



INVESTIGATING HOLLOW FOAMED CONCRETE BLOCK WALLS: EFFECT OF USING ADDITIVES AND JOINT MATERIAL TYPE

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ABSTRACT

This study is concerned with the effect of the use of additives and joint material type (cement mortar and adhesive material) in hollow foamed concrete blocks through testing walls built with these blocks by applying axial compression force. In this study, three walls were built. In the first wall, cement mortar as a joint material between the cuboid blocks was used. While, in the second wall bonding adhesive material was used. In the third wall, conventional of foamed concrete (without additives) was used in producing the hollow block units which were bonded by using a bonding adhesive material. The compressive behavior and modulus of elasticity were studied, and the deformation and failure of masonry walls were studied as well. It was observed that the use of a bonding adhesive to bond the block units made of additives gave the highest compressive strength (1.08 MPa) which was about (27 and 38) % higher than the cement mortar wall and the hollow concrete block wall without additives respectively and the modulus of elasticity (46.9 MPa) and also gave the highest bearing capacity (214 kN). However, the use of a bonding adhesive helped in reducing the wall displacement. Finally, it was found that the lower the fractal dimension (D) the stronger the wall.

KEYWORDS

Additives, Bond shear strength, Compressive strength, Foamed concrete, Hollow Block, Joint materials, Walls.



1. INTRODUCTION

Energy efficiency and sustainability standards are crucial to consider in the design of new construction and should not be neglected. In civil engineering, mortar is essential because it holds bricks and blocks together in buildings. Lime and cement are the two basic types of mortar that are used traditionally. The most traditional kind, lime mortar, has been in use for many years (Ahmed and Kamau, 2017). For building constructions, mortar joints are crucial for both loading and thermal insulation (Jasiński, 2019; Li et al., 2020). The thickness of the mortar bed joint is one of the factors that determine the compressive strength of bricks. Because masonry is a composite material, the kinds of stresses that arise from uniaxial compression depend on the mortar's and the masonry unit's respective elastic properties (Reddy and Rao, 2009). Aerated concrete blocks (AAC) loading performance is enhanced by the high strength of the mortar in the mortar joints, but their thermal resistance may be lowered as a result of the precise thermal bridge that forms across the mortar joints (Reddy and Rao, 2009; Raj and Dixit, 2020). In a study of (Raj and Dixit, 2020) polymer modified mortar (PMM) and sand cement mortar (SCM) are two types of joint materials (mortar) that were used to assess the strength of the binding between AAC stones. In comparison to masonry constructed using PMM mortar, the masonry constructed with SCM mortar had a lower shear bond strength. (Zengin et al., 2018) studied the effect of using cement mortar and natural hydraulic lime as binders and their thickness on the behavior of the walls. It was noticed that the use of cement mortar helped in improving the load by about 121% higher than that of natural hydraulic lime. Furthermore, a low cement content of cement-sand mortar has a reduced shear bond strength. Three different mortar mixture types were employed by (Zahra and Asad, 2021) to construct the stocked blocks. Each mortar was created in a mortar mixer by varying the ratios of water, lime, cement, and sand. There were other blocks that were hollow and solid. There were two applications for the mortar: complete mortar and face shell mortar. Because the mortar in these situations is smaller than in full bedded stocked blocks, face shell bedded stocked blocks typically have a 15% drop in masonry strength. (Jassim, 2022) studied the effect of using additives in the production of solid hexagonal concrete blocks with a density of 1500 kg/m^3 to build a wall. It was noted that the use of additives contributed to improving the compressive strength of the walls by about 46%.

In this study, the bonding adhesive under the influence of shear force and the bonding effect of additives in hollow foam concrete blocks manufactured with a density of 1300 kg/m^3 were studied, in addition to studying the use of joint materials (cement mortar in a ratio of 1:3) and bonding adhesive and their effect on compressive strength, modulus of elasticity, failure mode

and fracture dimension in hollow foam concrete walls.

