A REVIEW ON CONCRETE HOLLOW BLOCK WALLS: MATERIALS AND MECHANICAL PROPERTIES

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ABSTRACT

Concrete hollow blocks are commonly used in building construction, particularly for multi-story buildings, factories, and residential structures. Hollow blocks are more practical because of their lightweight, and the most significant feature is the ease with which they can be ventilated. Mortar is the glue that holds the blocks together in a masonry assembly. Mortar must be long-lasting and capable of holding the masonry together while also helping to form a water-resistant barrier. Typically, cement and sand are used to make mortar, with lime or a plasticiser added to increase workability. This paper provides an overview of modern masonry hollow block wall construction, starting with an overview of its applications and benefits, and offers an experimental work of concrete hollow block and mortar units, such as water absorption, 5-hour boiling test, compressive strength, density, flexural strength test, and compressive strength, and consistency test for mortar. The findings revealed that the compressive strength for a masonry hollow block is 8.39 MPa at 28 days which does not pass the specifications for it to be a load-bearing unit and the compressive strength of mortar is approximately 21.34 MPa at 28day. To improve economy and productivity, compressive strength, density, masonry hollow block properties, and masonry wall behaviour with the factors to consider for load-bearing and non-load-bearing wall construction were summarised and described, and key reference lists were included. A review of the Concrete Hollow Block material and mechanical properties.

Keywords: Construction, Experiment, Hollow Blocks, Masonry, Materials

1.0 INTRODUCTION

The concrete hollow block allows for thinner walls, resulting in more floor space because the air space in the block accounts for 25% of the total area of the block, moreover, it is still among the earliest building materials in use today (Yang *et al.,* 2019, Umair *et al.,* 2022, Edri *et al.,* 2020). Cement concrete blocks are more popular than traditional building materials like bricks and stones. To use blocks in construction, the overall length and height of the wall must be fixed to allow for the use of a single or half-length block. Due to their low cost, these concrete hollow blocks are commonly used in compound walls and because of their lightweight, concrete hollow blocks are more useful, and the most important feature is their ease of ventilation. Cement, sand, and stone chips are used to make concrete hollow blocks. It lowers construction costs by reducing the use of cement in masonry work (Varshney, 2016). For thousands of years, masonry was the dominant building material until the nineteenth century, when modern materials like concrete, steel, and wood appeared (Maldonado *et al.,* 2019). Masonry is the only traditional in-fill material used in reinforced concrete frames. Due to variables including resource availability, societal limitations, cultural affinity, and economic feasibility, structured masonry has gained popularity in the construction of monumental, administrative, and residential buildings (Parajuli *et al.,* 2020, Parsekian *et al.,* 2018). In previous studies, to form masonry walls, beds, and head joints were used to connect concrete hollow blocks (Hasan *et al.,* 2021, Ma *et al.,* 2016, Gabor *et al.,* 2019, Reboul *et al.,* 2018, Al-Shugaa *et al.,* 2019, Chi *et al.,* 2019, Calderón *et al.,* 2020, Materials & 2018) this implies that skilled workers are required in the construction process. For thousands of years, using mortar to bond block units on top of each other has proven to be a successful technique, primarily justified by its simplicity and durability during construction (Popescu *et al.,* 2015). The masonry has good sound, heat, and moisture insulation properties because of the hollow space between the blocks, the air space in the block accounts for 25% of the total area of the block, and hollow blocks enable thinner walls and more floor space. Cement concrete blocks have surpassed traditional building materials such as bricks and stones in popularity. To use blocks in construction, the wall's overall length and height must be fixed, allowing for the use of a single or half-length block. The hollow concrete blocks were discovered for a variety of reasons:

- Sound management,
- Dead load is low,
- Resistance to fire,
- Sufficient strength,
- Outstanding thermal insulation,
- Economy,
- Exceptionally long-lasting,
- Environmentally Sound,

- Reduced mortar consumption,
- Quick and Easy Building System,
- Improved architectural features.

Disadvantages are:

- The load-bearing capability of hollow blocks is decreased by the combined mass of wall decoration materials.
- Hanging heavy objects on such walls is extremely dangerous.

Applications are:

- In load-bearing structures, hollow blocks are used.
- It's used to build frame structures like high-rise residential apartments and other similar structures.
- It is used on the ground, such as roadside walkways.
- It is also used in unusual applications such as roadside and backyard plantation tree guard blocks.

Concrete hollow block is most effective in load-bearing structures, where it can provide load support, space division, fire and weather protection, and thermal and acoustic insulation, all of which must be separately accounted for in a framed building. According to the allowable stress design, under a working load, the stresses developed in a member must be less than the allowable stresses (Varzaneh *et al.,* 2020, Muthukumar & Kumar, 2015). Clay bricks, both unfired and fired, concrete bricks, and hollow concrete blocks are just a few of the masonry materials available (A. L. Murmu and A. Patel, 2018). Concrete blocks hollow have the potential to reduce energy consumption, consume fewer raw materials, and have a lower environmental impact, as a result, concrete hollow blocks have become increasingly important in the construction industry (N. Sathiparan, M. K. N. Anusari, 2014).

1.1 Literature Review

The compressive strength of masonry was reported by Udi *et al.,* (2020) where it is affected by several factors, such as the aspect ratio of the units, the mortar strength, the unit strength, and the relative values of the units and mortar (ratio of height to least horizontal dimension). Unit orientation with reference to the applied load direction and bed joint thickness. The criteria stated highlight how difficult it is to determine the strength of the brickwork with accuracy. (Kuddus & Fabregat, (2017) discovered that the compressive strength of blockwork would also be affected by the change in mortar designations. The strength of block wall panels could be significantly increased by using high-strength mortar instead of low-strength masonry units while building blockwork, and vice versa. Bakhteri *et al.,* (2012), shown empirically that for a brick of a certain height, the strength of a brick falls as the junction thickness grows, and it was demonstrated by Bakhteri *et al.,* (2004) using the aid of finite element modelling. Additionally, it was discovered that eccentricity of loading also has an impact on the brickwork's strength. When force is applied farther from the centre of a wall panel that is uniformly loaded, there is sometimes an apparent increase in compressive strength. Sureshchandra *et al.,* (2014) find out the compressive strength of hollow blocks with partial and full replacement of sand by quarry dust. After replacement he found that 50% replacement of sand gave high strength, and 100% replacement of sand gave low strength. Fortes *et al.,* (2015) studied the compressive strength of un-grouted, grouted masonry and masonry units. This research work indicates an increase in the compressive strength of the masonry with increasing compressive strength of the units.

