load (L)- KN	Compressive strength (N/mm^2)
2.08	39138.00	99.33	125.00	3.19

3.2 Determination of the properties of joint materials

From the experiment (Figure 4a), the normal consistency of cement was observed to be 29%. Similarly, from the sieve analysis (Figure 4b), the fineness modulus of sand was found to be 2.74 which means the average size of particle of given fine aggregate sample was between 0.3mm to 0.6mm which comes under the limit of sand used in mortar as per BIS (2116) .



(a) (b) (c) (d)

Figure 4 Properties of joint materials: (a)normal consistency of cement, (b)sieve analysis of sand, (c)mortar cube samples, (d)compressive test of AAC block

The compressive strength of the cement sand mortar of ratio 1:4 and 1:6 used in the experiment (Figure 4c) was observed to be 14.97 N/mm^2 and 8.67N/mm^2, respectively, while the PMM had the compressive strength of 11.56 N/mm^2 as shown in the **Table 4.**

Table 4 Results of compressive strength test of cement sand mortar after 28 days of curing

Mortar ratio	**Weight of mortar cube samples (Kg)**	**Water cement ratio (w/c)**	**Cross-sectional area of mortar cube sample (mm²)**	**Maximum load applied (N)**	**Compressive strength (N/mm²)**
1:4	0.78	0.67	4900.00	73333.33	14.97
1:6	0.75	0.91	4900.00	42500.00	8.67
PMM	0.65	0.33	4900.00	56666.67	11.56

3.3 Shear bond strength of masonry triplet

(a) (b)

Figure 5 AAC triplet sample: (a) preparation of triplet sample, (b) triplet test

Triplet specimen were prepared and tested as shown in *Figure 7* (a) and *Figure 7* (b). Three different failure patterns of the triplet specimen were observed during the test. As expected, the joint failure in shear was sudden and brittle. Most of the triplet specimens exhibited the block failure. The failure of the block-mortar interface using the triplet test took place in either of the following patterns:

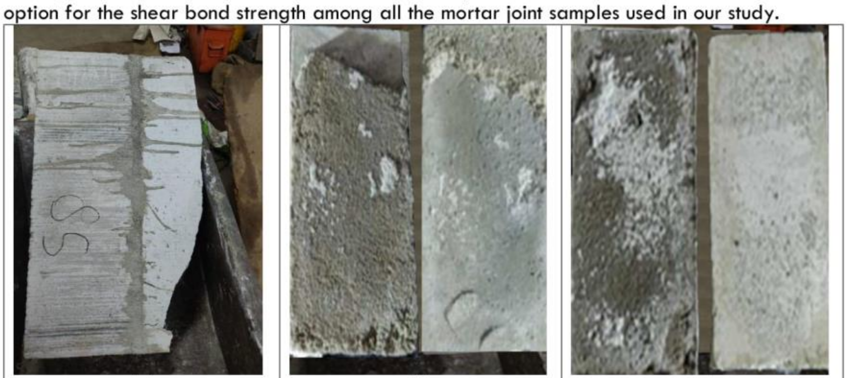
1. Failure of block (Type A as shown in Figure 6 (a)),
2. Failure of mortar (Type B as shown in Figure 6 (b)),
3. Failure of block-mortar interface (Type C as shown in Figure 6 (c)).

Table 5 Results from the triplet test of AAC masonry

Mortar	Thickness (mm)	Cross sectional area (mm²)	Load (Kg)	Shear bond strength (N/mm²)	Failure type
1:4	10	59000.67	1073.33	0.09	1 in Type A, 2 in Type C
	15	**59090.45**	**1510.00**	**0.13**	**2 in Type A, 1 in Type C**
	20	58856.89	750.00	0.06	1 in Type A, 2 in Type C
1:6	10	59256.33	1076.67	0.09	2 in Type B, 1 in Type C
	15	59234.44	1013.33	0.09	1 in Type A, 2 in Type B
	20	58934.33	976.67	0.08	2 in Type B, 1 in Type C
PMM	**2-3**	**59278.33**	**1385.00**	**0.12**	**2 in Type A, 1 in Type C**

From the triplet test results (as shown in Table 5), the values of the shear bond strength of AAC masonry using the cement-sand mortar were found to be in the range of 0.06-0.13 MPa while the AAC masonry with PMM had the highest shear bond strength of value 0.12 MPa. For the cement sand mortar mix of 1:6, the majority of the failure pattern exhibited was either type B or type C or both. However, in case of cement sand mortar mix of 1:4 ratio, joint with 15 mm mortar thickness exhibited highest shear bond strength of 0.13 MPa with failure type A being pre-dominant.

Hence, cement-sand mortar of ratio 1:4 with mortar joint thickness 15 mm seems to be the better option for the shear bond strength among all the mortar joint samples used in our study.



