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STUDY ON THE MECHANICAL PROPERTIES OF AUTOCLAVED AERATED CONCRETE

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Abstract: *The demand for green buildings requires the use of construction materials with high thermal performance, a low carbon footprint, and adequate structural strength. Autoclaved aerated concrete (AAC) stands out as an effective solution, offering favorable mechanical and thermal properties. In this study, the mechanical properties of five autoclaved aerated concrete specimens were analyzed. The tests carried out revealed compressive strength values around 3 MPa. The results confirm the strength characteristics through comparison with data from literature.*

Keywords: *construction materials, autoclaved aerated concrete, mechanical properties*

1. INTRODUCTION

Known by various names, from aerated concrete to autoclaved lightweight concrete - this material has been a staple of the industrial landscape since the early 20th century. Its evolution was not a single event, but the result of a series of ingenious patents that shaped the technology we use today.

It all began in 1880, when German researcher Michaelis laid the groundwork for the steam-curing process. This discovery was soon followed by experiments in 1889 on aerating concrete with carbon dioxide and by the innovation of 1914, when the use of aluminum powder in combination with calcium hydroxide made it possible to produce a porous cement, revolutionary for that era.

The turning point, however, came in 1920, thanks to the Swede Axel Eriksson. He succeeded in patenting the "lime formula," an aerated mix based on lime and ground slate, thus taking the decisive step toward the modern form of AAC [1].

Global expansion truly began after 1937, when the transfer of know-how and technology licensing allowed the material to cross borders. The postwar period was marked by the rise of industrial giants that dominated the market: the Swedish companies Siporex and Ytong, the Dutch firm Durox, and the German company Hebel.

Autoclaved aerated concrete is a construction material made from a mixture of cement, sand, water, gypsum, and lime. Its specific properties—which are, in fact, superior to those of other types of lightweight concrete, such as low weight and superior insulation properties—are achieved by adding aluminum powder to the mixture. The result is a porous structure with the characteristics mentioned above [2].

Autoclaved aerated concrete (AAC) is emerging as a leading construction solution, recognized for its durability and low environmental footprint. A major advantage of this material is its responsible use of resources, as it incorporates recycled industrial waste, such as fly ash, into the production process. Its effectiveness is demonstrated by its massive success in international markets with rigorous standards: In Germany, AAC is used in over 60% of construction projects, and in England, it holds a market share of approximately 40%. Its global popularity is due to an unbeatable combination of benefits: speed of construction, superior thermal insulation, and cost-effectiveness. Thus, by utilizing affordable raw materials and delivering long-lasting technical performance, AAC remains the ideal choice for green and efficient real estate developments. [3]

2. ADVANTAGES OF USING AUTOCLAVED AERATED CONCRETE

This building material offers a number of advantages: thermal performance due to the aerated structure of the autoclaved aerated concrete (AAC), which provides superior thermal insulation compared to traditional masonry materials. The air bubbles reduce heat transfer, and the thickness of the elements contributes to increased thermal resistance, resulting in more stable indoor temperatures and lower energy costs. Additionally, the material's airtightness limits energy loss. Sustainability:

AAC contributes to reducing the environmental footprint due to its energy efficiency, durability, and eco-friendly manufacturing process. The use of natural materials, recyclability, and low weight lead to reduced transportation costs, waste, and energy consumption throughout the product's lifecycle. In addition, AAC products contain no volatile organic compounds and do not affect indoor air quality. Fire resistance: autoclaved aerated concrete is an inorganic, non-flammable material with no risk of explosion, making it suitable for applications with high fire protection requirements. Depending on thickness and application, AAC elements can achieve a fire resistance rating of up to four hours. AAC is resistant to moisture and severe weather conditions. By applying mineral coatings, moisture resistance can be further improved. AAC blocks and panels are available in various sizes and can be used for walls, floors, cladding, and fencing systems. Thanks to the properties mentioned above, AAC is ideal for residential, commercial, educational, and industrial buildings, including for partition walls and interior partitions [4].

3. MANUFACTURING

The manufacture of autoclaved aerated concrete in various forms is a well-established technological process. The methods used to carry out these manufacturing procedures are similar, though each manufacturer claims to have patented innovative solutions for this type of material. The production process can be simplified into four key stages: preparation of raw materials, molding and cutting of the concrete block, autoclaving, and storage and delivery [5].

The main raw materials used are sand, Portland cement, and lime. The process begins with the grinding of silica-rich materials (sand, fly ash, etc.) in ball mills. The grinding process can be carried out dry, to obtain powders, or wet, when a slurry is produced [6]. The addition of aluminum powder leads to the formation of a cellular structure; this process occurs in an alkaline environment created by the mixture of Portland cement and lime. Under these conditions, hydrogen is released as a gas from the mixture. Gypsum is added to the AAC composition to control setting time, improve mechanical properties, and control the gasification process [7]. During heat treatment (autoclaving), the addition of gypsum aids in the formation of toberomite, a mineral that contributes to high mechanical strength [8].