2.0 MATERIALS

2.1 Standard Sizes of Concrete Hollow Block

A concrete hollow block is one with at least one large hole or cavity running through it and solid material accounting for 50 to 75% of the total volume calculated from the block's overall dimensions (Varzaneh *et al.,* 2020). Concrete hollow block units come in a wide range of sizes and shapes to accommodate a wide range of construction needs, examples include stretchers, corners, double corners, piers, jambs, headers, bullnoses, partition blocks, and concrete floor units. The concrete hollow blocks' nominal dimensions must be used, whether hollow (open or closed cavity) or solid, and the concrete blocks' nominal sizes are as follows:

Length: 400, 500, or 600 mm,
Height: 200 or 100 mm,
Width: 50, 75, 100, 150, 200, 250, or 300 mm.

Along with the previously mentioned blocks, half lengths of 200, 250, and 300 mm are required to match the full lengths. Table 1 shows the sizes and weights of different concrete hollow blocks. The length tolerance of the units must not exceed +/- 5 mm, and the maximum height and width variation must not exceed +/- 3mm (Nalon *et al.,* 2022).

Table 1: Different sizes and weights of hollow blocks (Varshney, 2016)

S/No	Description	Size in (cm)	Approximate mass in Kgs
1	Entire hollow	39 x09 x 19	10.0
2	Hollow in half	19 x 09 x 19	5.1
3	Half a lintel	19 x 14 x19	7.5
4	Hollow lintel	19 x19 x 19	9.3
5	Floor slab	50 x 20 x 12.5	18.0

2.2 The Geometry of the Concrete Hollow Block

Concrete hollow block units for masonry construction are available in different shapes and sizes, and strengths, the standard block is the most common type, which comes in two shapes, open-end units, double-open-end units, lintel units, and knock-out units are popular styles. To improve the thermal reduction of vertical partitions, openings in concrete hollow blocks are used and the lightening/simplification of block handling lowers the structural load of the building (Nalon *et al.,* 2022). Compared to solid blocks, although using hollow elements saves material costs, internal acoustic resonances within the blocks can be increased by the core holes in the blocks, which are associated because of their lower surface weight, resulting in a significant reduction in the system's sound reduction. The sound reduction index is influenced by the geometry of the holes, which is determined by the blocks' net and gross area ratios, with their weight ratios, resulting in various sound transmission reduction curves (Oliveira *et al.,* 2021). When producing high-strength concrete blocks, some plants used a variety of concrete block geometries. Because the net area increases and the desired

Table 2: Concrete Hollow Blocks Classification Based on Compressive Strength and Density (ASTM C140/C140M-14, 2014)

Type	Grade	The block density is kg/mm³	Minimum Compressive Strength Unit Average N/mm²	Individual Unit Minimum Strength N/mm²
Hollow block (open & closed cavity) loadbearing unit	A (3.5)	Not less than 1500	3.5	2.8
	A (4.5)		4.5	3.6
	A (5.5)	Not less than 150 but not less than 1,000	5.5	4.4
	A (7.0)		7.0	5.6
	B (2.0)		2.0	1.6
	B (3.0)		3.0	2.4
	B (5.0)		5.0	4.0
Hollow block (open & closed cavity) non-loadbearing unit	C (1.5)	Less than 1500 but not less than 1,000	1.5	1.2
Solid load	D (5.0)		5.0	4.0
Bearing unit	D (4.0)	Not less than 1800	4.0	3.2

compressive strength is easier to achieve, 32mm thick face-shell concrete hollow blocks will be produced if the plant lacks a strong compressive block moulding machine. This is an option, however, has some drawbacks: the mass of concrete hollow blocks rises (by about 15%), putting building lower ends under stress the productivity of laying the units falls; and transportation costs increase. Another advantage of using this type of concrete hollow block is that involuntary changes in the high-strength of concrete are avoided due to the thinner face-shell thickness of these blocks (Gauthier & Hawley, 2007, Abd Manan *et al.,* 2019, Abd Manan *et al.,* 2021, Beddu *et al.,* 2020) lower-strength concrete hollow blocks are less likely. This choice is significant because it avoids the need for the plant to halt production when the compressive strength of the block varies, like other large-scale companies that typically produce concrete hollow blocks with a 25 mm face-shell thickness, plants frequently alter the proportions of the mixture as well as the settings of the equipment (Cintya3 *et al.,* 2012).

2.3 Concrete Hollow Block Classification Based on Compressive Strength and Density

These types of masonry units are categorised as concrete hollow blocks load-bearing and non-load-bearing units (open and closed cavity) and shall conform to the following grades as can be seen from Table 2. The minimum block density for Grade A concrete block unit is 1,500 kg/m³ as load bearing is designed at 28 days to have low average compressive strengths of 3.5, 4.5, 5.5, 7.0, 8.5, 10.0, 12.5, and 15.0 N/mm². Group B concrete hollow block units are also used as load-bearing units, and their block density must be between 1,100 kg/ m³ and 1,500 kg/ m³, and at 28 days should have average compressive strengths of at least 3.5 and 5.0 N/mm² (Amalkar *et al.,* 2020). Grade C units are non-load bearing and must have a minimum block density of 1,500 kg/ m3 but not less than 1,000 kg/m3, and they are designed to have average compressive strengths of at least 1.5 and 1.2 N/mm² at 28 days (ASTM C140/C140M-14, 2014).

