Strength and Thermal Properties of Hollow Foamed Concrete Blocks considering Various Parameters

Abubaker Mohammed Sulaiman
Department of Civil Engineering, College of Engineering, University of Anbar, Iraq
abu22e1006@uoanbar.edu.iq (corresponding author)

Ameer A. Hilal
Department of Civil Engineering, College of Engineering, University of Anbar, Iraq
ameer.hilal@uoanbar.edu.iq

Zaid Al-Azzawi
Department of Civil Engineering, College of Engineering, University of Anbar, Iraq
zaid.kani@uoanbar.edu.iq

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ABSTRACT

Hot weather is one of the main problems the residential building construction field faces, especially in the southern hemisphere. Therefore, there is an increasing need to produce materials capable of reducing the high temperature impact. These materials should be characterized by thermal insulation properties without, though, their mechanical properties and load resistance being affected. In this research, cuboid and hexagonal hollow concrete blocks were produced from lightweight foam concrete with different hole shapes and a hole ratio of 30%. An analytical study was conducted for 8 models using the ANSYS v16 program, while the compression behavior and thermal performance of the selected models were studied. Ordinary Portland Cement (OPC), water, sand, and foaming agents were deployed in the production of foamed concrete. In addition to the use of admixtures, materials, such as Superplasticizer (SP), Class F Fly Ash (FA), and Silica Fume (SF), were also utilized. Moreover, the effect of the hole's shape and the method of bonding were studied. The compressive strength of the concrete blocks, bond shear strength, thermal conductivity, and thermal resistance were tested. It was found that the cuboid shape of the hole block H7 was the most acceptable compared to the other shapes, with a compressive strength of 3.75 MPa, thermal conductivity of 0.149 W/m.k, and a bond shear strength of 0.157 MPa. At the same time, it was found that using bonding adhesive material gave the best results, with the cuboid blocks being compared to using mortar and mechanical bonding.

Keywords- strength; thermal; foamed concrete; blocks; hole shape; bonding methods

I. INTRODUCTION

The summer temperature in Iraq may reach 52 °C, whereas in winter it can go down to 0 °C [1]. There are over 5 million homes in Iraq's residential sector, and the country's population is rapidly growing. These homes typically consist of two stories and are mostly built with load-bearing walls. Since the exterior walls make up more than 50% of the exposed surfaces, which involve walls, roofs, and grounds, they are the main cause of the heat transmission to and from the house enclosures. Over 40% of the world's energy consumption is caused by the housing sector [2], which also accounts for roughly one-third of the greenhouse gas emissions. Reducing the value of the thermal energy passing through building walls and into the building space is required to lower the rate of energy consumption in buildings [3]. Owing to the variations in the construction materials that are accessible in the area, along with their distinct properties and preparation costs, it is imperative to select the most suitable option; that is the one which has the least amount of heat leakage and weight [4]. Several studies have been conducted on ways to reduce the thermal conductivity coefficient of the building materials, such as blasted bricks and concrete blocks [5-9]. However, the lack of previous studies exploring the hole shape in concrete blocks and its effect on the latter's compressive strength and thermal performance has made this topic a subject of interest. In addition, hollow concrete blocks made from foamed concrete have not been previously investigated, which significantly contributes to their reduced weight compared to solid blocks.

Their thermal conductivity is also compared to that of ordinary concrete. Authors in [10] presented a theoretical study on the effect of the hole shape on the compressive strength and thermal performance of different shapes of hollow blocks. They observed the compressive strength of the block with the circular hole. They also noted that increasing the transverse barriers and decreasing the longitudinal barriers leads to an increase in compressive strength. Authors in [11] investigated the effect of the hole shape on the thermal performance of 24 different samples. It was shown that for blocks with the same hole ratio, the shape of the holes influenced heat transfer reduction through the block. In addition, the results demonstrated that rectangular shapes have better thermal efficiency than circular shapes.

Hollow concrete block masonry is widely used in applications where the masonry must be grouted and strengthened to boost axial and lateral capacity. Research projects are currently concentrated on creating high-rise masonry structures using concrete blocks based on [12, 13]. Similarly to clay bricks, concrete blocks are often utilized in unreinforced masonry buildings, making the market more competitive. Utilizing concrete blocks has also the advantage of requiring fewer blocks to build a given wall size. This means that workmanship is reduced, thicker walls can be constructed with a single block width in contrast to conventional brickworks, and better thermal comfort is provided because of the voids in the blocks [14, 15]. The mechanical properties of foamed concrete units are primarily dictated by their density. An increase in density is followed by a corresponding decrease in their void percentage. Nevertheless, when the unit density decreases, the thermal insulation capacity increases [16]. The mechanical and thermal characteristics of foamed concrete were investigated in [17]. In wall construction, the compressive strength of foamed concrete, with dry density from about 860 kg/m^3 to 1245 kg/m^3, ranges from 2.36 MPa to 6.5 MPa. Also, authors in [18] evaluated the water content, water absorption, compressive strength, and tensile strength of aerated concrete blocks. Aerated concrete blocks were shown to absorb more water than traditional clay bricks. Furthermore, it was exhibited that the former's compressive strength rose in proportion to the dry density development, being roughly 4-6 times less than that of a regular clay brick. Additionally, increasing mortar strength in the joints enhanced the loading performance of aerated concrete block masonry. The thickness of the mortar bed joint is one of the parameters that determine the compressive strength of a masonry wall. Masonry is a composite material, so the kinds of stresses that arise from uniaxial compression depend on the mortar's and the masonry unit's respective elastic properties [19]. Three different mortar mixture types were employed in [20] to construct the stocked blocks. Each mortar was created in a mixer by varying the ratios of water, lime, cement, and sand. Some blocks were hollow and solid. There were two applications for mortar: complete mortar and face shell mortar. Given that the mortar is smaller in face shell bedded stocked blocks than in complete bedded prisms, the average drop in masonry strength was 15%. The compressive strength, shear strength, and tensile bond strength of the stack-bonded Autoclaved Aerated Concrete (AAC) block masonry prisms were measured and discussed in [21]. The shear bond strength was 0.22 MPa on average. Two types of failure patterns were observed in the masonry triplets during the shear bond strength test. Initially, the failure through the AAC block units when the AAC block was weaker than the block adhesive bond, and subsequently, the failure through the block adhesive bond when the latter was weaker than the AAC block. Two different failure mechanisms were evidenced in the tensile bond test; the block failure in the case of a stronger tensile bond, followed by the block adhesive failure in the case of a weaker tensile bond. Authors in [22] used cement mortar and interlocking in the construction of solid hexagonal units, with failure having been observed in the interlocking. The failure of cuboid masonry was detected when the strength of the block adhesive bonding materials was less than the strength of the cuboid block.