(a) *(b)* *(c)*

Figure 6 Different failure patterns of AAC triplet specimen: (a) failure of block (type-A), (b) failure of mortar (type-B), (c) failure of block-mortar interface (type-C)

3.4 Tensile bond strength of masonry cross-couplet

(a) *(b)*

Figure 7 AAC cross-couplet specimen: (a) cross-couplet ssamples, (b) tensile bond strength test of cross-couplet specimen

The cross-couplet specimen was prepared and tested as shown in the *Figure 7* (a) and *Figure* 7(b) respectively and the failure patterns observed during the test are shown in *Figure* 8(a) and *Figure* 8(b). The joint failure in tension was sudden and brittle. The failure of the cross-couplet specimens occurred in either of the following four patterns:

1. Complete block-mortar interface failure (Type I),
2. Partial block-mortar interface failure (Type II),
3. Partial tensile failure of the block (Type III),
4. Complete tensile failure of block (Type IV).

Table 6 Result of cross-couplet test of AAC masonry

Mortar	Thickness (mm)	Cross sectional area (mm^2)	Load (Kg)	Tensile bond strength (N/mm^2)	Failure mode
1:4	10	33000.00	96.67	0.03	3 in Type IV
	15	36666.67	140.00	0.04	3 in Type IV
	20	34833.33	116.67	0.03	3 in Type IV
1:6	10	34866.67	73.33	0.02	3 in Type IV
	15	33600.00	106.67	0.03	3 in Type IV
	20	34233.33	83.33	0.02	2 in Type II, 1 in Type IV
PMM	**2-3**	**26812.00**	**170.00**	**0.19**	**3 in Type IV**

From the cross-couplet test (as shown in *Figure* 7 (a) and *Figure* 7 (b), the tensile bond strength of AAC block masonry were found in the range of 0.02- 0.19 MPa. Masonry from PMM had the tensile strength of 0.19 MPa with predominant Type IV failure.

However, the tensile bond strength of the cross-couplet using the cement-sand mortar of ratio 1:6 with 20 mm thickness exhibited predominant Type II failure. All other combination of cement sand mortar had the Type IV failure. Thus, any of the above cement-sand mortar combination except 1:6 mortar ratio of 20mm thickness can be preferred.

Since, most of the AAC masonry showed Type IV failure, it exhibited that the tensile strength of the AAC masonry joint is higher than the tensile strength of the block itself. Thus, all the possible mortar combination (except cement sand mortar 1:6, 20 mm thickness) can be recommended.

(a) (b)

Figure 8 Different failure patterns of AAC cross-couplet specimen: (a) partial block-mortar interface failure (Type-II), (b) complete tensile failure of block (Type IV)

Partial interface failure (Type II as shown in *Figure* 8 (a) was mainly observed using the 1:6 mortar of joint thickness 20 mm. In this type of failure, a portion of either block or mortar gets stuck to each other. In case of complete tensile failure of block (Type IV as shown in *Figure* 8 (b) the block completely failed in tension and the joint remained intact. This type of failure occurs when the bond strength of block-mortar interface exceeds the tensile strength of block. The failure pattern of type (IV) was observed mainly using the mortar PMM, 1:4 mortar of all joint thickness and 1:6 mortar with joint thickness of 10 mm and 15 mm.

3.5 Comparison of bond strength using various joint materials and different joint thickness

From Table 5 and *Table 6*, both shear and tensile bond strengths of the AAC masonry using cement-sand mortar was less as compared to the shear and tensile bond strength of PMM.

Although the 1:6 mortar had a low shear bond strength, its tensile bond strength for joint thickness of 15 mm was similar as compared to the tensile bond strength of 1:4 mortar.
From the experiment, either PMM or cement sand mortar ratio 1:4 with thickness 15 mm was found to be satisfactory for shear bond strength as compared to other combination. However, in case of tensile bond strength, all the combination (except cement sand mortar of ratio 1:6 & 20 mm thickness) was found to be satisfactory.

4. Conclusions

Shear and tensile bond strength of the AAC masonry using triplet and cross-couplet specimen was studied. In order to study the masonry bond strength, the AAC masonry have been assembled using either ordinary sand-cement mortar or PMM in combination with cement slurry coating.

- 1:4 mortar mix of thickness 15 mm showed the maximum shear bond strength of 0.13 MPa while the PMM mortar showed 0.12 MPa. In both of these mortar mixes, failure of blocks was the predominant failure type.
- PMM mortar showed the tensile bond strength of 0.19 MPa which was the highest among all types of mortar mix. Among the cement sand mortar, 1:4 mortar mix of 15 mm thickness showed the highest tensile bond strength of 0.04 MPa.
- Considering both the tensile and shear bond strengths of the AAC masonry as well as the failure pattern, among all the combinations used in this experiment, either PMM or cement-sand mortar of ratio 1:4 and thickness of 15 mm can be used for the AAC masonry.

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