2.4 Physical Properties of Concrete Hollow Block

The basic requirement for any concrete hollow block is to provide Moisture Movement, absorption of water, drying Shrinkage, compressive strength, density, and durability (Varshney, 2016). Hollow concrete blocks, apart from providing the above-listed benefits, possess adequate strength and structural stability, are highly durable, fire resistant, economical, and provide a fast and easier construction system. In addition to this, they provide aesthetic beauty by providing better architectural features (Hendry, 2001). The physical characteristics of masonry hollow concrete blocks are shown in Table 3:

Table 3: Physical Properties of Concrete Hollow Block

S/N	Type	Grade
1	Moisture Movement	A maximum of 0.09%
2	Absorption of Water	A maximum of 10%
3	Drying Shrinkage	A maximum of 0.06%
4	Compressive Strength	For Grade A: 3.5 to 15.0 N/mm² For Grade B: 3.5 and 5.0 N/mm²
5	Density	For Grade A: 1500 kg/m³ For Grade B: 1100 kg/m³ to 1500 kg/m³

3.0 EXPERIMENT

3.1 Concrete Hollow Block

The Malaysian city of Penang provided the masonry hollow block units for this investigation, the prepared block is shown in Figure 1. The concrete hollow block units used have identical dimensions and configurations and are manufactured in a single production batch (190 mm × 140 mm × 390 mm).

Figure 1: Masonry Hollow Block

Figure 2: Boiling Machine Test

3.2 Mortar

The type of mortar used in this study was grade 30 (1:3), this type of mortar is described by (BSI 5628: British standards institution (BSI). BSI-5628, 1992, G. Mohamad *et al.,* 2007). The volume ratio of cement and sand used was that suggested by Wheeler, (2005). The water-to-cement ratio used for mortar was 0.5, and the mortar was batched immediately before mixing. The mortar was mixed with water until a homogenous mixture was obtained. A pan-type mixer was used, with each batch receiving a minimum mixing time of 5 minutes. Throughout the test procedure, consistent sources of material were used, and all ingredients were rigorously batch-mixed by volume to ensure consistency of mortar qualities.

3.3 Water Absorption

The amount of water that a unit can hold when saturated is referred to as its water absorption. Absorption can reveal a concrete mix's degree of compaction, or the volume of voids present in a block. Variations in absorption may be a sign of hazardous substances in the combination, inadequate mixing, and/or compaction of the concrete mix, as well as variations in compressive strength, tensile strength, and durability, issues with laboratory procedures, or other causes for a specific mix design, manufacturing, and curing process (ASTM C140/C140M-14, 2014, BS 1881-122:2011+A1, 2020).

3.4 5-Hour Boiling Test

The concrete hollow block used in this study is not suitable to be tested using the vacuum method due to its size; the boiling test method shown in Figure 2 was adopted. The first step of the process is to dry the concrete block samples for 72 hours (temperature 110ºC) in the oven. They were then cooled at room temperature and weighed. The concrete hollow blocks were transferred into a water tank for one-hour heating and subsequently boiled for 5 hours. The cooling process was done again at room temperature for 16 to 19 hours for the blocks to naturally lose heat. After that, the samples were removed from the water, wiped down with a damp cloth, and weighed. The following equation is used to calculate water absorption. This test complied with (MS 76, 1972).

Water absorption, % =

$$\% = \frac{100(w_d - w_s)}{w_d} \tag{1}$$

Where: w_d = dry weight of the specimen
w_s = saturated weight of the specimen

3.5 Compressive Strength Test

Concrete hollow block units are subjected to compressive strength testing to make sure they adhere to the applicable unit specifications' minimum strength criteria *(EVALUATING THE COMPRESSIVE STRENGTH OF CONCRETE MASONRY - 2012 IBC/2011 MSJC - NCMA*, n.d.), according to Figure 3. This test is performed on a concrete block with a dimension of 140mm x 190mm x 390mm to find the failure and breakage point of the concrete block as well as the strength. It is applicable for production control, performance, and compliance testing. The compressive strength is calculated using the following formulae:

$$f = \frac{W}{A} \tag{2}$$

Where: f = compressive strength of the specimen (N/mm^2)
W = maximum load (N)
A = average of the gross area surfaces of the specimen (mm^2)

Figure 3: Compressive Strength Machine

3.6 Density Test

The density test determines the density of the concrete block, and the test is conducted with conformity to (BS EN 12390-7, 2009). At 100ºC, the concrete block samples are dried to a constant mass. Each block's dimensions are given in centimeters (to the nearest millimeter), and the total volume, V, in cubic centimeters must be calculated after the blocks have been cooled to room temperature. After that, the blocks are weighed in kilograms (to the nearest 10 g) m_{dry}. The average for the three blocks is taken as the average density. The formula for the density of the concrete block is as shown in the Equation below:

$$D = \left(\frac{w_d}{w_s - w_i}\right) \times 1000 \quad (3)$$

where: D = density (kg/m^3)
w_d = oven dry weight (kg)
w_s = saturated weight (kg)
w_i = immersed weight (kg)

3.7 Flexural Strength

An object's modulus of rupture (or flexural strength) is the maximum amount of force that it can withstand before breaking or becoming permanently deformed. Flexural strength can be measured in two very similar ways. The ends of a long rectangular sample of the material are supported, leaving no support in the center, yet the ends are solid. The material is then loaded or pressed until the central section is broken. An increasing load is delivered to the center of the sample during a three-point bending strength test until the material permanently breaks or bends. Increased forces can be applied while the force at the failure point is carefully recorded using flexural test equipment. The only difference between a four-point bending test and a two-point bending test is that the load is applied simultaneously at both points, once further toward the center of the sample. The flexural strength is easier to calculate when one load or force is applied halfway between the supports and another part is applied halfway between them. Figure 4 demonstrates how the test was conducted.

Figure 4: Flexural Strength Test

The three-point bending strength test was employed in this study, and since length, width, and depth are all measured in meters in SI units, the force is measured in newtons, resulting in pascals (Pa), or newtons per square meter. Lengths, widths, and depths will be measured in imperial inches, and force in pounds-force resulting in pounds per square inch. The results were calculated using the following formulae:

$$S = \frac{3W\left(H/2 - x\right)}{bd^2} \quad (4)$$

Where: S = flexural strength (N/mm^2)
W = maximum applied load (N)
H = distance between support (mm)
b = width of the specimen (mm)
d = depth of the specimen (mm)
x = distance from the plane of failure to the midspan (mm)

3.8 Compressive Strength of Mortar

The mortars were cast in 50 mm × 50 mm × 50 mm molds as per (ASTM C 270-07, 2007, Khalaf, 2015) compressive strength of mortar standard test method. The mortar was cured for 28 days and 1.5 hours after mixing, the initial setting was removed. For the first 24 hours, the cubes were stored and covered with a polythene sheet before being removed from the mold and cured in water at 20^{o}C for 27 days. To determine the relative density of the mortar, the cubes were weighed in both air and water. They were then loaded at 0.1N/mm^2/sec to ascertain the mortar's compressive strength. The mortar cube during the compressive strength test is shown in Figure 5.