In the second stage, the prepared raw material mixture is poured into the mold. From this point on, two processes occur simultaneously within the mixture: expansion, resulting from reactions between the aluminum and the calcium oxide-based components, and the hardening process, resulting from the initial setting of the Portland cement. The time required for these two processes to occur varies between 0.5 and 4 hours. After hardening, the expanded mass is cut according to the intended applications of the final products. This entire process takes place under controlled temperature.

During the autoclaving stage, the raw products are transferred to pressurized chambers (autoclaves) at pressures between 10 and 12 atm and temperatures of 180–190 °C. Under these conditions, in the presence of steam, physicochemical changes occur in the AAC structures, leading to the final characteristics [6]. The autoclaving process imparts strength through the formation of complex silicates, resulting from the binding reactions of SiO_2 from sand or fly ash with $Ca(OH)_2$ produced by the hydration of Portland cement, as well as dimensional stability and other properties of the final hardened product. Typically, the duration of the autoclaving treatment can vary between 8 and 16 hours [8].

The final stage involves preparing the products for storage or delivery. Thus, after cooling, the blocks are palletized. A quality control check is performed to identify any defects, followed by storage or delivery to the customers.

4. TESTING PROCEDURE

The equipment used to perform mechanical tests includes a technical balance, a drying oven, and a compression testing machine.

The mechanical properties of autoclaved aerated concrete specimens depend on the amount of water present in the specimens being analyzed. Thus, specimens taken after the autoclaving process are dried in an oven until constant weight is reached, in order to estimate the moisture content, according to the following equation.

$$Water\ content = \frac{W_{SW} - W_{SD}}{W_{SD}} \cdot 100\ [\%]$$

where: W_{SW} –weight of the sample in the wet state
W_{SD} – weight of the sample in the dry state

Compressive strength is one of the most important mechanical properties that can be determined for cement-based specimens. For autoclaved aerated concrete, mechanical strength tests are performed on a MATEST E161-01 compression and bending testing machine for various ceramic materials: cement-based products, mortars, refractory products, bricks, etc.

The device has dual functionality, in that bending tests can be performed in the range of 0–15 kN, on rectangular specimens measuring 40x40x160 mm, or compression strength tests on cubic specimens with sides between 40 and 100 mm or cylindrical specimens with a height less than 180 mm, in the range of 0–250 kN.

5. RESULTS

5.1 Wather content

The samples are dried in an oven until a constant mass is achieved. Sampling is performed in accordance with the experimental procedure described above.

The results obtained for the samples analyzed are presented in Table 1.

Table 1. Water content (average values) for 5 samples analysed

AAC Sample	S1	S2	S3	S4	S5
Water content %	22.6	24.6	23.8	24.7	23.3

5.2 Mechanical Properties

Compressive strength (σ) is the ratio of the maximum force recorded (F) during the test to the cross-sectional area of the specimen (A), according to the following equation:

$$\sigma = \frac{F}{A} \ [MPa]$$

Table 2 presents the data for the first sample analyzed.

Table 2. Physical and mechanical properties of AAC sample tested

Characteristics / Sample	1	2	3	Average
Cross-sectional area A_c [mm^2]	10030.02	10010	9999.96	10020
Maximum force [KN]	29.80	32.50	31.70	31.30
Compressive strength [MPa]	2.97	3.25	3.17	3.12

The compressive strengths for all the specimens analyzed are shown in Figure 2.

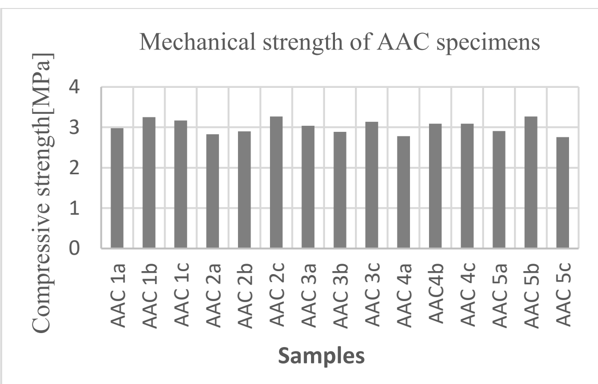

Figure 1. Compressive strength of the tested specimens

For the five test sample sets, an average compressive strength of 3.022 MPa was obtained (v. Table 3, Fig. 2).