The main objective of this research is to adopt the best hole shape in terms of compressive strength and thermal conductivity in hollow concrete blocks manufactured from foam concrete, by adopting different hole shapes with a hole installation ratio of 30% of the total block size. The effect of the hole shape was theoretically studied following the finite element method, while the best hole shapes were selected and investigated. In addition, the influence of the concrete blocks' shape and the joint material was examined.

II. FINITE ELEMENT ANALYSIS (FEA)

Based on previous studies, 8 shapes of holes were selected, with a 30% hole ratio of the block volume for all shapes, as depicted in Figure 1.

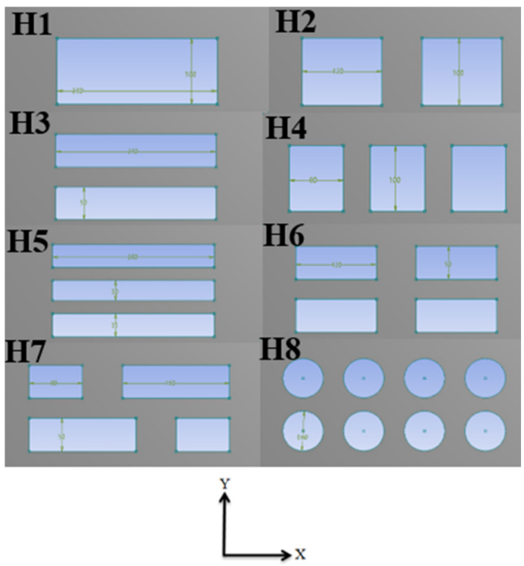


Fig. 1. Finite element study samples.

These different hole shapes were compared in terms of normal stress distribution and thermal performance. ANSYS v16 software was used. The modeled samples were produced from foamed concrete, with a compressive strength of 11.7 MPa and an elastic modulus of 7650 MPa, for the mix of foamed concrete made with additives. The elastic modulus values were calculated by (1), [23]:

$$E = 0.42\, f_c^{1.18} \quad (1)$$

where E is the elastic modulus in Mpa, and f_c is the compressive strength in MPa.

The specimens were designed to study the normal stresses by applying a static vertical load of 350 kN on the Z-axis. Regarding, the thermal performance, a temperature of 47.5°C was applied to the Y-axis. Figure 2 portrays the effect of longitudinal and transverse barriers on the heat flow through hollow blocks.

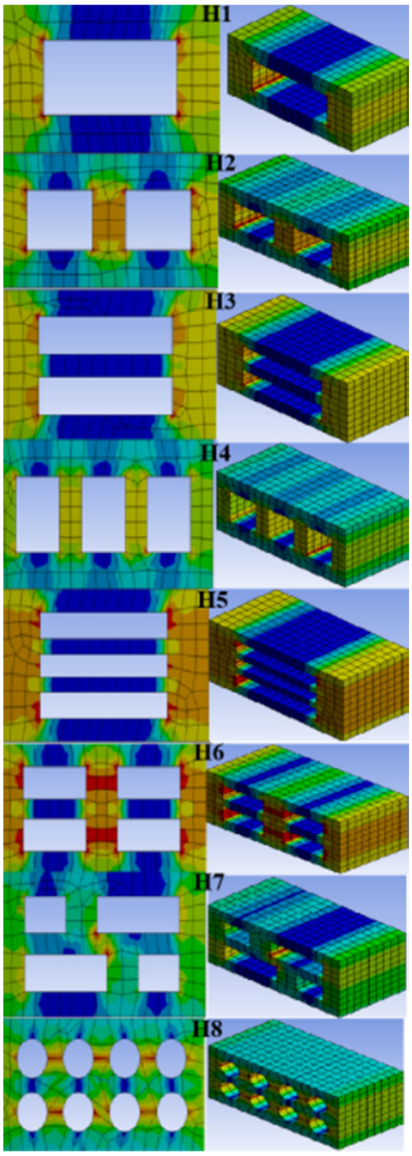


Fig. 2. Heat flow distribution.