Figure 5: Mortar Compressive Strength

Figure 6: Dropping Ball Test Apparatus

The dropping ball apparatus, as shown in Figure 6, was used to perform the mortar consistency test and under (British Standards Institution BSI, 1980). A consistency of approximately ± 1mm was used for the 1:3 designation mortars. The calculation of the result is using the formula as follows:

Compressive strength of mortar = max load carried by specimen/top surface area of the specimen Eq. 5

4.0 RESULTS AND DISCUSSION

The outcomes of tests conducted on the concrete hollow block's density, water absorption, and workability as well as its strength (concrete hollow block and mortar) as shown in Table 4. In the dropping ball test, the mortar type (¡¡) with the designation 1:3 had a consistency of about 10 ± 1mm. The mortar was used 1.5 hours after mixing before the initial setting was discarded. The amount of water that a unit can hold when saturated is defined as absorption. Absorption can indicate a concrete mix's level of compaction or the volume of voids within a block. The water absorption for the concrete hollow block used was approximately 7.362%. The density for a concrete hollow block is approximately 1,203 kg/m^3.

The hollow concrete block unit is subjected to an axial compressive load until it fails. Compressive strength tests are performed on concrete masonry units to ensure that they meet the minimum strength requirements of the applicable unit specification. The concrete hollow block used has a compressive strength of approximately 8.39 N/mm^2. The compressive and tensile strengths of the mortar are approximately 21.34 MPa and 33.23 kN, respectively. An object's modulus of rupture (or flexural strength) is the amount of force it can withstand before breaking or becoming permanently deformed. The flexural strength of the concrete hollow block used was approximately 3.91 N/m^2.

Table 4: Engineering Properties of Masonry Concrete Hollow Block

Engineering Properties	Values (Unit)
Workability (dropping ball apparatus)	10 ± 1mm
Water Absorption	7.362%
Density	1,203 kg/m^3
Compressive Strength (hollow concrete block unit)	8.39 N/mm^2
Compressive Strength (mortar)	21.34 MPa
Tensile Strength (mortar)	33.23 MPa
Flexural Strength (hollow concrete block unit)	3.91/mm^2

4.1 Construction of Concrete Hollow Block

Until recently, traditional masonry methods of wall construction mostly remained the same, drawing criticism that masonry buildings take too long to construct and are hard to locate competent labor, in part due to unpleasant on-site working conditions (Hendry, 2001). The utilisation of innovative site practices, pre-fabrication, and new sorts of units have been the main areas of attention in efforts to ameliorate the situation (Hendry, 2001). Masonry structures are defined by their shape and certain material characteristics, such as those of the mortar and masonry units. As a result, the material properties must be established before thinking about the structural behaviour of the structural element. When designing masonry structures, compressive strength and deformations are important mechanical features to consider. Masonry mechanical properties are significantly influenced by the composition of masonry units (Maroliya *et al.,* 2012, Mohamad *et al.,* 2007, Khalaf, 2015), hollowness, material type, and mortar bed joints are all factors to consider (Köksal *et al.,* 2005 Hendry, 2001). Increased lateral strain due to nonlinearity in the stress-strain relationship is associated with concrete microcracking (G. Mohamad *et al.,* 2011, Drysdale & Hamid, 1979, Shrive & El-Rahman, 1985). Understanding the mechanisms of deformation and failure is essential for determining a wall's carrying capacity and improving understanding of its compressive strength.

Masonry works best in load-bearing structures because it can sustain loads, offer thermal and acoustic insulation, separate spaces, and protect against weather and fire, all of which must be accounted for, separately in a framed building. According to the allowed stress design, the stresses generated in a member while it is supporting a working load must be fewer than the allowable stresses. It is assumed that unreinforced masonry can withstand tensile stresses within allowable limits; however, the tensile strength of the masonry is ignored in reinforced masonry. The ACI code uses this design strategy for both unreinforced and reinforced masonry, whereas the IS code only applies to unreinforced masonry (Muthukumar & Kumar, 2015). The masonry nominal strength members must be multiplied by a strength reduction factor to achieve the design strength, which must be equal to or greater than the required strength. The necessary strength must be determined using a legally adopted building code's strength design load combination (Muthukumar & Kumar, 2015).

4.2 Modelling of Concrete Hollow Block

Masonry is a versatile building material comprised of several types of blocks, stones, ashlars, adobes, irregular stones, and other materials, and other units are examples of units and joints. Other materials, such as clay, bitumen, chalk lime/ cement-based mortar, glue, and others, can be used as mortar. The term "masonry" is called into doubt by the large variety of combinations that can be made by unit geometry, nature, and arrangement as well as mortar qualities (R.E. Klingner, 2010). High specific weight with low tensile and shear strengths and ductility are some of the mechanical properties of various types of masonry (brittle behaviour). For numerical analysis of masonry structures, the Finite Element Method is commonly used (FEM). Creating a finite element model of a structural element or the entire structure is the first step in the analysis process. Columns, arches, domes, and vaults can be represented in the geometrical model using trusses, beams, solid, membrane, plate, and/or shell elements. Various modeling strategies are available to represent the heterogeneous and anisotropy of masonry construction, depending on the desired level of simplicity and accuracy.

