REVISTA DE
ARQUITETURA IMED

Evaluation of the Physical and Mechanical Properties of Autoclaved and Foamed Concrete Blocks Marketed in Passo Fundo/RS Brazil

Avaliação das Propriedades Físicas e Mecânicas de Blocos de Concreto Autoclavado e Espumígenos Comercializados em Passo Fundo/RS Brasil

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Revista de Arquitetura IMED, Passo Fundo, vol. 8, n. 1, p. 111-128, January-June, 2019 - ISSN 2318-1109
[Received/Recebido: 23 julho 2019; Accepted/Aceito: 15 agosto 2019]
DOI: https://doi.org/10.18256/2318-1109.2019.v8i1.3441

Evaluation: *Double Blind Review*
Editor-in-chief: Marcos L. S. Oliveira

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Abstract

Cellular concrete is a light concrete that differs from others because of the presence of air voids (porosity) within the mortars. This air voids, formed by air bubbles, influences the behavior of such concrete. Cellular concrete blocks have been gaining market due to their characteristics which include thermal and acoustic insulation, and low density. However, properties, such as their low compressive strength limit the application of using this type of material, for example, use on structural walls (walls that may be subjected to imposed deformations or more significant occupancy loads), which require a minimum compressive strength of 3 MPa. Moreover, they should meet the minimum compressive strength required by the standard. Therefore, this paper sets out to evaluate the physical and mechanical properties of two types of cellular blocks commercialized in the region of Passo Fundo/RS, Brazil. Experimental assays were performed to determine the following properties: dry density, wet density, air voids, water absorption, thermal conductivity and compressive strength. The results showed that the autoclaved cellular concrete had better physical and mechanical properties when compared to the foamed cellular concrete, i.e., the autoclaved cellular concrete block had a higher compressive strength, lower thermal conductivity, lower density and its pores were more homogeneously distributed. However, the values found for the compressive strength of both blocks were lower than those determined by the manufacturers of these blocks. Therefore, autoclaved concrete blocks can be used for sealing masonry in buildings as it has achieved minimum compressive strength required for this type of wall. On the other hand, foamed concrete blocks, on average, presented values of compressive strength much lower (0.6 MPa) than values required for sealing masonry walls (1.5 MPa), requiring the manufacturer to review the trace formulation of these blocks.

Keywords: Cellular Concrete. Compressive Strength. Air Void. Water Absorption. Thermal Conductivity.

Resumo

Os blocos de concreto celular cada vez mais vêm ganhando mercado devido as suas características de isolamento térmico, de isolamento acústico, de baixa densidade, entre outras. Uma propriedade relevante é a resistência à compressão, a qual limita algumas aplicações deste tipo de material, por exemplo, a utilização em paredes estruturais (paredes que venham a ser submetidas a deformações impostas ou a cargas de ocupação mais significativas), as quais exigem uma resistência à compressão mínima de 3 MPa. Devido ao aumento da utilização do concreto celular nas construções, este trabalho teve como objetivo a avaliação das propriedades físicas e mecânica de dois tipos de blocos celulares comercializados na região de Passo Fundo/RS, Brasil. Ensaios experimentais foram realizados para determinar as seguintes propriedades: densidade seca, a densidade saturada, os índices de vazios, a absorção de água, a condutividade térmica e a resistência à compressão foram realizados. Os resultados mostraram que o concreto celular autoclavado apresentou melhores propriedades físicas e mecânicas quando comparado com o concreto celular espumígeno, isto é, o bloco de concreto celular autoclavado teve maior resistência à compressão, menor condutividade térmica, menor densidade e poros distribuídos de forma mais homogênea, porém os valores encontrados para a resistência à compressão de ambos os blocos foram inferiores aos determinados pelos fabricantes destes blocos. Portanto, os blocos de concreto autoclavado podem ser utilizados para alvenaria de vedação nas construções, pois atingiu a resistência à compressão mínima necessária para este tipo de parede. Já os blocos de concreto celular espumígenos, em média, apresentaram valores de resistência à compressão muito abaixo (0,6 MPa) dos valores exigidos para paredes de alvenaria de vedação (1,5 MPa), exigindo que o fabricante revise a formulação dos traços desses blocos.

Palavras-chave: Concreto Celular. Resistência à Compressão. Número de Vazios. Absorção de Água. Condutividade Térmica.