Transverse barriers increased the heat flow, as displayed in samples H2, H4, H6, and H8, by creating bridges transferring heat from the face exposed to it directly to the opposite face. The longitudinal barriers reduced the heat flow, as shown in the samples H1, H3, H5, and H7. Therefore it can be concluded that the heat flow decreases by increasing the longitudinal barriers and decreasing the transverse barriers. It was noted that the outer face of the blocks that have blue longitudinal barriers appears in dark blue, which means less heat flow, and this is observed in the samples H1, H3, and H5, while the sides had an orange hue, which increases the heat flow because of the former's thickness, 8 cm. The blocks with transverse barriers exhibited the appearance of red and orange colors, which indicates that they require a higher heat flow, as evidenced in samples H2, H4, H6, and H8. Regarding sample H7, the blue and green colors showed little heat flow, except for the inner edges, which exhibited very little red and orange, indicating high heat flow.

The temperature fields for the various block forms under study and for a 25.5 °C temperature differentiation is displayed in Figure 3. The temperature distribution for the investigated blocks is rather comparable, in contrast to the heat flow distribution, which is heavily influenced by the number and forms of the holes. The hue of the cavities in the block samples H1, H2, and H4 is mostly orange to light blue when there is just one longitudinal row of holes present in the blocks. The two longitudinal rows of holes in the blocks are primarily bright blue in the second row and largely orange in the first, which is warmer overall. Most of the temperature drop takes place in the holes, indicating that the voids serve as the primary heat transmission barrier in hollow blocks.

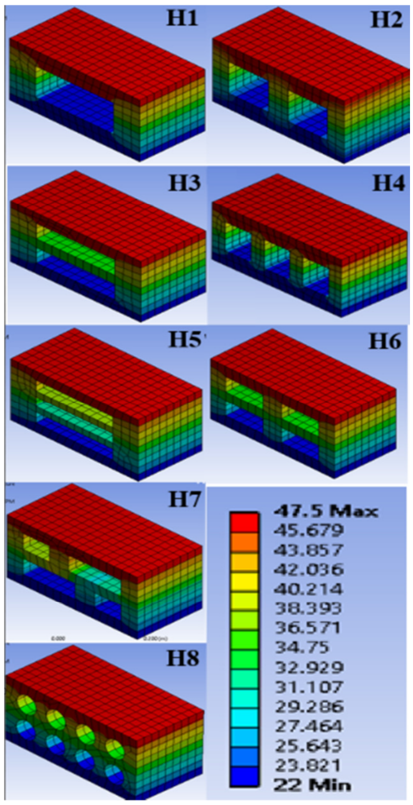


Fig. 3. Temperature distribution for block samples.

The temperature distribution within the blocks becomes further divided as a row of holes is added, keeping one section warm and the other section cold. This makes the temperature distribution within the blocks increasingly divided, maintaining one area warm and the other area cold. By doing this, the heat loss through the wall surfaces decreases, whereas the interior thermal comfort increases. Figure 4 depicts the distribution of the maximum principal stress in the 8 different perforated blocks examined. A visualization of the results shows no preference for a particular block configuration when it comes to the mechanical resistance to vertical compression in the z direction. This mainly occurs since the blocks were chosen to have similar void ratios, and thus a similar active area against pressure. The critical region for the first principal stress was located at the bottom of the blocks inside the cavities.

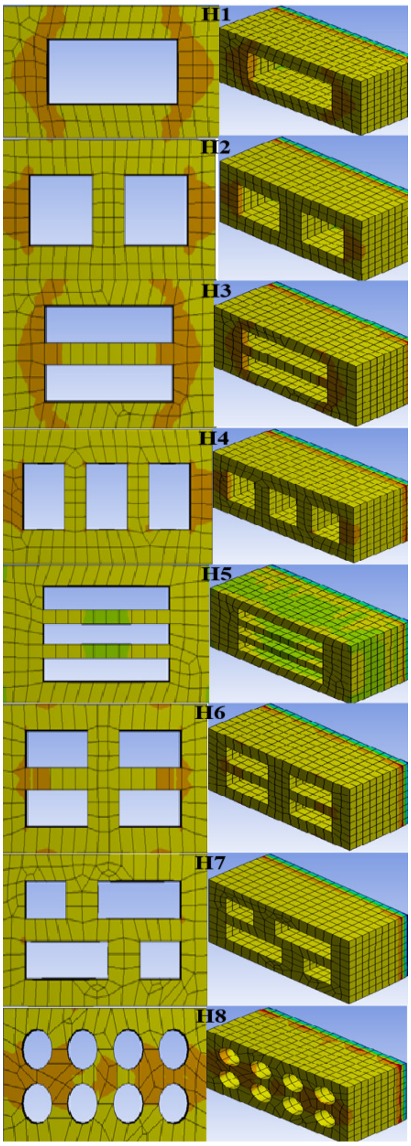


Fig. 4. Maximum principal stress for block samples.

Table I presents the values of the maximum principal stress and the heat flow values. According to the values illustrated in Table I, the values of the maximum principal stress are very close in all shapes. Therefore, the heat flow values will be relied upon to determine the shapes that will be worked on in the laboratory, as samples H2, H4, H7, and H8, consume a larger amount of heat flow to reach the maximum temperature applied to them.