The most significant issue encountered when modeling such structures is the difference in the mechanical properties of the masonry unit and mortar used to construct the masonry structure. A variety of modeling techniques can be used to examine masonry structures and computer software. In some of these studies, various modeling techniques are used to compare the results of the experimental study to the analysis results, ANSYS software is used for research on numerical simulations of masonry buildings (Eslami *et al.,* 2012, Kouris & Kappos, 2012). There are two types of masonry numerical modeling in general: macro modeling and micro modeling. The accuracy and precision of the simulation determine the modeling technique used in the analysis (Doran *et al.,* 2022). Micro modeling is divided into two types: detailed micro and simplified micro and the strategies shown in Figure 7 are described in greater detail (P.B. Lourenc¸o, 1996).

a) Detailed micro-modeling: this is the most precise method of simulation of the behaviour of masonry bricks; running analyses, however, takes time and is only useful for tiny masonry walls (Liu & Crewe, 2020). Both mortar and masonry are discrete inelastic continuum components and discontinuous elements also represent the interface between the mortar and the units. This analysis necessitates familiarity with each masonry constituent (unit and mortar), all masonry failure mechanisms, such as joint cracking, unit cracking, masonry crushing, and sliding over one head or bed joint, must be considered, as well as the interface (L. Macorini, 2013). In applications, finite elements, discrete elements, and limit analysis can all be used (A. Ordun˜ a, 2005). Micro-modeling: more computational effort is required for the studies, but the results provide a better understanding of masonry structural local behaviour. This method is ideal for research as well as small models for localised analysis (A. Giordano, 2002, P.B. Lourenc¸o, 1996).

b) Simplify micro-modeling: the behaviour of an expanded unit is the behaviour of a mortar joint, or a unit-mortar interface is represented by discontinuous elements known as interface elements, whereas the behaviour of a unit-mortar interface is represented by discontinuous elements known as interface elements. Masonry can thus be thought of as a series of elastic blocks joined together at joints by potential fracture/slip lines (G. Giambanco, 2001).

c) Macro-modeling (homogenisation theory): is the most fundamental strategy: masonry units, mortar, and mortar-unit interfaces are smudged in a homogeneous continuum material. Masonry is thus represented as an anisotropic homogeneous continuum, with masonry's macro constitutive behaviour obtained through a mathematical procedure that includes masonry components' geometry and constitutive behaviour (S.Y. Chen, 2008, G. Milani, 2006). When a structure has large dimensions and the stresses are distributed uniformly along the macro length, macro models are more useful (P.B. Lourenc¸o, 1996, S.Y. Chen, 2008). Large-scale structures can be efficiently modelled using the macro modelling approach. however, it is incapable of accurately capturing the detailed failure mechanisms (P.B. Lourenc¸o, 1996, Liu & Crewe, 2020, Lourenço, 1994).

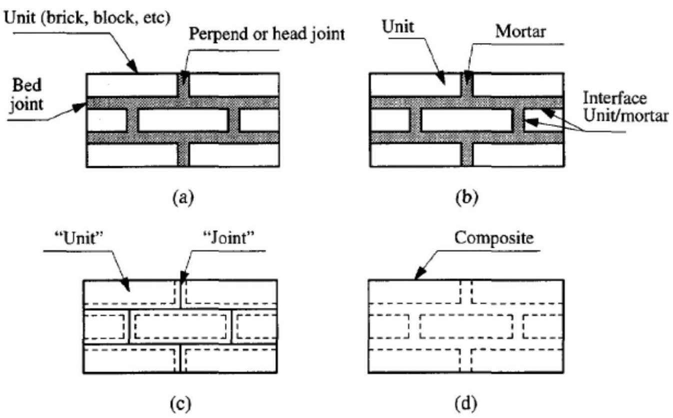

Figure 7: Methods for Modeling Block Masonry (a) An Example of Masonry; (b) Detailed Micro Modeling; (c) Simplified Micro Modeling; and (d) Macro Modelling (A. B. A. E. Mohamad & Chen, 2016)

4.3 Concrete Hollow Block Wall

A concrete hollow block wall is a heterogeneous structural composite material with mechanical properties determined by the composite components' properties and interactions (block and mortar), volume ratio, bond properties. Many researchers have conducted experiments to characterize the properties of masonry units for various masonry building systems Costigan *et al.,* 2015, Jafari *et al.,* 2017, Parajuli & Kiyono, 2015). The mechanical properties of masonry are influenced by the amount of stress in the joints, the direction of the bed joints, the shear modulus value, and the stiffness of the masonry structural parts (Kaushik *et al.,* 2007). The masonry's shear modulus was determined through compression tests and the diagonal test determined effective stiffness, which agreed well with the lateral tests that determined effective stiffness. Mathematical modeling of masonry, which is a composite material and, in general, refers to the material properties and constitutive elements relationship between masonry and its constituents, required for the combination of two different property materials, such as block and mortar. Masonry is an anisotropic, brittle composite material with distinct directional properties caused by brittle mortar joints, when subjected to extremely low levels of stress, masonry exhibits linear elastic behaviour, and after crack formation, high non-linearity is observed, causing stress redistribution through uncracked materials (Bui *et al.,* 2021). Increasing masonry bond tensile strength has a significant impact on transverse strength, as well as compressive and shearing strengths. Tensile splitting of the materials due to axial loading, rather than crushing or shear, is the most common type of compression failure (Kuddus & Fabregat, 2017). Out-of-plane failure mechanisms are prevented when the walls are not too thin and the connections between the floors and walls are appropriate. Masonry with sufficient strength at the corners and tension-resistant horizontal ties or bands are used to make the connections, and the masonry wall's in-plane shear capacity can then be utilized. The stiffness of walls degrades continuously under in-plane mechanisms after significant stiffness and strength loss, and the wall's gravity load-carrying capacity is eventually compromised, resulting in the structure's complete collapse due to the following reason:

- Mortar joint failure: this is common in masonry when the average compression is low.
- Shear tension failure of the unit: this occurs in masonry for intermediate average compression values.
- When the masonry's average compression is close to its uniaxial compressive strength, crushing failure occurs (Rai, 2017).

4.4 Compressive Strength of Masonry Block Wall

The compressive strength of the mortar influences masonry strength, significant variation in mortar strength causes variation in masonry strength (Nalon *et al.,* 2022). Mortar is made up of fine aggregate and binders that, when mixed with a small amount of water, form a workable and adhesive mixture (Nalon *et al.,* 2022). When calculating masonry compressive strength, several variables must be considered, including the thickness of the mortar joints, the height of the unit and its smaller horizontal dimension, the orientation of the unit concerning the direction of load application, and the strengths of the mortar and units. Many factors, both individually and in combination, indicate the difficulty of determining the masonry strength precisely. Masonry structural design necessitates a thorough understanding of the behaviour of the mortar and units assembled to withstand a variety of load conditions. The use of various types of blocks and mortar influences the behaviour of structural masonry elements significantly (Parsekian *et al.,* 2012). Masonry compressive strength is heavily influenced by block type, to a lesser extent by labor, and even less so by mortar type. The masonry's typical resistance to compressive loads is influenced by the unit's characteristic strength, the specified mortar used if the masonry is mortared, the shape of the unit, the thickness of the mortar joints, and the craftsmanship (Rai, 2017).

