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Mechanical and physical properties of Foamed Concrete Blocks

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الملخص العربى :

اكتسبت بلوكات الخرسانة الرغوية شعبية في سوق البناء بشكل كبير في العقد الماضي. لذلك، يجب دراسة التوصيف التفصيلي لخصائصه الهندسية الرئيسية لتطوير النموذج الرياضي والتحليل والتقييم وتصميم الهياكل المصنوعة من بلوكات الخرسانة الرغوية. توضح هذه الورقة بعض الخصائص الفيزيائية والميكانيكية الهامة لبلوكات الخرسانة الرغوية التي تم الحصول عليها تجريبيا. يتضمن ذلك خصائص امتصاص الماء، نسبة الرطوبة والكثافة وخصائص ميكانيكية مثل مقاومة الضغط ، ومعاير المرونة، ومقاومة الانحناء. ستشكل النتائج المقدمة في هذه الورقة الأسس لتقييم وتصميم هياكل البناء لبلوكات الخرسانة الرغوية.

Abstract:

Over the past ten years, Foamed Concrete (FC) blocks have experienced significant growth in popularity within the masonry market. Consequently, it is crucial to thoroughly examine and understand the key engineering properties of FC blocks in order to develop mathematical models, conduct analyses, evaluate, and design structures utilizing these blocks. This research paper highlights essential physical and strength properties of FC units that have been experimentally determined. These properties encompass water absorption and transmission, as well as strength-related aspects such as compressive strength, Young's modulus, and failure modes. The findings presented in this paper serve as a foundation for the assessment and design of masonry structures utilizing FC blocks.

Keywords: Foamed concrete blocks; mechanical properties; physical properties; light weight concrete blocks

1. Introduction

Throughout history, masonry has served as a widely adopted and cost-effective solution for building construction, involving the simple process of layering bricks and mortar. However, in modern times, masonry construction has become more intricate due to the need to comply with contemporary structural safety and sustainability codes [1]. Consequently, there is a pressing requirement to develop sustainable construction practices that address the cost and environmental challenges associated with conventional masonry structures. Therefore, it is crucial to identify and utilize alternative materials that can partially replace traditional materials in masonry construction. The field of building materials science is experiencing significant growth, with the discovery of various mixed materials aimed at enhancing strength. Recently, the development of materials science for building construction has focused on lightweight foam concrete, which offers a promising alternative. Lightweight concrete proves advantageous as a building material, particularly in the production of lightweight blocks. These blocks serve as a viable substitute for conventional blocks due to their reduced weight, larger size, excellent sound insulation, and superior thermal insulation. These characteristics not only enhance building performance but also increase the productivity of masons.

In structural design, the weight of concrete itself is a significant consideration since high-density concrete can significantly impact structural loading. To address this issue, efforts have been made to develop lightweight concrete with a lower specific gravity, typically ranging from 400 to 1800 kg/m^3 [2]. The demand for lightweight blocks is increasing rapidly in today's world. The primary advantage of these blocks is their ability to reduce the dead load of buildings, which in turn allows for smaller structural elements, particularly foundations. This reduction in size contributes to the creation of economical and aesthetically pleasing structures. Various methods can be employed to produce lightweight blocks, with one common approach involving the introduction of air to create a lightweight material. When air is introduced into a structure, it displaces coarse aggregates, resulting in the formation of lightweight material upon drying. This type of concrete is known as cellular lightweight concrete [3]. Lightweight concrete blocks, which are approximately 40% lighter than conventional clay bricks or solid concrete blocks, have become a preferred choice in modern framed building construction for infill masonry. This weight reduction translates into a decreased need for reinforcement in reinforced concrete frame elements. Additionally, the lightweight nature and low elastic modulus of lightweight concrete block masonry infills contribute to their high safety under out-of-plane dynamic loads [4]. There are various types of lightweight concrete blocks, and one of them is Foamed Concrete Blocks (FC), which fall under the category of lightweight concrete blocks.

The ancient Romans were the first to discover that adding animal blood to a mixture of small gravel and coarse sand with hot lime and water would create small air bubbles, making the mixture more workable and durable. In the past two decades, significant improvements in production equipment and better superplasticizers and foam agents have enabled the use of foamed concrete on a larger scale. Consequently, many studies have been conducted to comprehensively understand the characteristics and behavior of foamed concrete, making it easier to use in structural applications [5].

To produce foam concrete blocks, binding agents, aggregates, foaming agents, and water are used as raw materials. The dry materials and water are mixed thoroughly with high-speed impellers. The resulting slurry is then deposited into a buffer tank that is continuously agitated to prevent segregation. Specialized foam production equipment is used to generate pre-formed foam. A separate tank is used to mix the foaming agent and water, and compressed air is supplied based on the required amount of foam. The pre-formed foam is then injected into the slurry to create foam concrete. With minimal personnel, foam concrete can be easily placed [6].