TABLE I. MAXIMUM PRINCIPAL STRESS AND HEAT FLOW VALUES FOR BLOCK SAMPLES

Sample	σ_1 (Mpa)	Q (W/m^2)
H1	0.899	52.6
H2	0.884	54.4
H3	0.852	50.5
H4	0.885	61.6
H5	0.903	45
H6	0.806	46.3
H7	0.906	67
H8	0.818	60.4

III. EXPERIMENTAL WORK\

A. *Materials*

Ordinary Portland Cement (OPC) was used in the manufacture of the investigated foamed concrete mixes, based on [24]. Natural sand with a maximum size of 2.36 mm was also utilized [25]. A dose of 1 gm foaming agent added to 40 gm water was used to generate 1 L of foam. In addition, additives, such as Class F FA and SF were deployed. SP Sika ViscoCrete 180 GS at a rate of 1% by weight of the binder was also used. Table II outlines the chemical composition of cement, FA, and SF.

TABLE II. CHEMICAL COMPOSITIONS OF OPC, FA, AND SF

Oxide	OPC (%)	FA (%)	SF (%)
SiO_2	19.11	46.65	92.1
CaO	64.15	5.13	0.98
Al_2O_3	6.17	26.24	1.93
Fe_2O_3	3.72	13.44	1.02
SO_3	2.30	0.32	0.1
MgO	1.47	2.63	0.79
K_2O	-	1.57	-
Loss on ignition	0.90	3.72	3.1

B. *Mix Design*

In this research, two mixtures were adopted and designed using the absolute volumes method, with a density of 1300 kg/m^3 with and without additives, as shown in Table III.

TABLE III. MIX DESIGNS

Mix	FC13	FC13A
Target density (kg/m^3)	1300	1300
Cement (kg)	400	400
Water/binder ratio	0.5	0.32
Sand (kg)	700	700
Foam (L/m^3)	409	454
FA (kg)	100	-
SF (kg)	40	-
SP (kg)	4	-

C. *Specimen Preparation*

Cubic specimens with dimensions of 100 mm × 100 mm × 100 mm were cast to test the compressive strength. Foamed concrete blocks with dimensions of 400 mm × 200 mm × 200 mm were produced, for the selected 4 different shapes of holes.

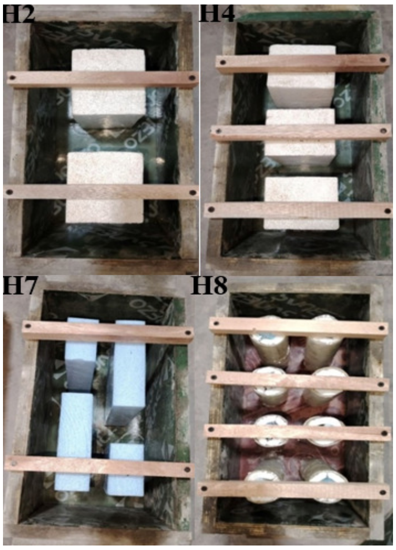


Fig. 5. Hollow block molds.

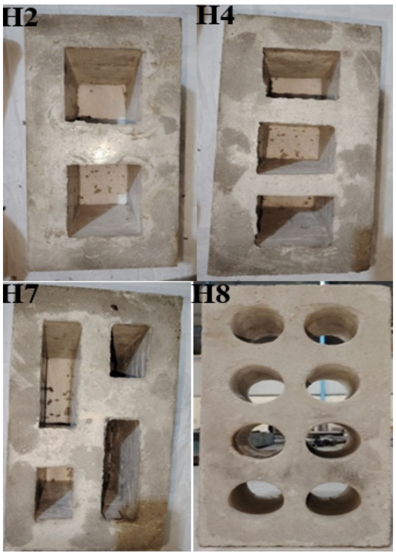
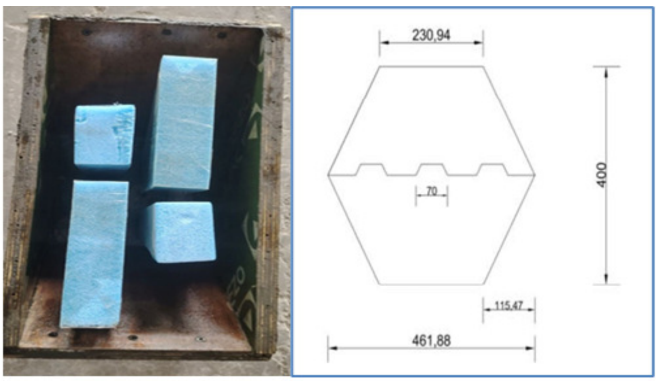


Fig. 6. Hollow foamed concrete blocks.



(a) (b)

Fig. 7. (a) Hexagonal molds, (b) dimension of hexagonal blocks.

Figure 5 displays the molds of the block units and Figure 6 shows the produced units. In addition, hexagonal molds measuring 230.94 mm on the side length were utilized to create foamed concrete blocks, both with and without interlocking. The dimensions of the molds used to create the block units are presented in Figure 7.

IV. TESTS

A. Compressive Strength

Using a digital compression testing machine with a 2000 kN capacity, a compressive strength test was performed in [26]. 100 mm cubes were tested for compressive strength at 7 and 28 days of age. The compressive strength of the hollow concrete blocks, though, was examined according to [27], as portrayed in Figure 8.

(a) (b)

Fig. 8. (a) Compressive strength of sample, (b) compressive strength of hollow concrete block.