Table 3. Compressive strength (average values) for 5 samples analysed

AAC samples	S1	S2	S3	S4	S5
Average Compressive strength [MPa]	3.12	3	3.02	2.99	2.98
Average	3.022				

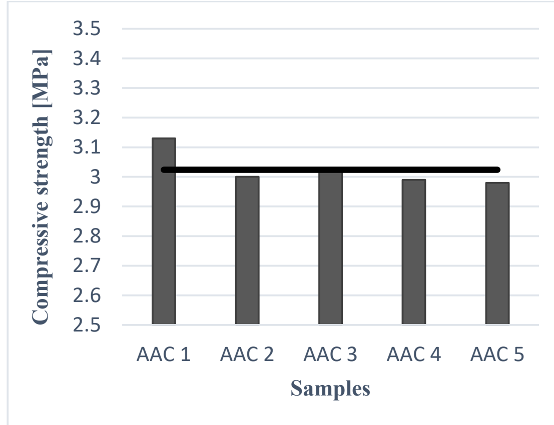

Figure 2. Average compressive strength of the tested specimens

By comparison, this paper presents some data from the literature regarding the compressive strength characteristics of autoclaved aerated concrete. Thus, Zhou et al. [9] present data for AAC specimens in which a portion of the lime content was replaced with steel slag and iron ore tailings, a product with a high silica content. For specimens in which the slag and iron ore tailings content varies between 0 and 24%, the compressive strength of the AAC specimens ranges from 2.9 MPa to 4.1 MPa, with the densities of the tested materials ranging from 530 to 640 kg/m³. Jiang et al. [10] report compressive strength values ranging from 1.5 MPa to 7.5 MPa for densities in the range of 400–800 kg/m³. In another source [11], finite element models were used to evaluate the mechanical properties of autoclaved aerated concrete, revealing a compressive strength of approximately 3.7 MPa for blocks used in masonry.

The compressive strength of autoclaved aerated concrete can vary under high-temperature conditions, reaching values as high as 5.04 MPa, thus highlighting the effect of heat treatment on the mechanical properties of ceramic products [12].

At the same time, there has recently been a strong emphasis on the recycling of construction materials due to the serious environmental issues they can cause. Under these conditions, the data presented [13]—where the concrete waste content reaches 60%—show that AAC products with a density of approx. 470 kg/m³ have a compressive strength of 2.16 MPa, and by adding 1% microsilica, the density of autoclaved aerated concrete products reaches approx. 513 kg/m³ and a compressive strength of 3.05 MPa. Furthermore, with a 7% addition of fly ash, the density of the AAC products was 462.52 kg/m³, yielding a mechanical strength of 2.86 MPa.

Eco-friendly blocks made of autoclaved aerated concrete offer exceptional strength, making them a preferred choice for construction projects. In terms of compressive strength, autoclaved aerated concrete products outperform traditional clay bricks. The compressive strength of autoclaved aerated concrete blocks, which incorporate fly ash, typically ranges between 3 and 4 N/mm², while clay bricks have a lower compressive strength, usually around

2.5 N/mm². This higher compressive strength allows for the use of autoclaved aerated concrete in load-bearing structures, ensuring the structural integrity and safety of the building.

Moreover, autoclaved aerated concrete blocks offer excellent flexural strength, making them highly resistant to cracking and bending. This characteristic is particularly beneficial in earthquake-prone areas, where the ability to withstand lateral forces is crucial. Thus, the flexibility of autoclaved aerated concrete blocks reduces the risk of structural damage during seismic events, providing increased safety for occupants [14].

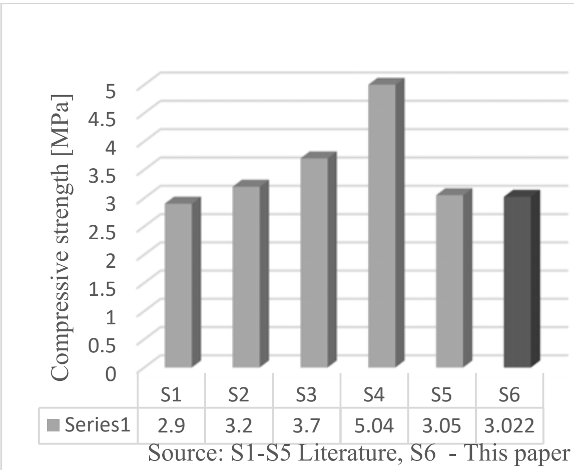

Figure 3. Comparative results of the mechanical strength of AAC blocks

The graph in Figure 3 presents, by comparison, the compressive strength results for specimens made of autoclaved aerated concrete. The first five results are sourced from the technical literature, while the last specimen represents the average compressive strength value for the five AAC commercial samples, analyzed in the laboratory.

6. CONCLUSIONS

This paper presents the results of mechanical tests on autoclaved aerated concrete samples.

The introduction provides a brief history of the material, the advantages of its use, and the technology involved in producing this construction material.

The tests carried out revealed compressive strength values around 3 MPa, a value within the average for this type of product: 2-4 MPa. Moreover, the results obtained were compared with data from the literature.

The water content of the samples analyzed range between 22.6 and 24.7%. No correlation could be made between these results and the mechanical properties of the samples analyzed. These results being dependent on other characteristics and properties of the AAC samples.

These results demonstrate that autoclaved aerated concrete exhibits a wide range of compressive strengths, influenced by factors such as density, material composition, and processing technologies. The use of industrial waste and improvement techniques can significantly contribute to enhancing the performance of this construction material.

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