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Thermal Analysis of Concrete Blocks and Stack-Bond Prisms under Different Boundary Conditions

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Abstract: Fire is a significant threat to human lives and the integrity of buildings. To better understand the complex behavior of masonry exposed to high temperatures, thermal analyses were carried out to evaluate the temperature distribution in concrete blocks and stack-bond prisms exposed to high temperature levels. The effects of distinct specimen boundary conditions (restrict or easy access to air circulation inside the voids of the block and prisms) on the thermal response of the masonry materials were investigated. Thersys 2.0 software was used to implement three-dimensional thermal analysis of distinct finite element models. Four-node tetrahedral elements and full integration were used in all models. The modeling approach was validated by experimental data obtained from thermocouples embedded into masonry components. The results indicated that the boundary conditions significantly affected the time required for homogenization of temperature in blocks and prisms. Easy access to air circulation inside the voids of the prisms provided a faster temperature homogenization. In this scenario, the prism reached temperature ranges of $(300 \pm 0.5\% \times 300)$ °C and $(600 \pm 0.5\% \times 600)$ °C after exposure times of 2 h and 2 h 10 min, respectively. When access to air circulation within the voids of the prisms was limited, the same temperature ranges were achieved after exposure times of 5 h 20 min and 6 h, respectively.

Keywords: masonry prisms; concrete blocks; mortars; modeling; fire; thermal properties of materials; finite element method

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1. Introduction

Fire is a significant threat to human lives and to the integrity of buildings. After exposure to elevated temperatures, masonry elements undergo a series of temperature-dependent physicochemical transformations and phase changes that degrade their original strength and stiffness [1–3]. In the face of increasing fire incidents, a comprehensive investigation of the heat transfer mechanisms of masonry elements is essential to ensure the protection of life and masonry structures.

In fire tests of construction materials, the specimens are exposed to hot gases, so heat transfer occurs through radiation from the furnace's heating instruments and convection mechanisms [4]. Masonry prisms have been widely used to investigate the behavior of masonry exposed to high temperatures, as they are more cost-effective specimens compared to masonry walls. Moreover, these types of samples are easier to construct and test. Fire tests of masonry prisms may provide interesting information about the masonry compressive behavior, in addition to the economic benefits associated with the small size of these types of specimens [5].

Some fire tests of masonry prisms have been carried out in computer-controlled electrical furnaces. For example, Leal [6] recently exposed masonry prisms to different temperature levels (200, 400, 600 and 800 °C) in a horizontally oriented furnace with side openings and sliding doors. To optimize the convection mechanisms within the hollow spaces of the prisms, the specimens were strategically placed on supports, ensuring both elevation and central positioning inside the furnace. Then, the authors obtained normalized degradation curves of the mechanical properties of concrete masonry prisms. Kiran et al. [7] exposed prisms of solid clay brick to the standard ISO 834 [8] curve (30, 60, 90 and 120 min) and natural cooling, using an electric furnace with inner dimensions of 700 mm × 400 mm × 400 mm. Reference prisms (without plaster) failed after a heating exposure higher than 60 min, whereas prisms coated with sand mortar, vermiculite mortar, or perlite mortar demonstrated superior fire resistance. Prisms of solid clay brick were also heated up to different temperature levels (200, 400 or 600 °C) in a box muffle furnace by Gao et al. [9], followed by natural cooling. They verified that the best residual strength improvements were provided by a reinforced layer of PVA (poly vinyl acetate) and steel fibers. Bittencourt and Antunes [10] placed hollow clay block prisms on the insulation floor of an electrical furnace and exposed them to different levels of high temperature (300, 600 or 900 °C) and natural cooling. The high thermal resistance of hollow clay units provided excellent residual mechanical properties to the masonry prisms.

Gas furnaces with high heating capacity have also been used in fire tests of masonry prisms. For instance, Leal et al. [11] tested concrete block prisms and small walls exposed to the standard ISO 834 curve [8] for 70 min and natural cooling in a gas furnace with inner dimensions of 4 m × 3 m × 1.5 m. A ceramic fiber blanket was placed on the top and bottom ends of the specimens. Fire-damaged prisms and small walls exhibited a compressive strength of approximately 14% compared to their initial strength. Neto [12] also investigated clay block prisms exposed to the standard ISO 834 curve [8] for 120 min and fan cooling in a gas furnace. The specimens presented mechanical property reductions of up to 98.5% after exposure to 900 °C. Dupim [13] reported fire tests of concrete block prisms exposed to the standard ISO 834 curve [8] for 70 and 120 min and fan cooling in a gas furnace. Specimens covered with a plaster layer and heated for 120 min presented residual compressive strength values from 6% to 9% of their initial strength.

