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Shear and tensile bond strengths of autoclaved aerated concrete (AAC) masonry with different mortar mixtures and thicknesses

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Abstract

Autoclaved aerated concrete (AAC) blocks are commonly used for masonry walls. In order to understand the strength of AAC masonry, it is essential to assess the tensile and shear bond strengths of the AAC block-mortar interface for various mortar combinations. This research investigates the bond strength of AAC block mortar interface made up of a) polymer modified mortar (PMM) and b) ordinary cement sand mortar of 1:4 or 1:6 ratio with thickness of 10mm, 15mm or 20mm. 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 0.13MPa with the failure of blocks as the predominant failure while the PMM had shear bond strength of 0.12MPa 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 0.19MPa, which was highest among all the test specimens used in this study. Considering both the tensile and shear bond strengths of the AAC masonry and based on the observed 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, polymer modified mortar, shear bond strength, tensile bond strength.*

1. Introduction

Autoclaved Aerated Concrete (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 10MPa while its density varies from 300 to 1000kg/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 1mm, 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 2-5mm thickness. Generally, in practice, cement-sand mortar thickness varies from 10-18mm (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 10mm, 15mm and 20mm.

2. Materials and Methods

2.1 AAC Blocks

In this study, 108 AAC eco-blocks of dimension 600mm x 200mm x 100mm 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 strengths of AAC masonry, properties of cement, sand, and AAC blocks used in the test were determined. Vicat apparatus with a 10mm 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 is the composite prepared by using polymer with cement and aggregates. A thin layer of PMM with thickness of 2-3mm is generally used in AAC block masonry (Thamboo & Dhanasekar, 2015). In this study, PMM was prepared by adding 300ml of water to 1kg of dry mortar mix.

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 10mm, 15mm and 20mm. 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). Compressive strength of cement sand mortar of ratio 1:4 and 1:6 and PMM was determined in accordance with IS:2250 (1981 Reaffirmed 2000, 1981).