1 Introduction

The construction market has been seeking to use materials that are better suited for sealing systems. These materials are characterized as being light and more efficient. This reduces their weight, and thus has a direct impact on the costs of the support structures (pillars, beams and slabs) and foundations. One of the most widely used alternatives is lightweight concrete, which has low density (320 to 1920 kg/m^3), higher noise absorption (acoustic insulation) and better thermal insulation (low thermal conductivity - generally less than 0.40 W/mK), which thus sees to it that it is much used in flooring and for vertical sealing (LAMOND; PIELERT, 2006; KULBHUSHAN *et al.*, 2018).

There are several ways to obtain a lightweight concrete, among which are the following: concretes made by totally or partially replacing conventional aggregates with light aggregates, these being the only ones produced that can reach an acceptable compressive strength for structural purposes (ANGELIN, 2014); cellular concrete with the addition of foamed agent or preformed foam (AL-MEHTHEL *et al.*, 2018); and, according NBR 13438, concrete with air bubbles generated by chemical reaction, which is known as autoclaved cellular concrete (ABNT, 2013a). Each type of material has its unique characteristics and can vary in physical and mechanical aspects in accordance with the shape, size, distribution and communication between the pores generated.

Nowadays, cell concretes, in the form of blocks, are being widely used in the sealing of staircases and antechambers, as they present high resistance against fire (FIUZA; CHAHUD, 2009). In addition, this type of block, when used in walls, offers better thermal and acoustic comfort when compared to that of the conventional masonry block. For example, according to Ramamurthy *et al.* (2009), aerated concrete blocks reduce the use of energy in a residence by 7%.

In Brazil, NBR 13438 (ABNT, 2013a) defines autoclaved aerated concrete blocks (AACB) as lightweight concrete which is prepared by adding aluminum powder and then the mixture undergoes a steam-saturated curing process under controlled pressure (12 atm) at a temperature of between 180°C and 200°C. According to Mathey e Walter J. Jr. Rossiter (1988), this curing process allows the material to have resistance strengths above 1.5 MPa and densities of around 500 kg/m^3, and this also results in well-distributed spherical pores with low capillarity.

Foamed cellular concrete blocks (FCCB) can be manufactured by incorporating air bubbles into them which is accomplished by adding preformed foam. This foam can be generated by a specific apparatus and introduced into the concrete mixture or by generating the foam by the mechanical action of the mixer in which the foamed agent that has been diluted in water is mixed with the other materials (CORTELASSI, 2005). The foam is obtained by using foaming agents which are the products of chemical composition that can produce stable air bubbles within the cement paste and mortar.

This is achieved by vigorous stirring or pneumatic pressure on the foam agent, which may be a surfactant or a protein. The air volume depends on the mixing regime and the time taken to do this, the concentration of the reagent, the temperature of the process, the volume of water added and the characteristics of the materials (PEDRO *et al.*, 2017).

NBR 12646 (ABNT, 1992) determines that the foam agent is the product of a chemical composition that can produce stable air bubbles inside cement pastes or mortars. These bubbles must remain intact throughout the entire production process.

According to Melo (2009) the incorporation of the air bubbles by using pre-formed foam allows control of the quality and quantity of foam which is generated and added to the mortar, which reflects considerably in the final product. The amount of air added to the mortar influences the lightness, the thermal and acoustic performance and the mechanical resistance of the material.

The materials and the amount of the constituents in FCCB directly affect the characteristics of the cellular concrete, such as: compressive strength, densities, air void and water absorption and thermal conductivity (AMRAN *et al.*, 2015).

The compressive strength is considered the main parameter of control of the quality and dosage of the concretes. According to Freitas (2004) the compressive strength of foamed cellular concrete varies for several reasons including factors such as: the amount of cement consumption, water/cement factor, age, type of cure, production process, foam agent, and amount and granulometry of the aggregates. Also, another determinant of foamed cellular concrete is its specific mass, which is directly related to its compressive strength and is strongly influenced by the amount of water added to the mixture and the relative humidity of the air. For Cortelassi e Toralles-Carbonari (2008), the specific mass of the foamed cellular concrete is influenced by the mixing time of the materials, since how long this is influences how pores are distributed and their uniformity.

On analyzing the market in cellular concrete blocks, the first use of AACB was in Sweden in 1924, due to its main characteristic: good thermal insulation. AACB began to be produced in Brazil in 1957, at PUMEX, now SIPOREX - Concreto Celular Autoclavado Ltda., the head office of which is in Ribeirão Pires - São Paulo. In addition to SIPOREX, AACB are manufactured by PRECON Industrial SA, its head office being in Belo Horizonte - Minas Gerais, and CELUCON Concreto Celular which is based in Santa Catarina. It should be noted that AACBs are regulated and consequently have better quality control (PAGANI, 2012).