2. MATERIALS AND PRODUCTION

In this study, hollow foamed concrete blocks with a density of 1300 kg/m^3 were produced without and with additives. The materials used in this study were ordinary Portland cement according to (ASTM C150, 2007), sand passed through a 2.36 mm sieve (Obaid and Hilal, 2021), tap water, and foam. Modified foamed concrete blocks were also produced with using fly ash Class F, silica fume, and superplasticizer to improve the properties of concrete mix. In this study, foamed concrete mix was designed using the absolute volumes method. The w/c ratio of the conventional mix was 0.5 (without additives), the percentage of fly ash was 25% of cement weight, the percentage of silica fume was 10% of cement weight, and the percentage of superplasticizers was 1% of cement weight, which in turn reduced the ratio of water to joint material to 0.32.

Cuboid hollow foamed concrete blocks with dimensions of (400 x 200 x 200) mm were used, See Fig.1. In this study, three walls were constructed. In the first wall (W1), cement mortar as a joint material between the cuboid blocks was used with the use of cement mortar at a ratio of 1:3 (cement to sand) and a thickness of 15 mm. While, in the second wall (W2), was made from the simle blocks used in the first wall, but with using bonding adhesive material (ISO SUPER FLEX 1054) by thickness 3 mm as a joint material instead of cement mortar, see Fig.2. In the third wall (W3), conventional of foamed concrete (without additives) was used in producing the hollow block units which were bonded by using a bonding adhesive material. Table 1 shows the densities and compressive strengths of the materials and block units to construct the investigated walls.

3. TESTS

3.1. Block Units

According to (ASTM C140M, 1991), the bond shear strength of the block units was determined. The bond shear strength of the blocks was calculated by dividing the applied load by twice the cross-sectional surface area of the block. Cement mortar was used at a ratio of 1:3 and a water-cement ratio of 0.5. The examination was carried out on three foamed concrete blocks at a density of 1300 kg/m^3 , see Fig.3a. moreover, a bonding adhesive material was used as joint material, see Fig.3b.

3.2. Walls

The compressive strength of masonry walls was evaluated in accordance with (BS EN 1052-1,1999). The present investigation examined the foamed concrete masonry walls compressive

strength, axial strain, modulus of elasticity, failure mode and fractal dimension. Two steel plates, 15 cm in width at the top and 40 cm in width at the bottom, were utilized to distribute the load on the wall. Linear variable differential transformers (LVDTs), which usually used to monitor vertical deformation, have been utilized in this study to measure surface strains on wall surfaces. Two LVDTs put on each wall face, and the total was four for the both faces. The measurement basis for these LVDTs was located in the middle third of the wall height, as shown in Fig. 4. The displacement (δ) of the wall was determined using LVDT1 and LVDT2, while, LVDT3 and LVDT4 were used to quantify the axial strain in each wall.



Fig. 1 Hollow foamed concrete blocks

Table 1 Densities and Compressive strengths of materials and block units used

Material	Density (kg/m ³)	Compressive strength (MPa)
Cement mortar	2187	7.2
bonding adhesive material	1793	9.8
Conventional foamed concrete blocks (without additives)	1320	2.2
Modified foamed concrete blocks (with additives)	1320	3.76



Fig. 2 Construction of wall



(a)



(b)

Fig. 3 Bond shear test for hollow blocks (a) cement mortar (b) bonding adhesive material

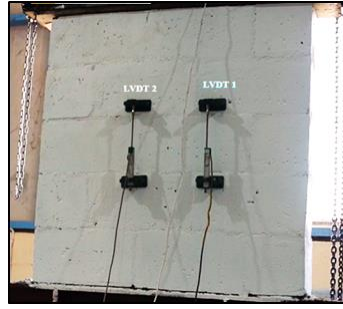


Fig. 4 Installation of LVDTs

According to the European standard EN 1052-1:2011 - Test methods for masonry - Part I (BS EN 1052-1, 1999), the modulus of elasticity of each wall can be calculated as the stress ratio of one-third of the maximum load to the corresponding stress value using the following equation:

$$E = \frac{\sigma}{3\varepsilon} \quad (1)$$

Where, E is modulus of elasticity, σ is maximum stress, ε is peak strain, at the force equal to one third of the fracture force.

Concrete is usually categorized as a semi-brittle material because of its steady pre-peak fracture propagation and post-peak strain relaxation. Concrete brittleness may now be measured with the use of fracture mechanics (Babu, 2008). The fractal dimension is known as one of the methods for estimating the effect of large surface cracks (A Hilal, 2015). The definition and determination of the fractal dimension D was also described in the study of the relationship between fractals and fracture by (Charkaluk, Bigerelle and Iost, 1998).