Masonry is constructed of two very distinct materials with extremely different mechanical properties: the stiffer block and the relatively malleable mortar, to which grout and reinforcement are added as necessary. Masonry has a very low tensile strength due to the regular distribution of various elements and the brittle connection between them. As a result, widely used unreinforced masonry should be expected to withstand compression loads. Under compression, masonry has three major modes of rupture depending on the relationship between the mortar's and the block's compressive strength:

a) When the mortar is very weak in comparison to the block, the masonry capacity is limited by the strength of the mortar, which usually fails by crushing.

b) When the mortar is moderately strong, the masonry capacity is determined by a combination of the compression and tension strength of the block, which typically fails due to lateral tension.
c) When the mortar is stronger than the block, the block's compressive strength limits masonry capacity.

Consider compressive strength as important property when designing masonry walls in a variety of loading scenarios. Several previous research studies on concrete hollow block masonry compressive behaviour have been conducted (Barbosa *et al.,* 2010, Fortes *et al.,* 2015), Thamboo & Dhanasekar, 2016, Zahra *et al.,* 2021). Several provisions in masonry design standards are also described to predict the axial compression strength of concrete block masonry (Zahra *et al.,* 2021, AS 3700, 2001). When it comes to predicting masonry compressive strength, however, there are differences between the standards. According to Rai, (2017) construction practices, geometry, the bond between the grout and the block, and other elements, all have an impact on how effectively grouted masonry works. Additionally, grouted masonry may be less effective than ungrouted masonry because the compressive strengths of ungrouted and grouted masonry varied depending on the materials employed (Atamturktur *et al.,* 2017). Dry-stacked concrete masonry unit compressive strength and interface roughness with varying strengths were investigated. They concluded that interface roughness has a substantial impact on load-displacement behaviour and ultimate dry-stacked assembly capacity.

Concrete hollow block compressive strength is significant for two reasons: first and foremost, the greater the resistance, the longer the durability; second, the strength of the block is critical in structural masonry for compressive strength of the structural element, together with the appropriate mortar and grout specifications in terms of net area, with international standards requiring a minimum compressive strength of 10 MPa. Masonry structural design necessitates a thorough understanding of mortar and unit assembly behaviour to withstand a range of load conditions. The use of various types of blocks and mortar influences the behaviour of structural masonry elements. The compressive strength of masonry is the governing mechanical property in structures that contain these elements. Mortar strength, unit strength, mortar-to-unit strength ratio, the relationship between unit height and smaller horizontal dimension, unit orientation relative to load application direction, and mortar joint thickness all have an impact on masonry compressive strength (Rai, 2017). Even though masonry compressive strength is primarily influenced by masonry unit properties and the interfacial bond between masonry units and mortar, as well as the joint mortar, masonry unit moisture content at lazing, mortar thickness, masonry prism slenderness, workmanship, and other factors all play a role (Sajanthan *et al.,* 2019). Bennett *et al.,* (1997) was suggested to use a straightforward equation to compare the compressive strengths of bricks with masonry, with masonry compressive strength being equal to 0.3 times brick compressive strength. However, most of the other empirical expressions also consider mortar strength.

4.5 Tensile Strength of Concrete Hollow Block Wall

The tensile strength of the block is frequently the weak point of masonry under vertical loads, it is critical to avoid cracking. The tensile strength of a concrete block should be 10% to 15% of its compressive strength; this method yields approximately 120% direct tensile strength (Tennant *et al.,* 2016). Concrete block masonry will shrink over time, just like any cement product if shrinkage is not managed, cracks can form, particularly in long walls. Extreme wall shrinkage can have an impact on the performance of other elements in the building, the amount of cement used, the type of aggregate used, and the environmental relative humidity all influence shrinkage deformation (Parsikian *et al.* 2019). Most of the shrinkage occurs during the steam curing process in the factory and shrinkage occurs more frequently in blocks that have only been moist cured. Units that have not been steam-cured for at least 28 days are therefore not recommended. Lightweight blocks shrink more than regular-weight blocks (from 0.04 to 0.08 percent) (from 0.02 percent to 0.05 percent). When wet blocks are used to build a wall, they expand and contract significantly after drying. The likelihood of shrinkage and pathologies increases when walls are laid wet, therefore, before installation, the concrete hollow block should not be wet (Inst., 1985). Masonry unit properties, mortar strength properties, loading eccentricity, all boundary conditions at the top and bottom of the wall, with the wall slenderness ratio (the ratio of effective height divided by effective thickness or effective length divided by effective thickness, whichever is greater) are considered (Amalkar *et al.,* 2020). These are the elements that contribute to a masonry block wall's strength, in addition to the previously mentioned factors, workmanship has a significant impact on masonry strength (Udi *et al.,* 2020). All the variables mentioned above changed during the construction and testing of full-scale wall panels, and a more realistic understanding of load-bearing masonry structural design was obtained, masonry's load-carrying capacity is typically measured in three ways:

- Tests on masonry components,
- Tests on masonry prism, and
- Full-scale wall specimens were subjected to tests.

Full-scale wall testing may provide a more realistic understanding of masonry performance because it considers all the preceding factors, plus the effect of masonry numerable joints (both vertical and horizontal). It is always best to create a full-scale masonry model that can be tested in real life when modeling any structure or element.