There are few regulations of the Brazilian Association of Technical Standards that deal with determining the properties and dimensions of FCCB. The only one is norm NBR 12646 (ABNT, 1992) that deals with erecting walls with foamed concrete molded on site. However, FCCBs are developed in small companies in which there is often little quality control and inspection. In Passo Fundo-RS, there is at least one company that manufactures FCCB, but this company does not present technical reports about the product. This calls into question its quality.

Finally, the main objective of this paper is to make a comparison between the physical and mechanical properties of two types of light concrete blocks (AACB and FCCB) marketed in the region of Passo Fundo, RS, Brazil. The properties analyzed were compressive strength, thermal conductivity, (dry and wet) densities, water absorption and the air void (porosity).

2 Materials and Methods

2.1 Materials

Three blocks of each type (AACB and FCCB) were used to perform the experiments, from which the assay specimens were obtained. Details of the blocks used and their respective dimensions are shown in Figure 1. For the sake of confidentiality, this study withholds the real names of the manufacturers of the blocks. Therefore, it deems the manufacturer of AACB as manufacturer A and FCCB as manufacturer B.

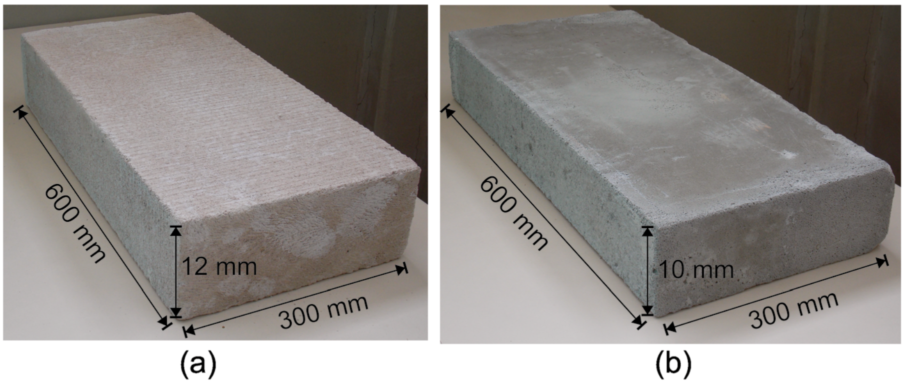

Figure 1. Blocks of cellular concrete (a) autoclaved and (b) foamed.

2.2 Characterization of the blocks

Experimental assays to determine the compressive strength, the thermal conductivity, the density (wet and dry), water absorption and the number of voids were used to characterize the blocks.

X-ray diffraction analysis (XRD) allows the evaluation of the crystalline structure of the materials and the identification of the minerals present. XRD measurements of block samples were performed with irradiations ranging from 5 to 25° (2θ), with an interval of 0.05° (2θ) for each one second. For XRD analysis the PanAnalytical equipment model X'pert PRO Multi-Purpose, with Cu Kα radiation = 1.5418Å at 40 kV and 30 mA.

The compressive strength test was performed as per NBR 5739 (ABNT, 2018). The cellular concrete blocks were prepared for the compressive strength test, as determined by NBR 7680-1 (ABNT, 2015). The test was performed using a hydraulic press, model PC200C (Instron, Norwood, MA, USA).

The tests of densities (dry and saturated), air void, and water absorption were performed following the standards ASTM C 948-81 (ASTM, 2009) and NBR 9778 (ABNT, 1987).

Figure 2 shows the experimental apparatus used to determine thermal conductivity, which was done by using a hot thermal wire on the surface. This technique has already been corroborated as a variant of the parallel hot wire by several authors (GRAZZINI; BALOCCO, 1995; AKIYOSHI *et al.*, 2001; SANTOS, 2002; 2005; FRANCO, 2007; SACHT *et al.*, 2010; LERMEN *et al.*, 2019) and is characterized as being a direct method that detects the transient temperature. The experimental system consists of two multimeters to determine the electric current and voltage; two samples in the form of a parallelepiped; a hot wire (0.5 mm diameter kanthal) connected to a power source; four temperature sensors (NTC); and a data acquisition system. The temperature sensors were calibrated for a range of 0°C to 100°C.