2.3 Methods

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

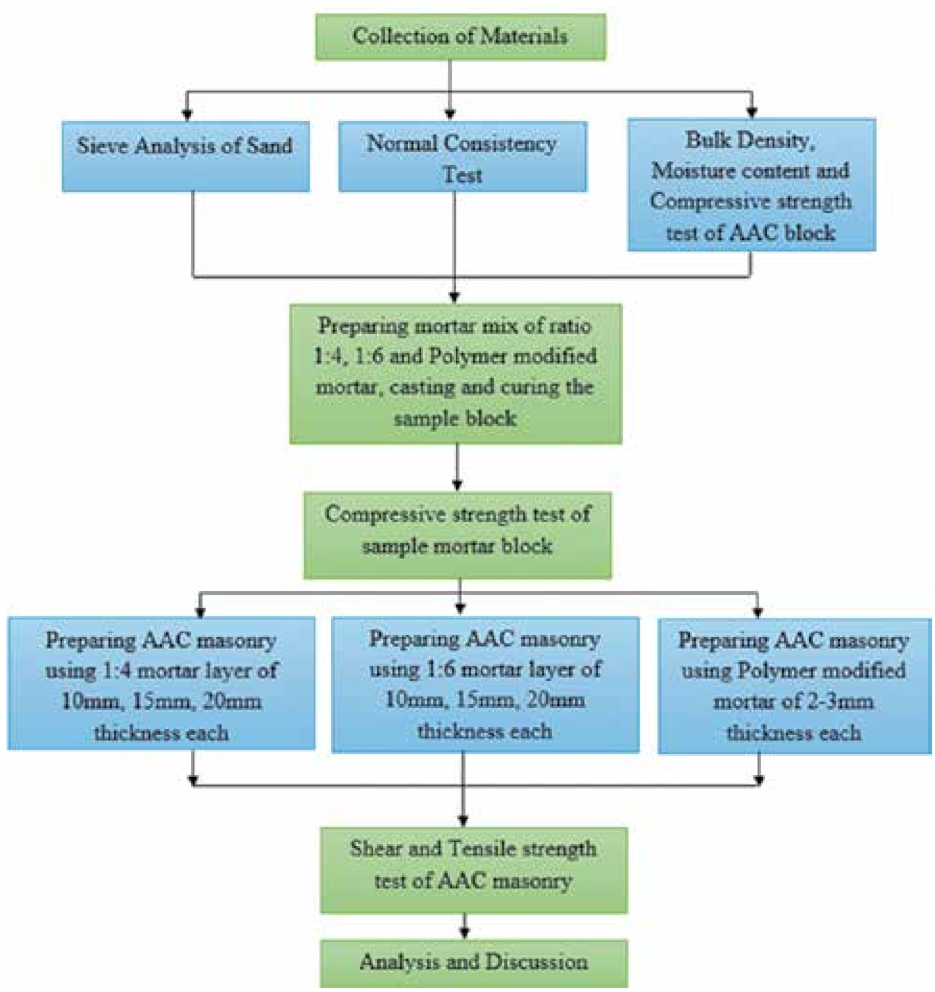

Figure 1: Overall flow of the study

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 200mm x 200mm x 100mm. Then the 9 pieces of AAC obtained from 3 samples were tested for compressive strength. Compressive strength for each piece was obtained by dividing the peak load with its area normal to the load.

2.3.2 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 Fig. 2.

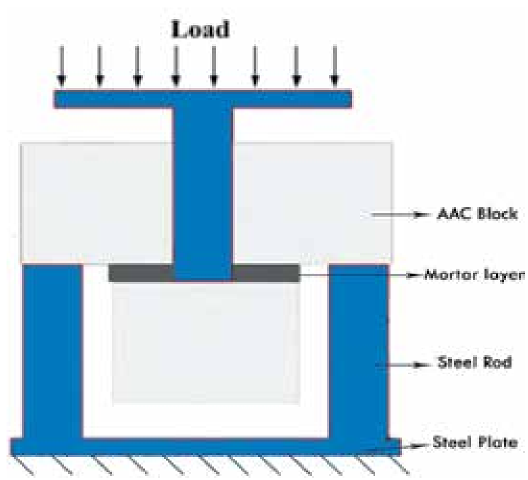

Figure 2: Setup for AAC tensile bond strength

Using a cross-couplet test, tensile bond strength of AAC block and mortar interface was determined as shown in Fig. 2. The tensile bond strength was computed corresponding to the peak load at failure which is given by:

$$\tau_t = \left(\frac{(Pt)max}{A}\right). \qquad (1)$$

Where,

Pmax	Peak load recorded at failure
A	Contact area of the joint

where τ_t is the tensile bond strength, (Pt)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).

2.3.3 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 Fig. 3.

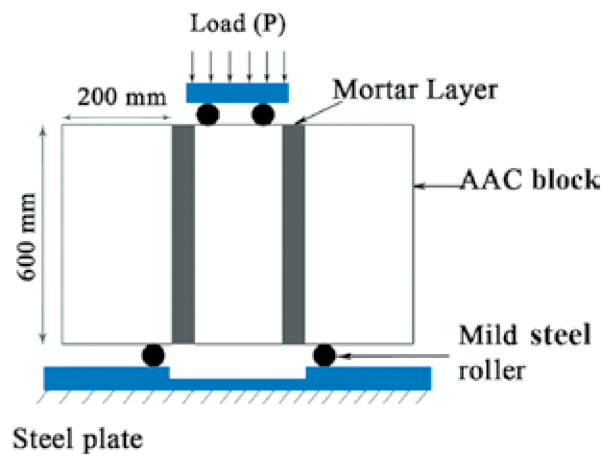

Figure 3: Setup of AAC shear strength test The shear bond strength is given by

$$\tau = \left(\frac{P_{max}}{2A_c}\right) \quad (2)$$

Where,

Pmax	Peak shear load recorded at failure
Ac	Contact area of the joint

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); and 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. Shear and tensile bond strength of the AAC masonry using PMM were determined thereafter. Similarly, results for the AAC masonry with cement sand mortar of ratios 1:4 and 1:6 and of thickness 10mm, 15mm and 20mm were observed as discussed below:

3.1 Physical Properties of AAC Block

From the experiment, average value of bulk density of the AAC blocks was 510kg/m^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 average compressive strength of AAC block samples was observed to be 3.19MPa as shown in Table 3.