4.6 Flexural Bond Strength

Hardened mortar's most significant physical property is its flexural bond strength. The mortar's bond strength to brick units allows lateral loads to be transferred to veneer anchors in veneer applications. The bond influences the overall strength of the wall's ability to withstand lateral and flexural loads in load-bearing applications. Bond strength is influenced by block texture, suction, air content, water retention, the pressure used to form the joint, mortar proportions, and curing methods (Notes, 2020). Bond strength, also known as flexural strength, is a significant property that influences the structural performance of masonry walls, particularly when subjected to lateral loads such as winds and earthquakes. The penetration of cement hydration into the surface bond strength between the mortars determines masonry and the masonry units. Hamid & Drysdale, (1988) reported that, filling the hollow block cores with grout resulted in very significant increases in the bed joints' normal flexural tensile strength. These strengths were significantly greater than the 100% solid units built in block work.

In a study by M. Martinez and S. Atamturktur, (2018) and Martínez & Atamturktur, (2019) on masonry walls under flexural with various parameters; grout strength, reinforcement masonry unit, and grout place, according to them, converting partially grouted walls to fully grouted walls increased the ultimate load capacity. The grout's compressive strength was increased, which increased the prism's ultimate lateral load capacity. Tennant *et al.,* (2016) conducted research, they tested flexural with cement-stablisation soil blocks specimens, parallel to the bed's joints failed when the flexural strength test exceeded the bond strength with the masonry.

4.7 Suction Rate of Masonry Unit

When compared to clay and calcium silicate units, concrete hollow blocks have the highest suction rate. In practice, the initial suction rate is used to measure the surface porosity of the unit, capillary action is used to transport water from the mortar to the unit, affecting the unit-mortar bond (Inst., 1985). When mortar bonds are laid, they have an initial absorption rate of 30 g/min/30 inc^2 (30 g/min/194 cm^2) or less. If the initial rate of absorption of the brick is greater than this value, it should be wetted for 3 to 24 hours before lying down. The surface should be dry when laying a wetted block in a mortar (Borcheltl & Melande, 1999, Walker, 1996).

4.8 Unit Concrete Hollow Block and Mortar Interaction

Concrete hollow block mortar must be sufficiently durable to withstand relevant micro exposure conditions for the duration of the building's intended life, and it must not contain constituents that can impair the mortar's or abutting material's properties or durability. The mechanical and geometrical properties of the units, with the bond strength between the units and the mortar, all influence masonry behaviour (Venkatarama Reddy & Uday Vyas, 2008). Mortar joints between block units are critical in determining masonry behaviour, but they are frequently regarded as weak points (Dhanasekar, 2010). Hydrated lime and/or Ordinary Portland cement (OPC) are two common binder elements in mortar formulations. Water is required to achieve the desired workability, the most important intrinsic factor affecting the characteristics of fresh mortar, along with those of hardened mortar and the combination is the removal or migration of water. The parameters of the masonry unit-mortar interface are influenced by the removal or movement of water from the mortar bed. Changes in moisture cause the mortar and masonry components to shrink and swell, and the temperature has an impact on joint quality. Several factors related to both the unit and the mortar influence the variation in suction caused by the collision of a masonry unit and new mortar. The mortar may hold little or no water in some cases, while in others, the masonry unit absorbs all the water. Suction affects the mortar bond's strength and porosity, as well as its water tightness and other properties, the water present after suction, rather than the initial water content of the mortar determines its strength.

5.0 MORTAR

5.1 The Role of Mortar

Mortar is typically specified to meet ASTM C270 (Gheni *et al.,* 2017) and in a masonry assembly, mortar is the glue that holds the bricks together. Mortar must be strong enough to hold the masonry together while also aiding in the formation of a water-resistant barrier. Furthermore, when mortar is applied, it accounts for both dimensional variations and blocks physical properties. The mortar ingredient composition, proportions, and properties all have an impact on these requirements (Hendry, 2001). The shape of the mortar and grout has a large influence on the wall's tightness. Low-strength, easy-to-apply mortars will form a more weatherproof seal at the mortar/block interface. It is worth noting that the compressive and tensile strengths of the mortar must be less than those of the block (Rai, 2017). Masonry failure is caused primarily by the masonry units; therefore, strain compatibility for the physical interface is required (Chourasia *et al.,* 2019). Tensile cracking in the joint causes the masonry to fail if the block is more powerful than the mortar, the masonry will develop a vertical crack. Shear failure of the bond at the block mortar interface, resulting in tensile splitting. The block would crumble rather than split if it were tougher than the mortar (Sajanthan *et al.,* 2019). The strength grade of mortar is the most common way to identify it; an M12 mortar after 28 days should have a minimum compressive strength of 12 N/mm^2.

According to Euro code 6 (Kuddus & Fabregat, 2017), masonry mortar is classified into three types: general-purpose, thin-layer, and lightweight mortars, all of which can be designed or prescribed. Factory-made pre-batched masonry mortars and factory-made semi-finished masonry mortars (*Types of Mortar - Masonry Structures Eurocode - Euro Guide*, n.d.). Hardened mortar quality in designed mortars should be determined by its compressive strength, prescription mortars, on the other hand, use predetermined proportions for the intended use; in prescribed mortars, adequate adhesion depends on the type of mortar used, and the units to which it is applied determine the result. Masonry mortar composition varies depending on wall thickness and construction technique. For 220 mm thick masonry walls, a richer mix of 1: 6 is used, while for 115 mm thick non-load bearing (partition) walls, a richer mix of 1: 4 is used, and masonry mortar thickness ranges between 10 and 15 mm (Chourasia *et al.,* 2019). According to Bolhassani *et al.,* (2016), Portland cement lime mortar type 'S' after 28 days has an average compressive strength of 13 MPa and is used in constructing concrete masonry walls. The coarse grout meets ATSM C476 (*ASTM C476: Standard Specification for Grout for Masonry : American Society for Testing and Materials : Free Download, Borrow, and Streaming : Internet Archive*, n.d.) specifications, with a slump test of 250 mm and an average net of 23 MPa compressive strength.

5.2 Joint Thickness

Due to its inherent properties that meet the various requirements of both exterior and interior walls, concrete hollow block is a popular building material. While these are the most important reasons for the popularity of concrete hollow block, performance should not be overlooked. Like any other construction system, the field performance of a concrete hollow block wall system is heavily influenced by design decisions. When crack control measures, such as control joints, are used correctly, they can help ensure that the concrete hollow block performs satisfactorily. Control joints are one method of alleviating horizontal tensile stresses caused by shrinkage of concrete hollow block units, mortar, and grout; they are vertical planes of weakness with high stress built into the wall to allow for shrinkage-induced longitudinal movement. A bond break is formed by using a backer rod and sealant to replace all or part of a vertical mortar joint, these seals the joint while allowing for slight movement. Joint reinforcement and other horizontal reinforcement at control joints should be avoided unless structurally necessary, as they limit horizontal movement (Scutaru, 2018).