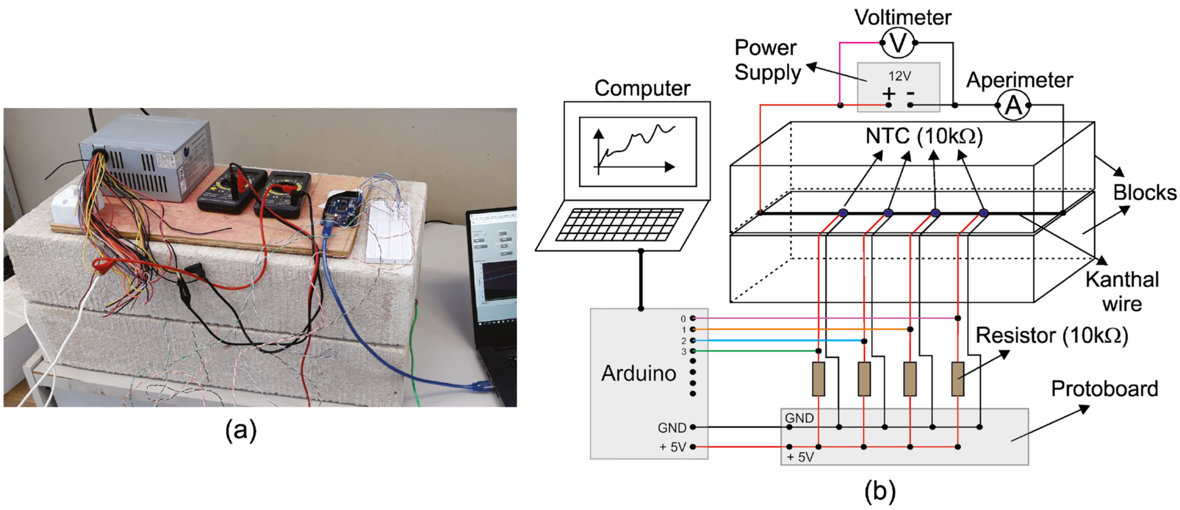

Figure 2. (a) image of the experimental apparatus used to determine the thermal conductivity and (b) the schematic design of the apparatus.

3 Results and Discussion

3.1 Compressive Strength

The results of the axial compression assays are shown in Figure 3. Note that, on average, the AACB showed a higher compressive strength than the FCCB did.

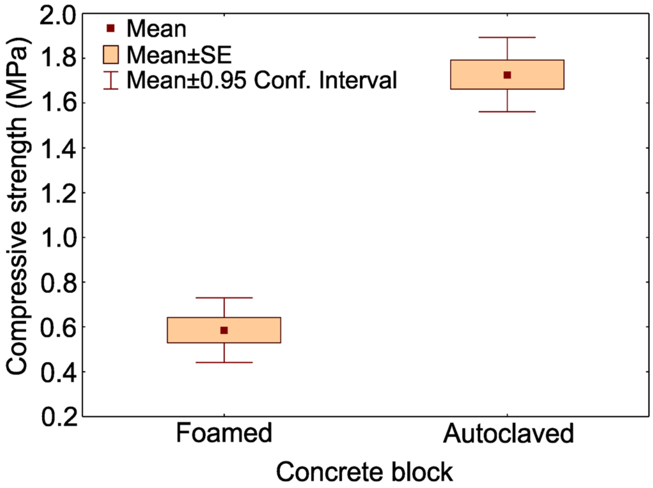

Figure 3. Compressive strength in relation to concrete block types.

The AACB showed an average resistance of 1.70 MPa, thus meeting the value required by NBR 13438 (ABNT, 2013a) which is at least 1.5 MPa. For the FCCB, there is no current Brazilian standard, the closest one can get is to use the one proposed by the American Standard ASTM - C 495 (ASTM, 1999), but for comparative criteria it was framed in the same NBR as the AACB. Therefore, its compressive strength is around 0.60 MPa which is below the minimum required by the standard.

The characteristics found can be related to the formation properties of the pores, While the AACB has the formation of a larger number of voids with smaller diameters, the FCCB has a smaller number of pores, but these are of a larger diameter, which can be seen by comparing the densities of the samples. Another characteristic to be emphasized is the capillarity of the pores since the AACB has more spherical and separated pores and the FCCB presents amorphous aspects connected by capillaries, directly affecting its strength, since its structure is directly connected with the distribution of forces within the matrix (CORTELASSI; TORALLES-CARBONARI, 2008; FAVARETTO *et al.*, 2017; PEDRO *et al.*, 2017). This difference between the capillaries of the autoclaved concrete block and the foamed concrete block is shown in Figure 4.