In this context, the thermal analysis of masonry prisms is of paramount importance to understanding the behavior and performance of materials under such extreme conditions. According to Torregrosa and Diez [14], the thermal behavior of masonry elements is very complex, depending on the intrinsic characteristics of masonry units and mortar joints. Heat transfer takes place by conduction mechanisms in the components' solid parts and by convection and radiation mechanisms on the external surfaces and surfaces of the cavities of the masonry elements. Assis and Neto [4] verified an important role in the radiation mechanisms inside the cavities of concrete blocks. Consequently, the contribution of air convection mechanisms to heat transfer inside the voids was negligible when high emissivity values were used on the cavities' surface.

The boundary conditions of the specimens during the fire tests have a substantial impact on their temperature distribution profile, as these conditions determine how heat is transferred and dissipated. Although different boundary conditions have been used in the previous fire tests of masonry prisms, there is no systematic evaluation of the thermal response associated with these distinct test methods.

Numerical analyses have been widely used for investigation of the thermal behavior of masonry structures [15–17], as numerical models can provide detailed and continuous temperature distributions throughout the entire analyzed domain. Due to the limited number of thermocouples, it is difficult for the experimental analyses to achieve a high level of detail in capturing the temperature distribution of complex systems. Additionally, the challenges associated with the placement of thermocouples inside the masonry specimens pose inherent difficulties. The insertion of thermocouples can change the natural thermal flow within the materials, potentially influencing the temperature distribution being measured.

For example, Russo and Sciarretta [18] used the DIANA 9.6 software (DIANA FEA BV, Delft, Netherlands) to develop the structural analysis of heat-damaged models of stack-bond prisms produced with hollow clay blocks with different ratios between net and gross area (α), i.e., α = 1.00, 0.70, 0.55 or 0.40. Their objective was to capture the cracking behavior under both thermal and mechanical stresses. This software provided a heat flow analysis that reproduced the heat transmission throughout the specimen and its hollows. A constant density was used for blocks and mortar, the specific heat was not presented, and equivalent thermal conductivity values were used to treat the air cavities as a fictitious material and account for the heat exchange inside the voids of the blocks. Stress–strain curves were inputted for masonry units and mortar joints. The authors simulated the thermo-mechanical behavior of the different models during and after the standard fire exposure prescribed in ISO 834-1 [8]. However, the authors emphasized the need for further experimental validation to support the calibration of the model.

Using the finite element method (FEM) software MASA (Macroscopic Space Analysis, University of Stuttgart, Stuttgart, Germany), Bošnjak et al. [19,20] carried out thermo-mechanical numerical analyses of stack-bond prisms of masonry made of solid calcium silicate bricks. Their experimental and numerical studies aimed to provide more information for assessing fire-damaged masonry structures. The authors used four-node tetrahedral elements to mesh the masonry components. The specific mass, thermal conductivity and specific heat of the materials of the numerical models were not reported. The microplane model with a relaxed kinematic constraint was used as the constitutive law for quasi-brittle materials. Additionally, the assumption of a perfect bond was made between mortar and bricks. According to the authors, their model appeared to be suitable for simulating the behavior of masonry elements exposed to elevated temperatures. According to Bošnjak et al. [19,20], further validation with a more complete database (tests at both the specimen and component levels) is needed to finalize the modeling parameters.

Rodovalho and Corrêa [21] carried out a thermal simulation of FEM models of stack-bond prisms made of hollow concrete blocks elaborated in the ABAQUS 6.14 software (SIMULIA, Johnston, RI, USA). The primary objective of their work was to assess the thermal insulation capacity of concrete block masonry in a fire situation based on numerical simulations of masonry prisms. The masonry components were generated using elements of the DC3D8 "heat transfer" family. The authors modeled the fluid domain inside the cavities of the blocks using solid elements of the FC3D8 "fluid" family and applied the fluid-structure interactions. The radiation in the voids of the blocks was not represented. Variations of specific mass, thermal conductivity and specific heat with temperature were obtained from various papers published in the literature. The authors only applied the temperature increases to the external faces of the prisms that were directly exposed to the inner chamber of an oven. The numerical models were validated by comparing the average temperature increases obtained numerically with the results of a masonry experiment featuring mortar coating on the specimen's face exposed to fire.

The ABAQUS 6.14 software was also used by Rodovalho, Corrêa and Neto [22] to carry out thermo-mechanical numerical investigations of FEM models of stack-bond prisms exposed to high temperatures. The authors aimed to numerically verify the mechanical strength of concrete block prisms under compression and fire conditions. According to the authors, the thermal properties used in these models were the same as those used in the paper published by Rodovalho and Corrêa [21]. The stress–strain curves and damage models were obtained from various papers published in the literature. A satisfactory alignment was achieved between the experimental and numerical stress–strain curves at room temperature. Nevertheless, the results from the thermo-mechanical simulations were not validated through experimental data.