General purpose and lightweight mortar beds and perpendicular joints should be not less than 6 mm thick and not more than 15mm thick, whereas thin-layer mortars should be not less than 0.5 mm thick and not more than 3mm thick (Zahra *et al.,* 2021). The failure mode or mechanical properties of prisms built with strong mortars were unaffected by variations in joint thickness ranging from 5 to 20mm (Nalon *et al.,* 2022). Vertical control joints in concrete hollow bock wall are only required when control joints are required. When using materials with different movement properties, such as concrete and clay masonry, the movement difference must be accounted for in the design.

5.3 Water Retentivity

Water retentivity refers to a mortar's ability to retain water against suction and evaporation, in general, it is an indirect measure of mortar workability (Notes, 2020). Unless an absorptive concrete hollow block unit is used, mortar should be able to withstand the rapid loss of mixing water to the atmosphere on a dry day (this prevents loss of plasticity). Because water loss stiffens the mortar, weather-tight joints are impossible to achieve. A water-retentive mortar long enough to remain soft and plastic to allow concrete hollow block, units must be precisely aligned, leveled, plumbed, and adjusted to the proper line without breaking the mortar's intimate contact or bond with the unit (Bindiganavile *et al.,* 2016). Split blocks, for example, are low absorption units, and may float when they meet a mortar with a high water retentivity. As a result, a mortar's water retentivity should be within acceptable limits. Water improves mortar workability; entrained air, extremely fine aggregate, or cementitious materials improve not only the mortar's workability or plasticity but also its water retentivity.

5.4 Workability

Due to similarities between mortar and concrete materials, the most misunderstood aspect of concrete hollow block mortar is its water content. Many designers make mistake of assuming that mortar specifications are the same as concrete specifications, especially in terms of the water/cement ratio (Bindiganavile *et al.,* 2016). Numerous specifications specify that the mortar should be mixed with as little water as possible while remaining workable, and they prohibit retempering the mortar while it is being constructed. The compressive strengths of mortar mixed and placed according to these specifications are more excellent, however, the bond strengths are weaker. The maximum bond strength within the mortar's capacity will be provided by mixing the mortar with the most amount of water consistent with workability (Hendry, 2001).

5.5 Failure Criteria

The strengths and strains to be uniform at the materials' contact, the connection between the blocks and the mortar is crucial. Complex stress conditions act on the components because of adhesion and strain equality. A triaxial compressive condition known as confinement is applied to mortar when it is more deformable than the block. Its mechanical characteristics, compressive strength, and elastic modulus make mortar a useful confining material that prevents free expansion. Mortar behaves differently when compressed than when it is simply compressed, for example, is modified therefore, the confining modifies the masonry system performance (Khalaf *et al.,* 2015, G. Mohamad *et al.,* 2015, Hayen *et al.,* 2004). Tensile stress in the block or mortar joint crushing, which happens when mortar hits its confining strength limit, can cause masonry to fail. Therefore, the proportions of the mortar mix and the block be comparable to prevent failure due to tensile stress in the block. The mortar has a significant impact on the behaviour of the masonry when the joint crushing failure occurs, without lowering the failure load (Nalon *et al.,* 2022). In prisms built with low-strength mortar, the mortar-block connection had been severed. According to Parsekian *et al.,* (2019) and Fonseca *et al.,* (2019), because of tension in the block shells, the grouted prisms failed while the grout cores remained intact, and the components acted in a non-homogeneous but uniform manner. High-strength concrete hollow block grouted prisms were compressed, and the hollow prism failed because of vertical cracks and block crushing close to the mortar joint, whereas vertical cracks and debonding of concrete hollow block and grout caused the grouted prism to fail (Thaickavil & Thomas, 2018). Masonry prisms made of cement-stabilized pressed earth bricks and burnt clay bricks were investigated for their behaviour and strength. Because of the outward bursting force caused by Poisson's effect on the composite specimen, they discovered vertical cracks in the middle of the specimens in their experiment. They also discovered that masonry unit strength and the strength of masonry prisms were significantly influenced by mortar strength. In addition, the masonry unit's volume fraction, the bed joint's volume ratio to mortar, and the specimen's height-to-thickness ratio were all calculated, all influenced the masonry prisms' strength. This occurrence has been confirmed by G. Mohamad *et al.,* (2007), in the investigation of the tested prism with various block strengths and four types of mortar. Masonry's nonlinear behaviour is primarily due to the mortar, and different types of mortar cause masonry prisms to fail in different ways.

6.0 CONCLUSIONS

Cement concrete hollow blocks are becoming more popular than traditional building materials like bricks and stones because the air space in the block accounts for 25% of the total area. Hollow blocks enable thinner walls, resulting in more floor space; this saves material and lowers construction costs. Additionally, it speeds up the building, conserves steel and cement, and lowers labor expenses on the project site. These blocks help masonry structures lose weight naturally while also improving physical properties, noise reduction, and thermal insulation. They also have areas where electrical conduits, water pipes, and soil pipes can be hidden. Masonry hollow blocks can be used to build load-bearing and non-load-bearing walls, depending on the material's compressive strength. If cost reductions over alternative materials can be accomplished, masonry hollow blocks seem to have a bright future in the construction sector. The appropriate experimental procedures have been done to achieve the objectives of this study. The characteristics of hollow concrete blocks and mortar are known based on the results. The conclusions are listed below:

- The compressive strength for a masonry hollow block is 8.39 MPa at 28 days which does not pass the specifications for it to be a load-bearing unit. The standards state that the compressive strength must exceed 7 MPa for it to be qualified as a load-bearing unit. The compressive strength of mortar is approximately 21.34 MPa at 28day is also in accordance with the specification.
- The masonry hollow concrete blocks are considered dense due to their dry density values that exceed 1500 kg/m^3.
- The water absorption rate of masonry blocks is lower than that of ordinary concrete blocks as the former has low permeability.

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