B. Bond Shear Strength

The bond shear strength of the blocks was determined according to [28]. This test includes identifying the bond shear strength of the cuboid block that involves different hole shapes using cement mortar at a ratio of 1:3 (cement: sand) and a water-cement ratio of 0.5. The examination was conducted on three foamed concrete blocks with a density of 1300 kg/m³, as evidenced in Figure 9. The bond shear strength of the blocks was calculated by dividing the load by twice the cross-sectional surface area of the block.

Fig. 9. Shear bond strength test for cuboid blocks.

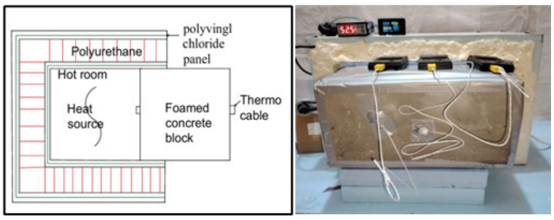
C. Thermal Conductivity and Thermal Resistance

Thermal conductivity can be referred to as the ability of heat to be transmitted through a unit thickness to a direction perpendicular to the surface of the unit area. Thermal conductivity was conducted using a TPS 500 machine on slices (50 mm length × 50 mm width × 30 mm thickness) that were drilled out from a 100 mm cube based on [29]. For each mix, the average value of 3 samples was adopted. The foamed concrete block was tested in terms of thermal conductivity and thermal resistance by placing it in the locally made oven chamber, so that one side of the block was exposed to heat and the other side was open to the atmosphere. Temperature (T1) is maintained at 47.5°C (±5°C) for 4 hours and Temperature (T2) is measured on the upper side of the plate every half hour using a thermal cable. The foamed concrete blocks are kept in the oven for 4 hours because the temperature in Iraq in the summer reaches a maximum of 52 °C during the time period from 10 am to 2 pm. So, the hollow foamed concrete blocks were tested under 52 °C for a period of 4 h. Thermal testing is performed on the selected 4 different hole shapes, as shown in Figure 10. The thermal conductivity k (W/m.k) is calculated using (2), [30]:

$$k = \frac{QL}{A\Delta T} \qquad (2)$$

where Q is the heat flow (W), L is the thickness of the block (m), A is the area (m^2), and ΔT is the temperature difference between the hot room and cold room (K). With respect to thickness, thermal conductivity is inversely related to thermal resistance (R-value). According to [31], the certified thermal conductivity of air is 0.024 W/m.k. The value of R [32] was obtained by:

$$R = \frac{L}{KA} \qquad (3)$$



(a) (b)

Fig. 10. (a) Locally made thermal conductivity testing device, (b) block unit during thermal conductivity test.

V. RESULTS AND DISCUSION

A. Mixes And Blocks Units

1) Compressive Strength

Figure 11 demonstrates that the strength of the FC13A mix (with additives) increased by about 68.6% compared to the traditional mix (FC13). This increase is attributed to two main reasons: firstly, the use of SP, which in turn led to a reduction of the water-cement ratio from 0.5 to 0.32 [33]. Secondly, the use of mineral additives due to their pozzolanic properties, which in turn helped in strengthening the bonding of the mixture, and thus creating a less porous Interfacial Transition Zone (ITZ) [33, 34].

Considering the blocks' strength, the peak load was divided by the area of each block to find its compressive strength. Figure 12 displays the compressive strength results for the investigated foamed concrete blocks. It was noted that the H8 shape gave the highest strength compared to the other hole shapes. The reason for this is that the load is distributed on the whole circumference of the circular hole, whereas in the rectangular hole the load was transmitted to the sharp ends [36]. It was previously stated that the compressive strength increased with increasing the internal angles in the shapes. However, the strength of H4 was higher than that of H7 even though the internal angles of H7 were more than those of H4. This is due to a reduction in the thickness of the edge subjected to the load.

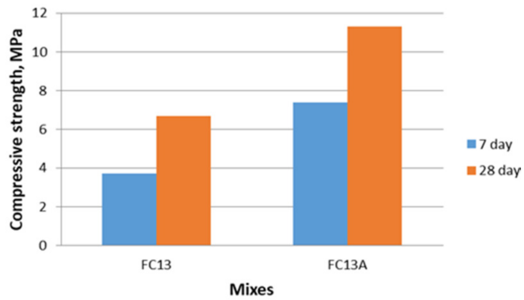


Fig. 11. Compressive strength of investigated foamed concrete mixes.

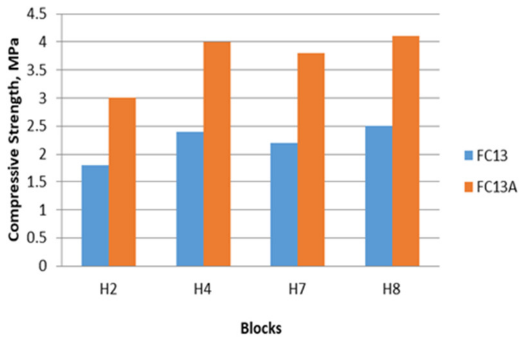


Fig. 12. Compressive strength of hollow foamed concrete blocks made with different hole shapes.

2) Bond Shear Strength

Figure 13 illustrates the results of the bond shear strength test for hollow foamed concrete blocks made with different hole shapes.