Crack fractal dimensions were calculated using Image J software box-counting approach. Using this procedure, a rectangular mesh with varying grid sizes ($x_1, x_2, \dots$) is applied to the digital crack. Logarithmic plot of $\log(N)$ versus $\log(1/x)$ can be created by changing x and counting the number of grids. As shown in Fig.5, the fractal dimension D is the slope of the fitting line. The fractal dimension increases with the complexity of the fracture path appearance (Guo et al., 2007).

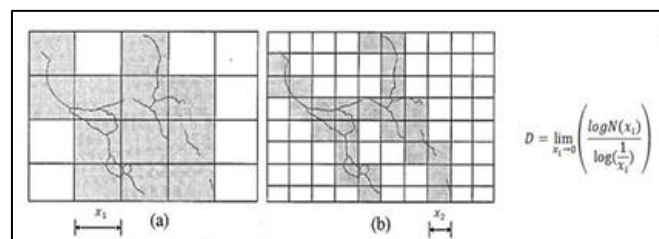


Fig. 5 Crack patterns using the box counting method (Chiaia, Van Mier and Vervuurt, 1998).

4. RESULTS AND DISCUSSIONS

4.1. Bond Shear Strength

It was found that the bond shear strength in stacked block units using the adhesive material (0.336 MPa) gave an increase of 53% compared to using cement mortar (0.157 MPa). This

indicates that the bonding property of the adhesive material used was better than that of the cement mortar. and failure was observed in all stacked blocks tested through the bond material. When the adhesive bond was weaker than the foamed concrete block, it failed (Bhosale *et al.*, 2019).

4.2. Compressive strength

By dividing the maximum load that the wall can withstand by the area that the load is applied over, the compressive strength of foamed concrete walls was determined. It was stated that; concrete block strength and the strength of adhesive material that bonds the block units are together responsible of determining the compressive strength of the wall (Radovanović *et al.*, 2015).

After calculating the compressive strength of foamed concrete walls, it was found that the compressive strength of the wall (W1) bonded by cement mortar was 0.845 MPa. An increase in strength by about 27% was observed when bonding adhesive material used instead of cement mortar in wall (W2). This may be attributed to the fact that the strength of the walls increases with the increase in the compressive strength of the joint material. While, to examine comparing the effect of using additives in the block units walls (W2) and (W3), it was noticed that the compressive strength of the W2 wall increased by 38%. This is due to the fact that the compressive strength of foamed concrete block units with additives is higher than that compressive strength of foamed concrete block units without additives. In the case of using additives, an increase in compressive strength was noticed due to the effect of the pozzolanic properties in decreasing pores in interfacial traditional zone (ITZ) and that materials reduce water content in the mix (Toutanji and El-Korchi, 1995). Additionally, using of superplasticizer was reduced the amount of mixing water and thus increased the compressive strength (Al-Shwaiter and Khalaf, 2023), see Fig.6.

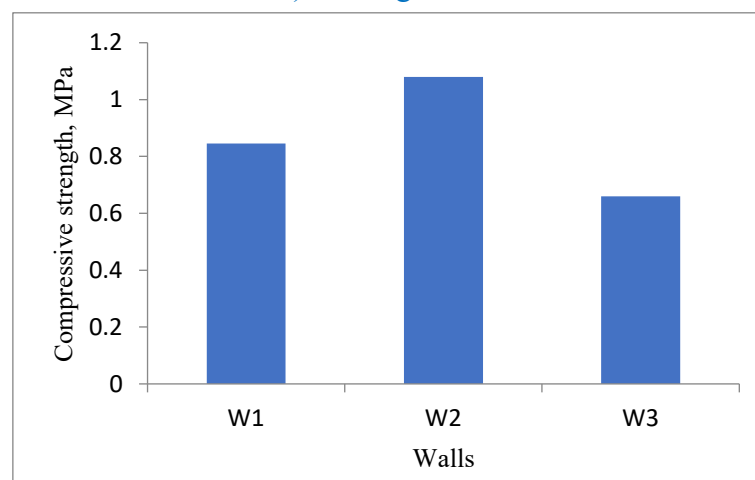


Fig. 6 Compressive strength of walls

4.3. Load- displacement curve

From the load-displacement curves shown in Fig.7, it was observed that the wall behaved flexibly until the appearance of the first crack, where the relationship was almost linear, then after the appearance of the first crack, the relationship turned to non-linearity.