According to Avadhoot Bhosale et al [4], density is a crucial parameter that significantly influences various physical properties of CLC Blocks. In the current examination, the bulk density of CLC cube specimens falls within the range of 750 to 820 kg/m³, which aligns with the specifications outlined in IS 2185 Part 4. Two significant parameters, WA (water absorption) and IRA (initial rate of absorption), play a vital role in determining the bond quality and strength of masonry work. The estimated mean WA of CLC cube specimens ranges from 18 to 28% of the specimen weight. Additionally, the mean IRA values for the 50 mm, 75 mm, and 100 mm CLC block samples are estimated to be 1.02, 2.51, and 1.435 kg/m²/min, respectively.

Nambiar et al [7] reported that foam concrete exhibits lower water absorption and sorptivity compared to the corresponding base mixes. These properties decrease as the foam content increases. The reduction in water absorption and sorptivity with increased foam volume can be attributed to the reduced paste content. Furthermore, the presence of air voids creates a more tortuous path for water migration, which also contributes to the dampening of the transport phenomenon in terms of sorptivity.

In cement-sand-fly ash mixes with a given foam content, higher water absorption and sorptivity are observed compared to cement-sand mixes. This is primarily due to the higher water-solids requirement for achieving a stable and workable mix in cement-sand-fly ash mixes. Additionally, for a given density, the increased paste volume resulting from reduced foam content contributes to the increased sorption of fly ash mixes, further augmenting these effects.

According to Amritha Raj et al [8], density is a significant factor that greatly influences the compressive strength of foam concrete. The compressive strength of foamed concrete was found to be dependent on factors such as age, porosity, and dry density. The density of foamed concrete blocks was observed to be lower than that of burnt clay bricks and conventional concrete, resulting in lighter structures. One of the remarkable properties of foam concrete is its excellent thermal insulation, which is attributed to its cellular microstructure. The thermal conductivity of foam concrete is influenced by parameters such as density, pore size, aggregate type, presence of fibers, and mineral admixtures. Thermal resistance is inversely proportional to the density of foam concrete. Interestingly, foam concrete achieved the same insulation properties as normal concrete while weighing only 20% and utilizing only 10% of the raw materials. The inclusion of 20% entrained air in the concrete increased the thermal resistance by 25% and reduced the dry density by 100 kg/m³, resulting in a reduction of thermal conductivity by 0.04 W/(m·K).

2. Experimental program

2.1. Preparation of specimens

In this article, commercially accessible lightweight FC blocks measuring 650 x 200 x 200mm were obtained from the local market, as depicted in Figure 7. The bulk density of the FC block was estimated to fall within the range of 709-730 kg/m^3, with an average density of 720 kg/m^3 and a coefficient of variation (COV) of 1.1% based on the testing of six samples. Test specimens of varying dimensions were cut from the FC block using an FC hacksaw.

Figure 7: Foamed Concrete Blocks

2.2 Test matrix for physical properties

The evaluation of various physical properties of the FC blocks included assessments of bulk density, moisture content, WA (Water Absorption), and IRA (Initial Rate of Absorption).

To determine the bulk density and moisture content of the FC units, tests were performed according to ASTM C1693 standards. The specimens were subjected to oven-drying for a minimum of 24 hours, with the duration limited to the point where consecutive weight readings showed no variations. The dry density of each cube was calculated by dividing its dry weight by its volume. The moisture content was determined by comparing the sampled mass to the dry mass, indicating the amount of moisture present in the FC specimen.


Figure 8: Initial Rate of Absorption Test Setup

Water absorption and transmission through porous media are crucial factors that impact the functionality, durability, and strength of masonry structures. In this study, the WA and IRA of the FC units were evaluated. WA represents the quantity of water absorbed by an oven-dried brick unit when immersed in a water bath for 24 hours. This test adhered to the ASTM standard C140-C140M. The IRA, on the other hand, measures the amount of water absorbed by a unit brick per minute when submerged to a depth of 3 mm. The IRA value provides insights into the material's absorptive capacity. The IRA test was conducted following ASTM C67-C17M standards. Figure 8 illustrates the setup for the IRA test.

The bulk density and moisture content of the FC units were evaluated in accordance with ASTM C1693. Table 4 presents the standards used for assessing the physical properties and the number of specimens tested for each parameter.

2.3 Test matrix for mechanical properties

The mechanical properties of FC blocks were assessed, with a focus on the most crucial engineering properties, including compressive strength, splitting tensile strength, and modulus of elasticity.

Compressive strength was determined following the ASTM standard C1693, specifically in the direction perpendicular to the direction of rise. Splitting tensile strength was evaluated in accordance with ASTM C1006, while the modulus of elasticity was assessed using ASTM C1693. Table 4 provides an overview of the standards employed to evaluate these mechanical properties.