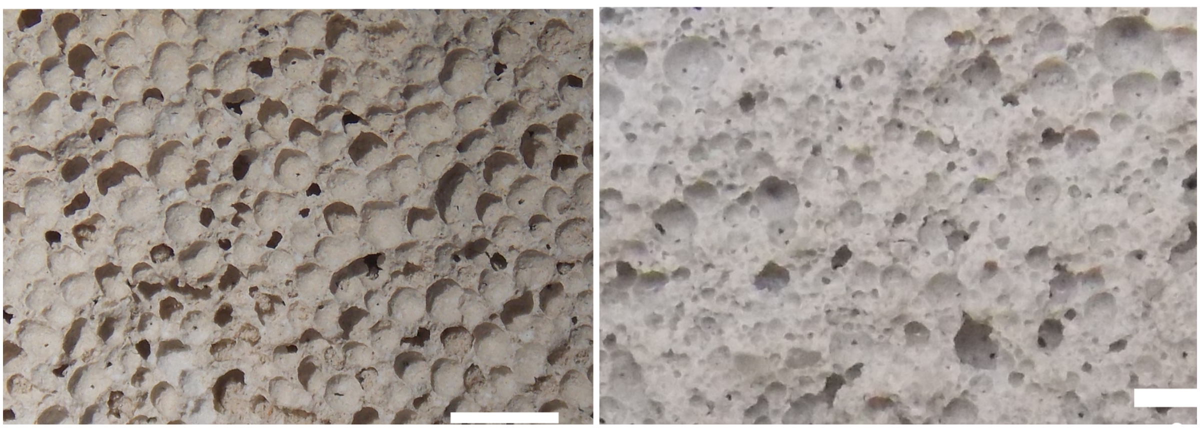

Figure 4. Macrograph of concrete blocks (a) autoclaved and (b) foamed.

According to Narayanan and Ramamurthy (2000), the presence and shape of the voids has a very great influence on the orientation of the hydration products They also point out that in the autoclaving part of the fine silicate material, the silicate reacts chemically with the lime and forms a hydrated calcium silicate. This compound is very similar to tobermorite, a mineral which is responsible for a gain in compressive strength.

The curing process also greatly influences the compressive strength. When the curing is done by autoclaving silica and calcium, these form a more organized structure (tobermorite), which is therefore more resistant than the blocks produced by the natural curing process as is the case of FCCB (JACÓE; RODRIGUES, 2014). The presence of tobermorite can be observed by means of the X-ray diffraction performed for the autoclaved concrete block (Figure 5).

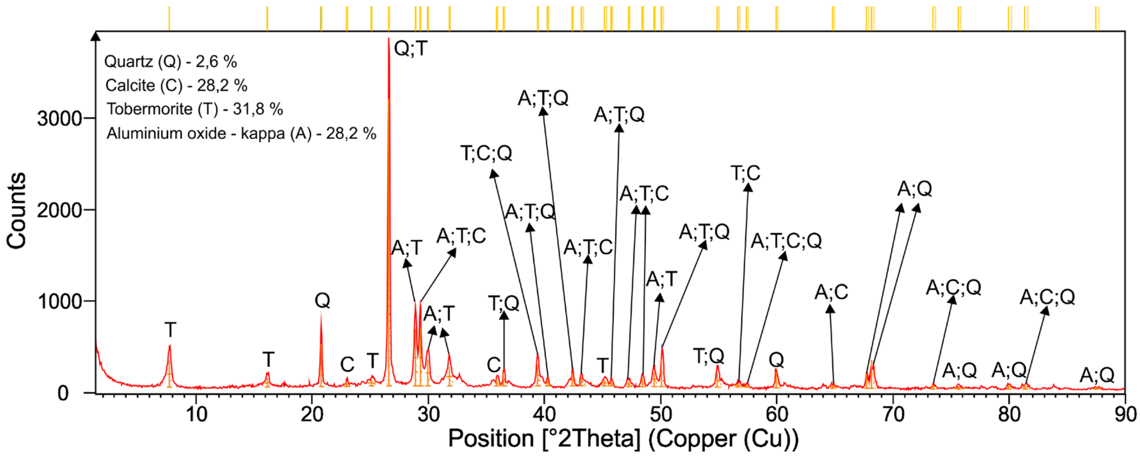

Figure 5. X-ray diffraction for the autoclaved concrete block.

The production of a cell block using a natural curing (non-autoclaved) technique according to Cooke (2012) yields minerals of low crystallinity, an amorphous C-S-H, which exhibits a much lower compressive strength than that produced by autoclaving. Moreover, Cooke (2012) points out that it can the natural curing process of a block can take a few months for the block to reach considerable compressive strength. Figure 6 shows the x-ray diffraction for the foamed concrete and the main crystalline phases, calcite, quartz, portlandite and vaterite. Vaterite and calcite are two forms of calcium carbonate ($CaCO_3$), which are formed mainly by carbonation (LIU *et al.*, 2011).