It was found that using bonding adhesive material as a joint material in the W2 wall led to an increase in the maximum load by 27% and a reduction in displacement (h) by approximately 15% compared to the W1 wall in which cement mortar was used as the joint material. The reason for this may be attributed to the difference in thickness of the joint material, as well as the difference in compressive strength of the joint material (Zengin et al., 2018). It was discovered that the behavior of foamed concrete masonry walls improved with the use of additives. Modified foamed concrete block units (with additives) in W2 resulted in an ultimate load that was about 24% higher than that of W3 and a displacement of less than 10%.

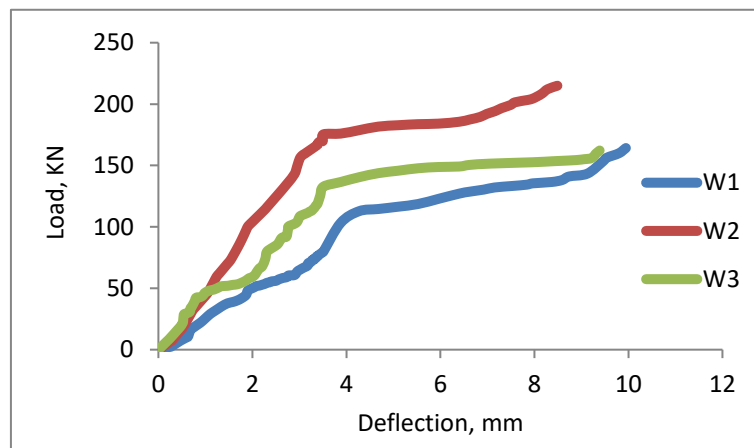


Fig. 7 Load- Displacement h curves of walls

4.4. Stress- Strain curve

Using load and displacement data collected from LVDTs in the middle third of the wall height, the stress-strain behavior of the walls was ascertained. The load was divided by the cross-sectional area of the cuboid walls (1000 length x 200 width) mm to find the stress of each wall. Through the division of the axial deformation by the 140 mm gauge length, the wall strain may be computed from the deformation recorded by the LVDT data. Before propagating the of first crack, a virtually linear increase in stress was found. The initial crack continued up and down through the broken mass units, and the nonlinear portion followed along until the maximum stress was reached prior to the energy being released by fracture. As a result, after reaching a peak strength, it can rapidly decline, and the strain equal to peak strength was referred to as the failure strain.

Fig.8 shows that utilizing bonding adhesive material as a joint material instead of cement mortar

assisted in increasing the maximum stress and lowering the maximum strain. The maximum stress and strain of the W1 wall are 0.846 MPa and 0.071, respectively. For wall W2, they were, however, 0.8965 MPa and 0.044, respectively. It was also observed that W3 wall gave lower stress and higher strain compared to the W2 wall.

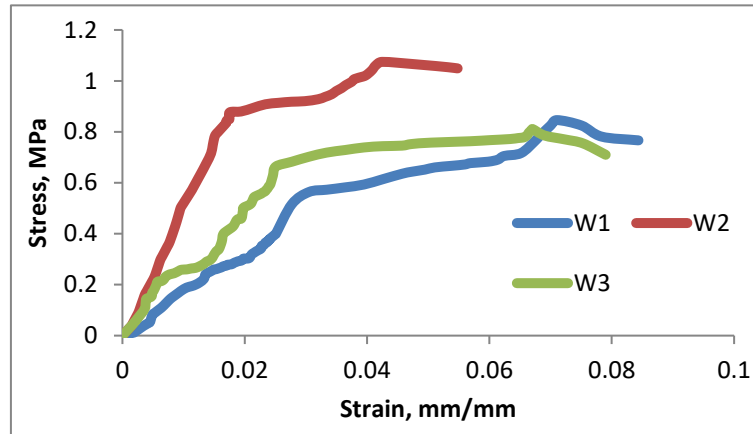


Fig. 8 Stress- Strain curve of walls

4.5. Modulus of elasticity

As shown in Fig.9, the modulus of elasticity when using cement mortar as a joint material in the W1 wall was reduced by 68% compared to using bonding adhesive material in the W2 wall. The modulus of elasticity in the W3 wall (without additives) also decreased by 56% compared to the W2 wall (with additives). This is due to the direct relationship of the elastic modulus with the compressive strength. Property noting that the total volume of the binder increases with the use of additives (Yildirim and Sengul, 2011).