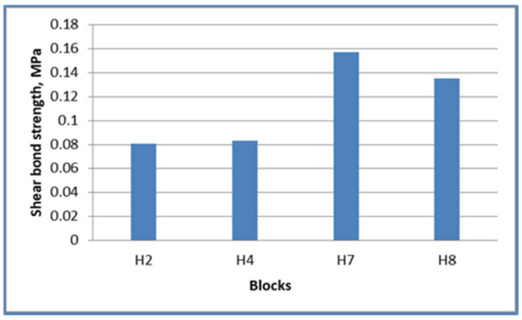


Fig. 13. Effect of hollow shape on shear bond strength.

It was observed that H7 gave the highest bond shear strength, with failure being noted in all stacked blocks tested through the bond material. Failure in the block adhesive bond was spotted when the bond was weaker than that of the cuboid block [21]. It was evidenced that the shear bond strength in H7 increased by 48%, 47%, and 14% compared to H2, H4, and H8, respectively. The increase in the shear strength of H7 bond may be attributed to the increase in the number of longitudinal barriers parallel to the direction of the shear force.

3) Thermal Conductivity and Thermal Resistance

A slight increase, of about 3%, was observed in thermal conductivity when FA, SF, and SP were added to the FC13A mix compared to the conventional mix, FC13. The mix with additives, FC13A, had a slightly higher thermal conductivity, 0.49 W/m.k, than the conventional mix, 0.43 W/m.k. The reason for this is that the thermal conductivity of foamed concrete is determined not only by the air volumetric fraction, but also by the thermal conductivity of the solid materials, namely mortar or cement paste, which are made denser by the physical and chemical contribution of SF and FA. Also, less porosity is observed due to the reduced w/c ratio with the addition of a SP. Moreover, the pore structure of a material is important as it influences its thermal conductivity. So, in the current study, the additions in combination resulted in a more uniform void distribution, which reduced void connectivity and increased thermal conductivity [37]. In block units, the results presented in Figure 14 indicate that the thermal conductivity decreased in the rectangular hole and increased in the circular hole.

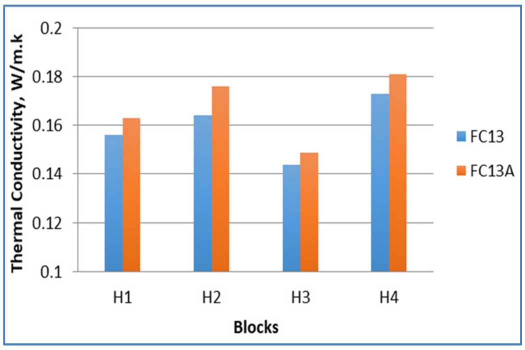


Fig. 14. Thermal conductivity of foamed concrete blocks.

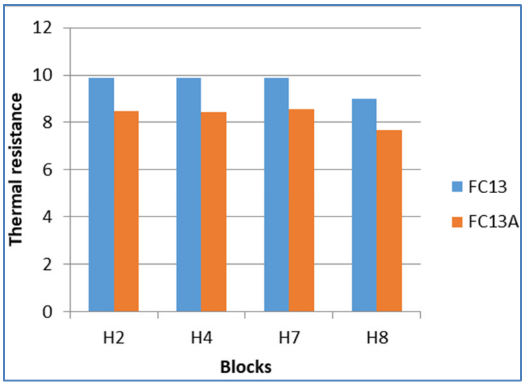


Fig. 15. Thermal resistance of foamed concrete blocks.

The results also demonstrate the the best value for thermal conductivity was noted in H7. The reason is that the longitudinal barriers work to reduce thermal conductivity, which in turn works to increase thermal resistance, while the transverse barriers operate as a thermal bridge within its/their/the structure, in addition to raising the value of thermal resistance [9, 10]. It was noticed that the percentages of thermal conductivity reductions for the H2, H4, H7, and H8 blocks were 66%, 65%, 70%, and 63%, respectively, compared to their corresponding material thermal conductivity value. It was also observed that the values of the calculated thermal resistance results were almost equal in H2, H4, and H7 blocks and were reduced in H8.

B. Block Shapes and Bonding Methods

1) Compressive Strength

Based on the results presented above, the hole shape H7 was chosen as the best in terms of strength and thermal properties. The effect of the type of joint material was studied using two materials, namely cement mortar (M1), with a mixing ratio of 1 cement: 3 sand: 0.5 water, and with a thickness of 15 mm and a compressive strength of 7.2 MPa. The bonding adhesive material (M2) was also utilized with a mixing ratio of 1 bonding adhesive material: 0.28 water, a thickness of 3 mm and a compressive strength of 9.8 MPa. In addition, the mechanical bonding technology was adopted with and without bonding material. Figures 16 and 17 demonstrate the tested specimens of two stacked blocks subjected to an axial load. B1 represents conventional hollow foamed concrete blocks stacked using mortar as the joint material. B2 represents conventional hollow foamed concrete blocks stacked utilizing bonding adhesive material as the joint material. B3 represents conventional hexagonal hollow foamed concrete blocks stacked using bonding adhesive material as the joint material. In addition, B4 denotes hexagonally stacked hollow foamed concrete blocks using mechanical bonding (interlocking) without employing joint material, while B5 denotes hexagonal stacked hollow foamed concrete blocks using bonding adhesive material as the joint material with interlocking.