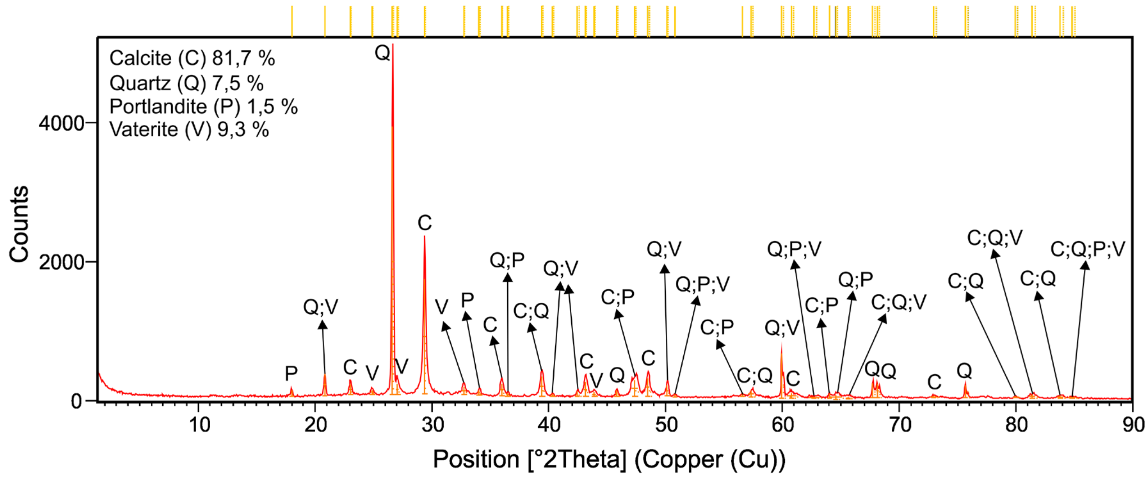

Figure 6. X-ray diffraction for the block of foamed concrete.

3.2 Dry and Wet Density

Density is one of the main characteristics of cellular concrete blocks, as it influences other properties, especially the compressive strength that tends to decrease when the density decreases and the thermal conductivity that increases when the temperature increases (MOTA, 2001).

The mean dry density of the specimens is shown in Figure 7 along with the statistical configurations assigned to the sample. On analyzing these, it can be identified that density of the FCCB sample is greater than that of the AACB, the difference being of approximately 100 kg/m³.

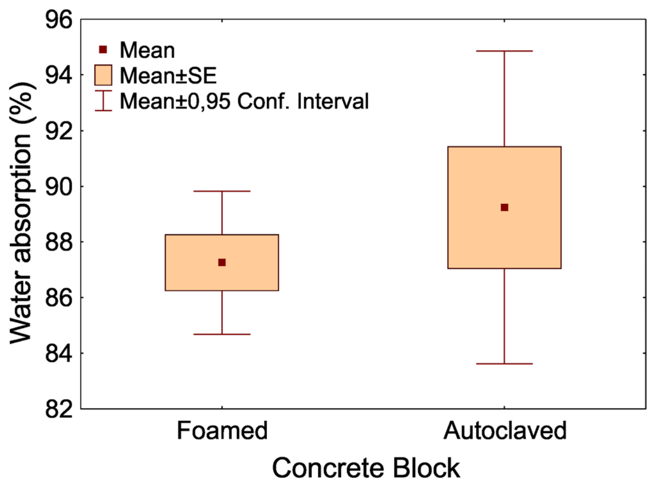

Figure 7. Dry bulk density for different concrete blocks.

From the graph shown in Figure 8, the wet density of the sample can be identified, and this shows that the values of the FCCB sample are higher than those found in the AACB sample.

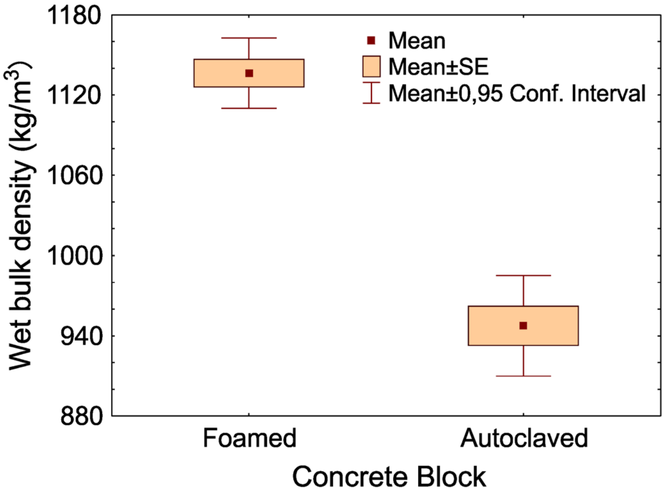

Figure 8. Wet bulk density for different concrete blocks.