4.6. Failure modes

It appears that the propagation of cracks in foamed concrete walls happens in stages, starting with the development and enlargement of tiny cracks, continuing through peak, and ending with the branching and bridging of big cracks (post-peak). It was noticed that various locations along the wall's height had vertical cracks as a result of the compressive strain. On walls W1, W2, and W3, the first cracks showed with loads of 88, 145, and 61 KN, respectively.

In Fig.10a, vertical cracks were observed as a result of the compressive load at random points along the height of the wall (W1). Vertical and horizontal cracks were also observed around the hollow concrete blocks, which indicates separation of the joint material as a result of weak cohesion between the mortar and the hollow foamed concrete block units.

For the wall (W2) shown in Fig.10b, it was observed that there were vertical and branching cracks through the hollow foamed concrete block units. This may be due to the fact that the bonding adhesive material is unable to withstand the tensile stresses resulting from slight bends or deformations in the wall.

For W3 shown in Fig.10c, it was observed that the hollow foamed concrete block units showed clearer vertical and branching cracks compared to W3. This is due to the absence of additives in the production of concrete block units used to construct the W3 wall.

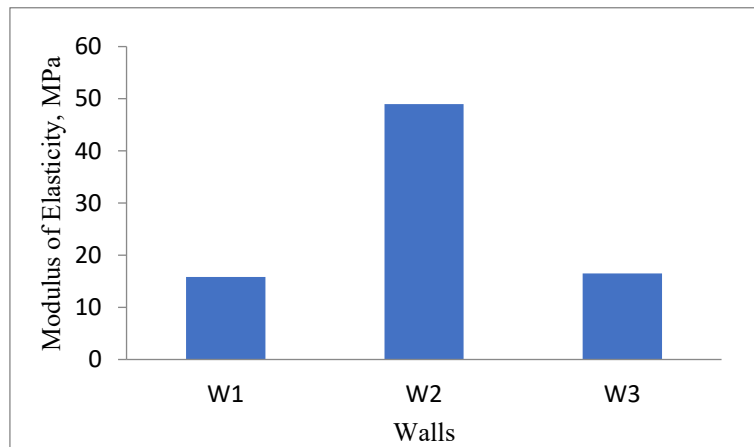


Fig. 9 Modulus of elasticity values for investigated walls

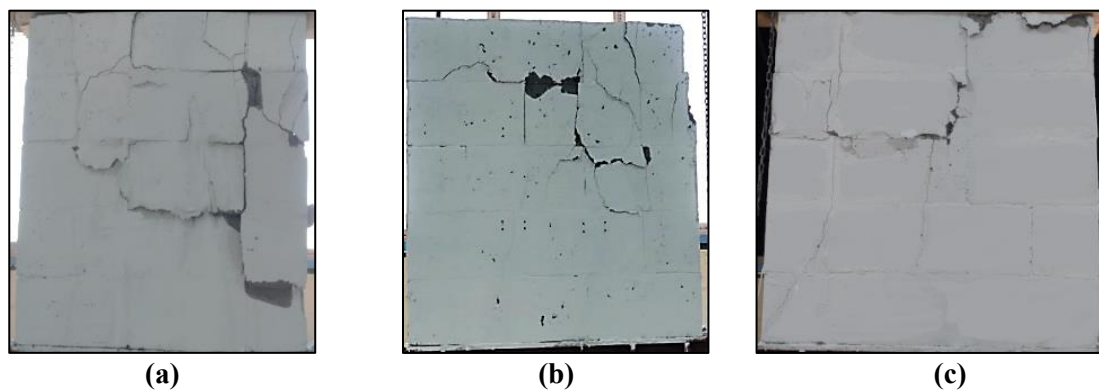


Fig. 10 Failure mode for walls (a) W1 (b) W2 (c) W3

4.7. Fractal dimensions (D)

Cracks on wall surfaces can be distinguished and calculated by their fractal dimension. Fig. 11 to 12 show the fractal dimension D of the tested walls. It was also found that using bonding adhesive material between the wall block units made the cracks more vertical, which led to a decrease in the fractal dimension D of the wall containing cement mortar as joint material. While, the fractal dimension of wall W3 increased as a result of the collapse of part of the foamed concrete blocks. In masonry walls, the fractal dimension value (D) the stronger the wall is higher the wall compressive strength. Fig.14 shows the relationship between compressive strength and fractal dimension.