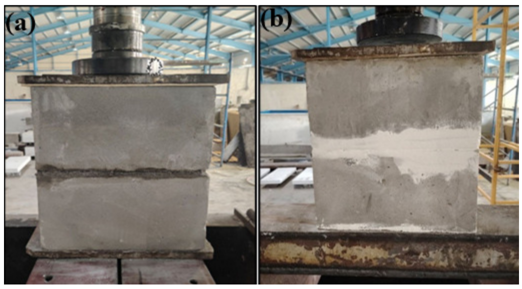


Fig. 16. Compression test for stacked block units (a) cuboid blocks with mortar joint material, B1, (b) cuboid blocks with bonding material, B2.

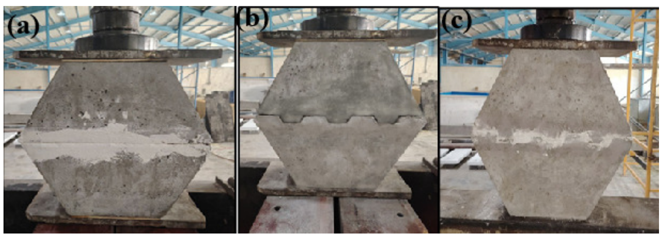


Fig. 17. Compression test for stacked block units (a) Hexagonal blocks with bonding material, B3, (b) hexagonal blocks with mechanical bonding, B4, (c) mechanical bonding techniques with bonding material, B5.

The peak load was divided by the area of each block to find its compressive strength. Figure 18 portrays the compressive strength of the stacked specimens. Through these results, comparisons can be made depending on the bonding material, block shape, and bonding method.

1. Bonding material: In terms of the bonding materials, B1 and B2, it was found that M2 helped in gaining a 15% higher compressive strength than that when using M1. Also, through B4 and B5, a 32% increase in compressive strength was noted when using M2 rather than when utilizing the binder and relying on mechanical bonding.
2. Block shape: Concerning the block shape (B2 and B3), a 50% decrease in the compressive strength of the hexagonal samples was noticed.
3. Bonding method: Regarding the bonding method (B3 and B4), it was found that mechanical bonding gave a 9% decrease in compressive strength compared to the binder bonding method. By fixing the M2 material (B3 and B5), a 21% increase in strength was recorded in the case of adopting the mechanical method.

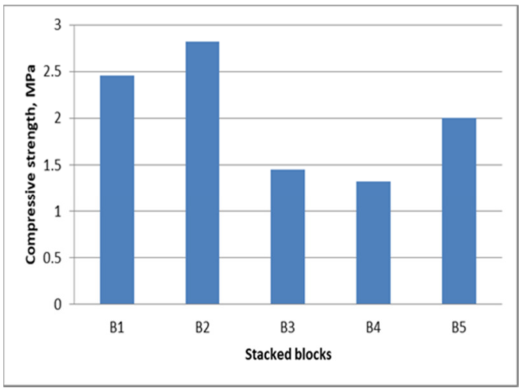


Fig. 18. Compressive strength of stacked blocks.

Figure 19 displays the failure mode of conventional stacked blocks, whilst Figure 20 shows the failure mode of stacked hexagonal blocks. It was noticed that the use of the bonding material and the mechanical bonding method in combination did not affect the nature of the failure occurring in the stacked blocks.

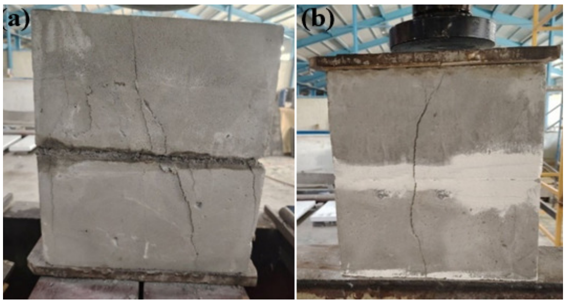


Fig. 19. Failure mode for block, (a) mortar joint material, (b) bonding adhesive material.

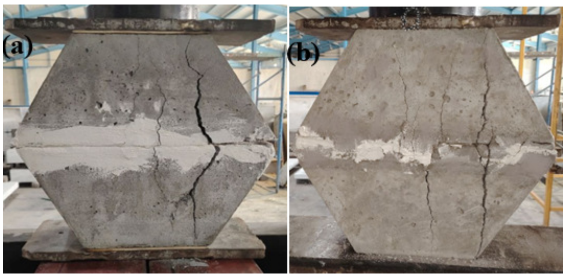


Fig. 20. Failure mode for stacked hexagonal blocks (a) without interlocking, (b) with interlocking.

2) Bond Shear Strength

In masonry constructions, bond shear strength is the most essential characteristic in determining their lateral load bearing capacity. The bond shear strength of foamed concrete masonry assemblages was measured using cuboid and hexagonal blocks. In Figure 21, it was observed that the highest bond shear strength was documented in the stacked blocks using M2, while the hexagonal blocks with mechanical bonding gave the lowest shear bond strength. When comparing B1 with B2, it was found that the bond shear strength in the blocks with M1 decreased by about 53% as opposed to that of the blocks with M2. By comparing B2 with B3, the hexagonal shape led to a 73% reduction in the bond shear strength compared to that of the cuboid shape. When the bonding methods (B3 and B4) were compared, it was evidenced that the use of the bonding material gave an increase in strength, of about 40%, compared to mechanical bonding. Finally, comparing B4 with B5, using the binder material M2 with mechanical bonding increased the strength by 160% in contrast to the mechanical bonding without joint material.