The results were consistent with the results of Ferraz (2011) and Ungkoon *et al.* (2007) and with the values established by NBR 13438 (ABNT, 2013a), which cites for Class C15 a dry bulk density of less than 500 kg/m³ unlike the FCCB which was above the maximum of the reference standard. The compressive strength of a concrete is accompanied by the increase of its density, which in turn is governed by the number of voids that the concrete presents and thus, the larger the air void the less the compressive strength of the concrete. This order presented by Narayanan and Ramamurthy (2000) and Castro and Pandolfelli (2009) is not observed in the samples, since AACB has characteristics (density) that would make it less resistant than FCCB.

The greater resistance of the AACB is linked to the production process that due to temperature and pressure allows the formation of tobermorite. It is this that guarantees a gain of mechanical resistance many times greater than the natural formation process, and does not depend on the density, since the process for hydrating FCCB is normal. Therefore the formation of the hydration products such as C-S-H is not accelerated as in the case of AACB and thus requires more time to gain in compressive strength. Another point explained by Jacóe and Rodrigues (2014) is the role of the organization of voids in the matrix of the block. The greater the organization and layout, the greater the compressive strength of the block. This fact helps explain the inversion of results that was found.

According to studies by Ungkoon, *et al.* (2007), they found data that are similar to those of this paper, when analyzing their samples under a microscope. The author found a very particular structure, namely, autoclaved concrete had a homogeneous structure with smaller pores, since the non-autoclaved block sample consisted of large pores without a standardized size which formed cavities throughout the sample.

Another factor influencing the wet density of the samples is the permeability, which is related to the shape, distribution and connectivity (capillarity) of the pores.

Hamad (2014) classifies these voids as open and unopened, the former having connection between the pores through communicating vessels allowing the absorption of water by capillarity. In this way the saturated density is not related to the quantity of pores but to the connectivity between the pores.

3.3 Air Voids - Porosity

Figure 9 shows the air void of each sample. The AACB had an average air void of 50%, while the FCCB had an average air void of, approximately, 45%.

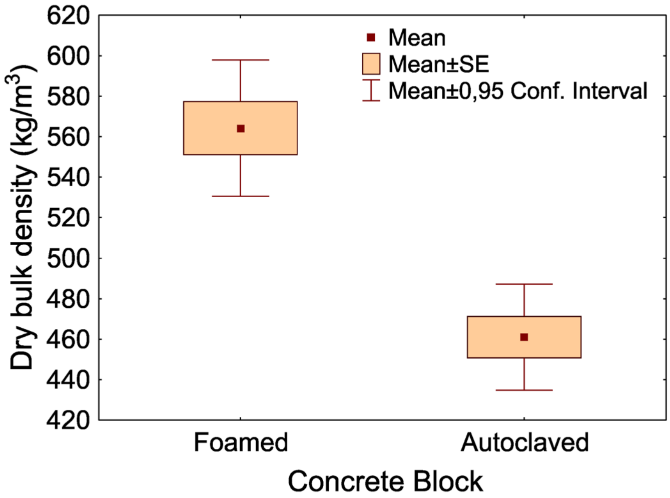

Figure 9. Air void for different concrete blocks.

According to the Brazilian Portland Cement Association (ABCP, 2002), for a foamed cellular concrete made on site, the range of the admitted percentage of void volume is between 35% and 45%. Currently, a draft project (ABNT, 2013b) lays down that foamed cellular concrete, when molded in place to seal multi-floor buildings, may have a maximum of 37% voids (SILVA *et al.*, 2018).

Comparing the two blocks, the higher air void does not represent a higher compressive strength, since the AACB has a higher air void and a higher compressive strength. This result is explained by the shape and distribution of the pores in the structure of the blocks, namely, the BBCA has uniformly distributed pores with little variation in size and, most importantly to ensure greater compressive strength, the pores are seldom interconnected (MEHTA; MONTEIRO, 2014).

3.4 Water Absorption

Figure 10 shows that the results of water absorption for each sample was similar, the highest rate of water absorption being in the AACB, with mean values of approximately 89% and the FCCB showed average water absorption of approximately 87%.