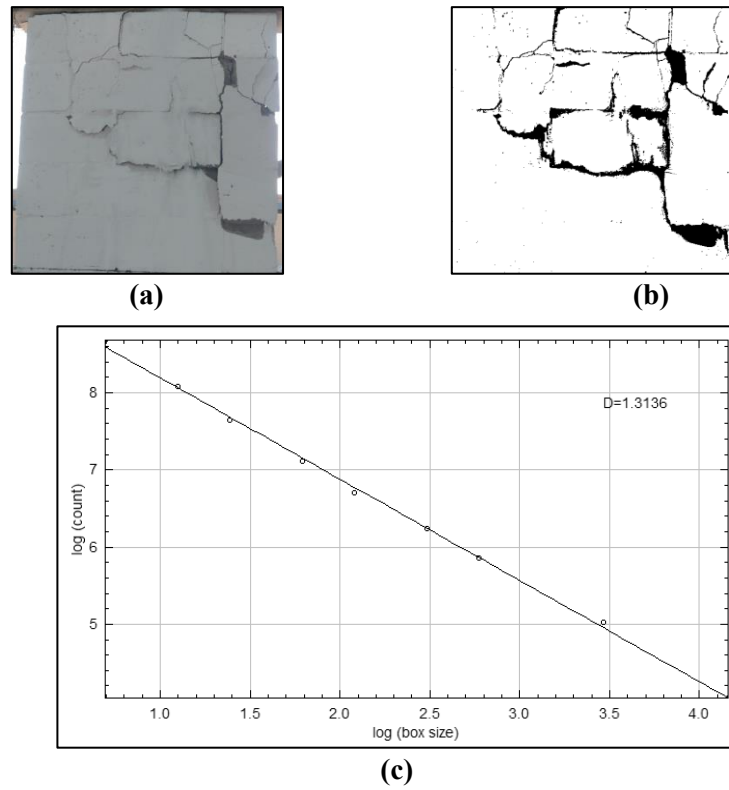


Fig. 11 Illustrates the cracks and the fractal dimension analysis of the W1 wall. (a) the original image showing the cracks, (b) the binary image highlighting the cracks more clearly, and (c) the graph Showing the fractal dimension

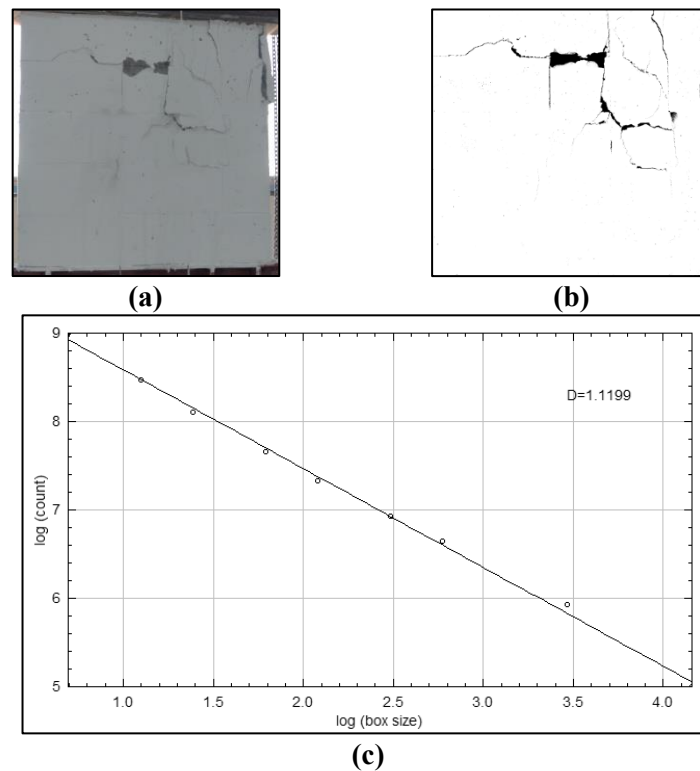


Fig. 12 illustrates the cracks and the fractal dimension analysis of the W2 wall. (a) the original image showing the cracks, (b) the binary image highlighting the cracks more clearly, and (c) the graph Showing the fractal dimension