Table 4: Test matrix of physical and mechanical properties

General Properties	Specified Properties	No. of specimens	Standards
Physical Properties	Bulk Density	3	ASTM C 1693
	Moisture Content		
	Drying Shrinkage		
	Water Absorption	3	ASTM C 140
	Initial Rate of Absorption	5	ASTM C 67
Mechanical Properties	Compressive Strength	3	ASTM C 1693
	Tensile Strength	5	ASTM C 1006
	Modulus of Elasticity	3	ASTM C 1693

3. Tests Results and Discussion

Various experimental tests were carried out on FC cube units to assess their physical and mechanical properties, including bulk density, moisture content, WA, IRA, compressive strength, splitting tensile strength, and modulus of elasticity. The subsequent section presents the findings obtained from these tests.

3.1Physical properties

The density of AAC has a significant influence on its physical properties. In this study, the bulk density of 40x40x16mm prism specimens ranged from 640 to 720 kg/m^3, with a low coefficient of variation (COV) of 0.04, as shown in Table 5. The bulk density values of FC block units were found to be nearly consistent regardless of specimen size, with a relatively low relative variation (indicated by COVs within 0.10). Moisture content of the FC blocks was also determined according to ASTM C1693 (ASTM 2017a). The mean moisture content in FC prism specimens ranged from 6% to 11% of the specimen weight, with a COV of 0.36, as shown in Table 5.

Water absorption (WA) and initial rate of absorption (IRA) are two important parameters that affect the bond quality and strength of masonry work. High WA in the initial stage can lead to reduced mortar strength due to incomplete cement hydration. It can also result in wall cracks and surface damage. As indicated in Table 5, the estimated mean WA of FC specimens ranged from 28% to 31% of the specimen weight. The mean IRA for 300x200x200mm FC blocks was 0.73 kg/m^2/min. The test setup for determining IRA is shown in. It is worth noting that capillary suction during the initial period has a greater impact on bond strength than total WA.

Therefore, it can be concluded that the porous nature of FC block masonry does not pose a concern for the development of bond strength.

3.2Mechanical properties

This study includes uniaxial compression tests, tensile strength tests, and modulus of elasticity tests on FC units. The results obtained from these laboratory tests are discussed in this section.

Figure 9: Compression Test Setup and failure

For the compressive strength test, three cube specimens were tested in the direction perpendicular to the direction of rise. Five specimens were tested for tensile strength, and three specimens were tested for modulus of elasticity. The average compressive strength, tensile strength, and modulus of elasticity, along with their corresponding coefficients of variation (COV), are presented in Table 5. It is evident from Figure 9 that the loading direction can influence the values of all three properties of the FC unit. The test setup and failure of the splitting tensile strength test are illustrated in Figure 10, conducted according to ASTM specification C 1006. Likewise, Figure 11 depicts the test setup and failure of the modulus of elasticity test, conducted according to ASTM specification C 1693.

Figure 10: Splitting Tensile Strength Test Setup and Failure

The compressive strength of FC units ranged from 2.5 to 4.7 MPa, with a COV of 0.25, as shown in Table 5. The splitting tensile strength varied from 0.17 to 0.27 MPa, with a COV of 0.18. The modulus of elasticity ranged from 2100 to 2400 MPa, with a COV of 0.07, as shown in Table 5.

Figure 11: Modulus of Elasticity Test Setup and Failure

Table 5: Test results for physical and mechanical properties

Property	Foamed Concrete Units
Bulk Density (kg/m^3)	719 (0.01)
Moisture Content (%)	8.65 (0.18)
Water Absorption (%)	30.1 (0.04)
IRA (kg/m^2/min)	0.73 (0.30)
Compressive Strength (MPa)	3.2 (0.25)
Tensile Strength (MPa)	0.24 (0.18)
Modulus of Elasticity (MPa)	2320 (0.07)

Note: Values in parentheses are COV

4. Summery and Conclusions

FC blocks have gained popularity in the construction industry due to several advantages, including their lightweight nature, sound and fire safety, low production cost, and utilization of waste fly ash. However, the lack of key engineering properties for FC block masonry poses a challenge for engineers in developing mathematical models and analyzing framed buildings with FC block infills. To address this issue, a comprehensive experimental investigation was conducted to determine the essential physical and strength properties of FC units. The following are the important observations and conclusions drawn from this study:

- The bulk density of FC block specimens was found to be approximately 50% lower than that of conventional clay bricks, primarily due to the porous nature of FC blocks. This lower bulk density results in reduced dead load for infill masonry, leading to more economical design of frame elements.

- FC blocks generally exhibit higher water absorption capacity compared to clay bricks. Therefore, caution should be exercised when using FC block masonry in exterior walls or walls exposed to moist environments. However, the capillary suction properties of FC blocks were found to be significantly better than those of clay bricks, as indicated by lower IRA values. Lower IRA values ensure improved bond strength in FC block masonry.

- The compressive strength of FC units was found to be approximately 80% lower than that of traditional clay brick units. Consequently, FC units are not suitable for load-bearing walls.

In summary, the study provides valuable insights into the physical and strength properties of FC units, highlighting their advantages and limitations for different applications in masonry construction.

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