Table 1: Bulk density of AAC blocks

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: Moisture content of AAC blocks

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: Compressive strength of AAC blocks (average of 9 tests)

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 the normal consistency of cement was observed to be 29% (Fig. 4a). Similarly, from the sieve analysis, the fineness modulus of sand was found to be 2.74 (Fig. 4b) which means the average size of particles of the fine aggregate was between 0.3 to 0.6mm and falls 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 an AAC block

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

Triplet specimens were prepared and tested as shown in Fig. 5a and Fig. 5b. 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 mode. The failure of the block-mortar interface using the triplet test occurred in either of the following patterns:

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

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 0.06-0.13MPa while the AAC masonry with PMM had the highest shear bond strength of value 0.12MPa. For the cement sand mortar mix of 1:6, 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, the joint with 15mm mortar thickness exhibited the highest shear bond strength of 0.13MPa with failure type A being pre-dominant.

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

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
	10	59000.67	1073.33	0.09	1 in Type A, 2 in Type C
1:4	**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
	10	59256.33	1076.67	0.09	2 in Type B, 1 in Type C
1:6	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**

(a) (b)

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

(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

The cross-couplet specimens were prepared and tested as shown in Fig. 7a and Fig. 7b, respectively. The failure patterns observed during the test are shown in Fig. 8a and Fig. 8b. 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).

(a)

(b)

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

Results from the cross-couplet test (as shown in Fig. 7a and Fig. 7b) are presented in Table 6. Tensile bond strength of AAC block masonry were found in the range of 0.02- 0.19MPa. Masonry from PMM had the tensile strength of 0.19MPa with predominant Type IV failure.

However, the tensile bond strength of the cross-couplet specimens using cement-sand mortar of ratio 1:6 with 20mm thickness predominantly exhibited Type II failure. All other combinations of cement sand mortar showed the Type IV failure. Thus, any of the studied cement-sand mortar combinations shown in Table 6 can be used for AAC block masonry with the exception of 1:6 mortar ratio of 20mm thickness.

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

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**

Partial interface failure (Type II as shown in Fig. 8a) was mainly observed using the 1:6 mortar of joint thickness 20mm. 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 Fig. 8b) 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 the block. The failure pattern of type (IV) was observed mainly using PMM mortar, 1:4 mortar of all joint thicknesses and 1:6 mortar with joint thicknesses of 10mm and 15mm.

(a) (b)

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

3.4 Comparison of Bond Strengths

From Table 5 and Table 6, both shear and tensile bond strengths of the AAC masonry using cement-sand mortar was less compared to the shear and tensile bond strength of PMM. Although the 1:6 mortar had low shear bond strength, its tensile bond strength for joint thickness of 15mm was similar as compared to the tensile bond strength of 1:4 mortar. From the experiment, either PMM or cement sand mortar ratio of 1:4 with thickness of 15mm was found the best for shear bond strength as compared to other combinations. However, in case of tensile bond strength, all the combinations (except cement sand mortar of ratio 1:6 & 20mm thickness) were found to be satisfactory.

4. Conclusions

This study investigated the shear and tensile bond strengths of AAC masonry using triplet and cross-couplet specimen. In order to study the masonry bond strength, the AAC masonry was constructed using either ordinary sand-cement mortar or PMM in combination with cement slurry coating. The following are the main findings:

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

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Conflict of Interests

Not declared by authors.

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