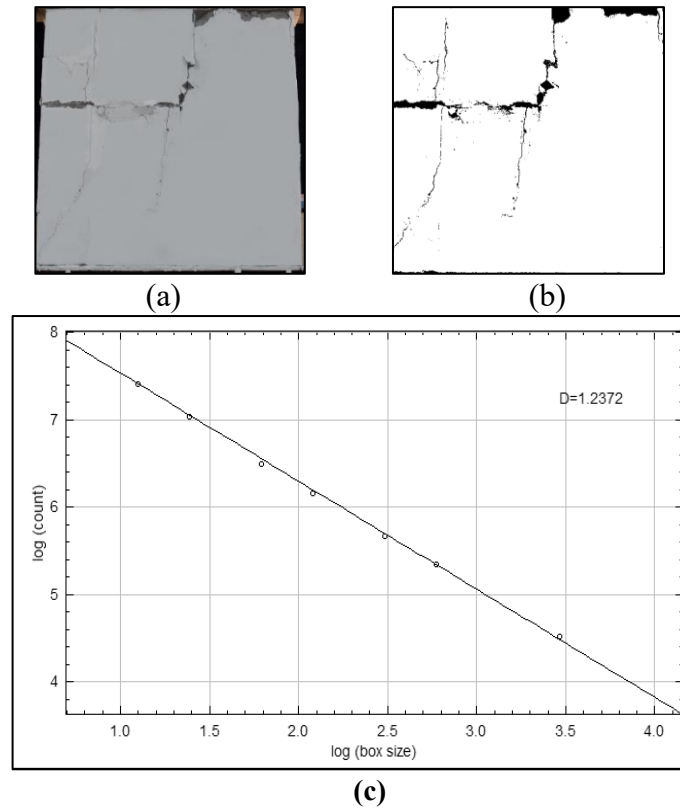


Fig. 13 illustrates the cracks and the fractal dimension analysis of the W3 wall. (a) the original image showing the cracks, (b) the binary image highlighting the cracks more clearly, and (c) the graph Showing the fractal dimension

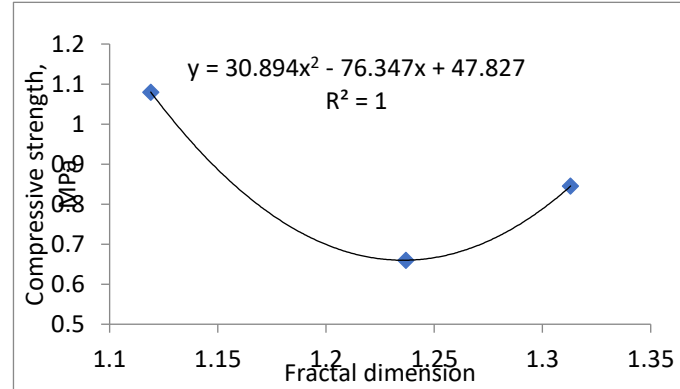


Fig. 14 Compressive strength-fractal dimension relationship

5. CONCLUSIONS

- The bonding adhesive material helped in increasing the bond shear strength by 53%.
- The compressive strength of foamed concrete walls was increased by around 27% with bonding adhesive material as joint material.
- The use of additives in producing of hollow foamed concrete block units increased the compressive strength of the walls by about 33%.
- Using a bonding adhesive material enhanced the modulus of elasticity of foamed concrete walls by about 68%.

- Utilizing additives in producing of hollow foamed concrete block units improved the modulus of elasticity of the walls by about 56%.
- The fractal dimension 1.1199 was improved when the wall block units bonded with a bonding adhesive material.
- The lower the fractal dimension (D) the stronger the wall.

6. RECOMMENDATIONS

- Use of different types of fibers in the production of solid and hollow concrete blocks
- Use other binding materials such as plaster and steel mesh.
- Study of the effect of earthquakes on hollow foamed concrete walls.

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