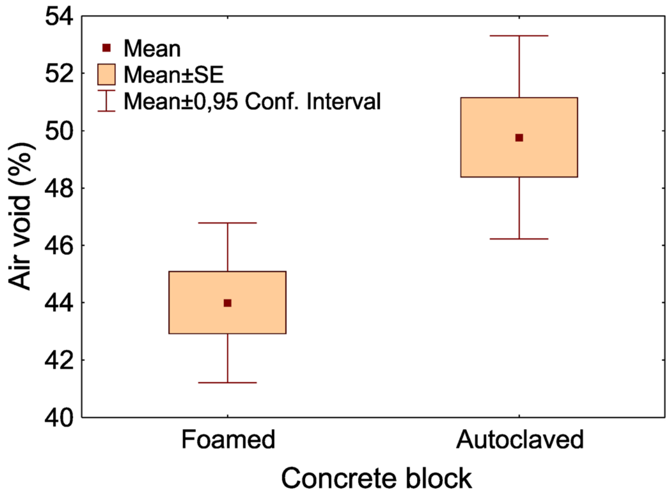

Figure 10. Water absorption for different concrete blocks.

Water absorption takes place in several properties of the porous materials, such as thermal conductivity and retraction when drying. As the cellular concrete blocks have high porosity, the water absorption characteristic becomes important vis-à-vis the other properties because the moisture content that can influence them is determined in large part by the extent to which the material absorbs water (MOTA, 2001).

Moreover, according to Mota (2001), this may influence the performance of the masonry functions by causing a lack of adhesion at the interface of the block with the mortar, since mortar can absorb water even in the curing stage or until the early loss of workability during settling.

In this context, the autoclaved cellular concrete block may be at a disadvantage in relation to the block of foamed cellular concrete since it was seen to have absorbed a greater amount of water, a characteristic directly linked to porosity.

According to Mathey and Walter J. Jr. Rossiter (1988), water absorption for the autoclaved concrete is neglected because it is considered low, but the results found in this assay indicated that the amount of water absorbed was high.

According to the ABCP (ABCP, 2002) cellular foamed concrete must have a water absorption range of between 22 and 28%, values well below those found for the samples analyzed in this study.

3.5 Thermal Conductivity

Thermal conductivity is a property that represents the flow of heat across the surface of the material. Figure 11 shows the thermal conductivity values found in the samples analyzed.

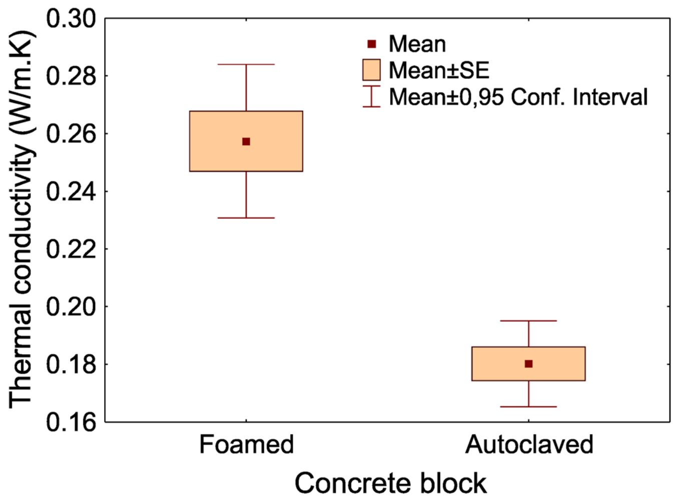

Figure 11. Thermal conductivity for different concrete blocks.

FCCB had a higher average thermal conductivity of approximately 0.26 W/m.K, i.e. it transfers more heat than AACB which has an average thermal conductivity of approximately 0.18 W/m.K. Thus, AACB offers better thermal insulation than FCCB. These results are in agreement with the literature (NARAYANAN; RAMAMURTHY, 2000; RAMAMURTHY *et al.*, 2009), namely, the higher the number of pores, the lower the thermal conductivity.

4 Conclusions

From the results found, a comparison can be made of the physical and mechanical characteristics of each block, where it is shown that the AACB presents patterns very similar to those shown in the bibliography, with compressive strength values and density values, according to the reference standard while FCCB which was compared to the same standard did not meet the same standards.

Regarding the parameters of the air void and water absorption, it was concluded that FCCB has a lower air void and yet has a much higher wet density than that presented by the AACB. This may be related to the presence of micropores that have made it block more hygroscopic due to phenomena of capillarity, to which the higher thermal conductivity is also linked.

Finally, it is concluded that the AACB presents better results than FCCB, thus making it more efficient and of higher quality, but other issues such as cost and energy spent on production should be considered when comparing these two types of block. Also, it is advised that the users of these blocks require the manufacturers to conduct experimental tests that can guarantee the minimum values required by the norms.

Acknowledgements

The authors, Richard T. Lermen and Rodrigo de Almeida Silva thank the Fundação Meridional for financial assistance by means of the productivity grant; The authors Djalmo Dutra dos Santos Neto and Leonel Nadal de Oliveira thank the IMED and CNPq, respectively, for financial assistance by means of the grant.

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