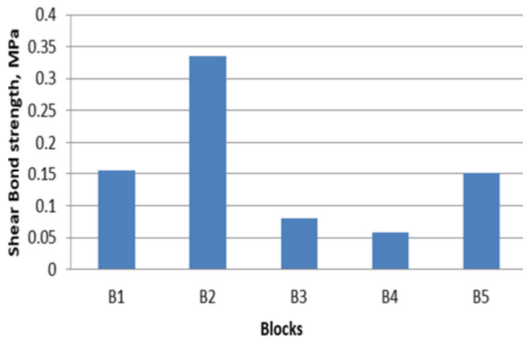


Fig. 21. Bond shear strength results.

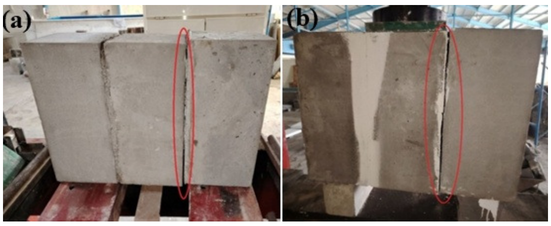


Fig. 22. Failure modes of stacked cuboid blocks (a) M1 joint materials, (b) M2 joint material.

It is worth noting that the bond shear failure in all the previously mentioned cases was observed in the binding material and method of connection, and there was no failure in the block used, as shown in Figures 22 and 23.

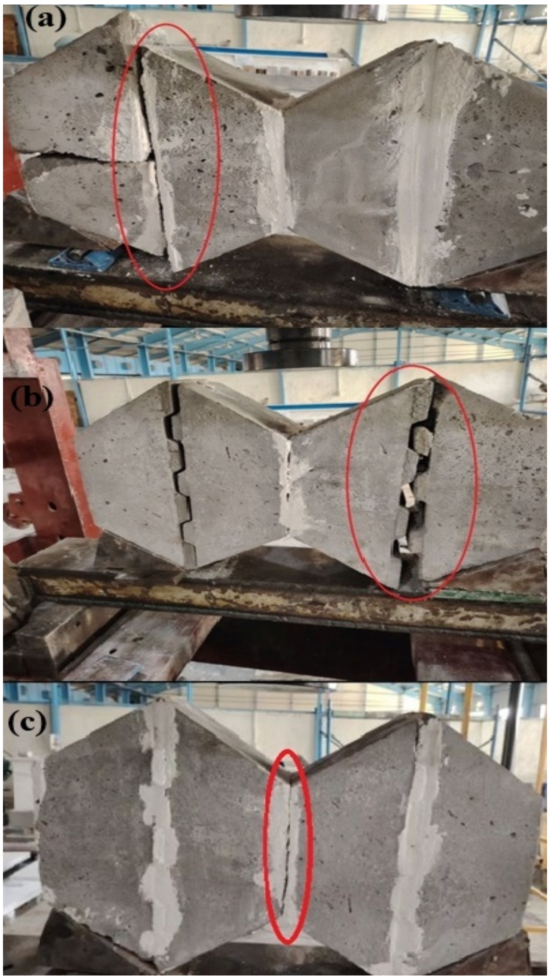


Fig. 23. Failure modes of stacked hexagonal blocks (a) without interlocking and using M2 joint materials, (b) with interlocking and not using a joint material, (c) with interlocking and using M2 joint material.

VI. CONCLUSIONS

By identifying the critical elements influencing the mechanical and thermal performance of hollow foamed concrete blocks, the conclusions reached from this work offer useful information for enhancing the design of hollow foamed concrete blocks.

- The compressive strength of foam concrete block units containing circular holes, 4.1 MPa, is higher than that of those containing rectangular holes.
- Increasing the thickness of the external sides and internal barriers increases the compressive strength.
- Through FEA, the use of rectangular holes improved the thermal performance of hollow foam concrete blocks compared to hollow blocks with circular holes.
- Through the numerical analytical study of hollow foam concrete blocks, the shape of the hole did not significantly affect the compressive strength of the hollow blocks.
- The thermal conductivity of foamed concrete building blocks containing rectangular holes is better than the one of those containing circular holes.
- Longitudinal barriers increase the thermal resistance inside the hollow blocks, which increases their thermal performance. Likewise, transverse barriers work to reduce the thermal resistance inside the hollow blocks, which reduces their thermal performance.
- Cuboid stacked foamed concrete blocks showed higher compressive strength, of about 50%, than hexagonal foamed concrete blocks.
- The use of the bonding material (bonding adhesive material) improved the compressive strength by about 15% and bond shear strength by about twice the strength obtained through the use of mortar.
- The mechanical bonding method exhibited a decrease in compressive strength, of about 9%, compared to when using bonding adhesive material.
- The mechanical bonding method demonstrated a decrease in bond shear strength, of about 40%, compared to the bonding method using a bonding material.
- The bonding method and binder did not affect the failure mode in the compressive strength test of stacked blocks.
- Failure occurred during bond shear strength testing in all stacked blocks through the bonding material.
- The use of a 3 mm thick bonding adhesive material in combination with the interlocking method improved the compressive strength of the hexagonal hollow foamed concrete blocks by about 13% compared to cement mortar, and by 34% compared to the mechanical bond.
- The use of bonding adhesive material in combination with the interlocking method improved the bond shear strength of the hexagonal hollow foamed concrete blocks by about 53% compared to cement mortar and by 62% compared to the mechanical bond.

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