FEM models of stack-bond prisms produced with hollow clay blocks with different geometries were evaluated in thermal numerical analyses carried out by Quispe et al. [23], using the ABAQUS 6.14 software. These authors aimed to numerically analyze heat transfer mechanisms in masonry prisms under fire conditions. The DC3D8 "heat transfer" finite element was used. Three different types of numerical approaches were investigated: a homogenized model, a detailed model with constant thermal properties, and a detailed model with thermal properties varying with temperature. The authors modeled a volume of air inside the cavities of the prisms to account for radiation and convection mechanisms. The results indicated that the homogenization approach provided conservative estimates. However, its computational demand was minimal when compared to that required by the other modeling approaches. Moreover, decreases in the value of α caused thermal insulation gains due to the low thermal conductivity of the air. Experimental studies were not carried out to validate the numerical results.

Depending on the location of masonry blocks and prims inside the furnace and the distribution of the furnace's heating instruments, the specimens will be subjected to different boundary conditions during the fire tests, which may change the heat transfer mechanisms inside their voids. Thorough attention must be given to the exposure of the open ends of hollow specimens to the heating instruments of the furnace. The specimens are sometimes placed directly on the insulating floor of the furnace. When at least one end of the specimens is covered with insulation material, the air circulation within the voids is restricted, potentially affecting the temperature distributions during the heating process because convection mechanisms are mitigated, and heat conduction through the air mass emerges as the predominant mode of heat transfer. On the other hand, placing the open ends close to the heating instruments promotes relevant air circulation within the voids of the specimens, which can decrease the time required for the experimental tests. This configuration enables convective interactions between the internal surface of the specimens and the hot gases, in addition to conduction mechanisms within the air mass.

However, the existing body of research lacks both experimental and numerical investigations of the complex patterns of temperature distribution within concrete blocks and stack-bond prisms. Previous studies have not undertaken a comparison of the influence of different boundary conditions on the thermal behavior of masonry specimens during heating tests. In addition, the formation of convection currents in voids of masonry blocks and prisms was not investigated in previous research and is often overlooked in fire tests. Moreover, there is a discernible gap in the literature regarding practical guidance on the time required for temperature homogenization of masonry specimens.

To fill this knowledge gap, the present work presents thermal analyses for evaluation of the temperature distribution in concrete blocks and stack-bond prisms exposed to different temperature levels, considering the effects of distinct boundary conditions. The following contributions derived from this study: (i) new insights on the intricate patterns of temperature distribution within concrete blocks and stack-bond prisms under predefined conditions; (ii) exploration of the nuanced effects of different boundary conditions typically used in fire tests on the thermal response of masonry prisms exposed to high temperatures, which contributes for refining fire testing methodologies; (iii) study of the impacts of the formation of convection currents inside the voids of the masonry specimens, exploring an aspect that has been neglected in fire tests carried out in previous research; and (iv) practical orientation related to the time required for temperature homogenization of concrete masonry materials subjected to elevated temperatures, contributing to the improvement of fire testing protocols for masonry materials. These contributions not only advance our understanding of temperature distribution mechanisms but also hold practical implications, thereby contributing to the enhancement of precision in fire testing methodologies for masonry structures.

This paper has been organized into four sections. Section 1 provides an overview of previous literature regarding the thermal behavior of masonry prisms and highlights the main contributions made by the present study. Section 2 shows the materials and methods used for conducting both experimental and numerical thermal analyses. Section 3 presents the findings derived from the experimental and numerical analyses, followed by discussions aimed at elucidating the significance of the obtained results. Section 4 elucidates the main conclusions drawn from this paper, along with recommendations for future research in this scientific field.

2. Materials and Methods

2.1. Experimental Analysis

Hollow concrete blocks donated by BLOJAF were characterized according to the ABNT NBR 12118 [24], which is similar to the ASTM C140/C140M [25]. The basic characterization of these masonry units is summarized in Table 1. These blocks were used in experimental tests for validation of the numerical analysis (Section 2.2) developed in the present paper.

Table 1. Characterization data of hollow concrete blocks.

Parameter	Average	SD
Length (mm)	289.3	0.3
Width (mm)	138.8	0.4
Height (mm)	189.9	0.8
Thickness of the face shells (mm)	26.3	0.3
Thickness of the webs (mm)	26.4	0.2
α value (%)	57.8	0.4
Net area compressive strength (MPa)	17.4	1.1
Water absorption (%)	6.0	0.4
Density (g/cm^3)	2.16	0.03

Notes: SD—standard deviation. α—ratio between net and gross area.

A K-type thermocouple was embedded into a hole drilled in the blocks' webs (diameter of 8 mm) using a bench drill machine (Figure 1a). The location and depth of the hole are indicated in Figure 1b. Then, the following recommendations provided by Medeiros, Parsekian and Moreno Jr [26] were implemented: the hole was filled with cement paste, taking special care to eliminate any gaps or fixation failures.

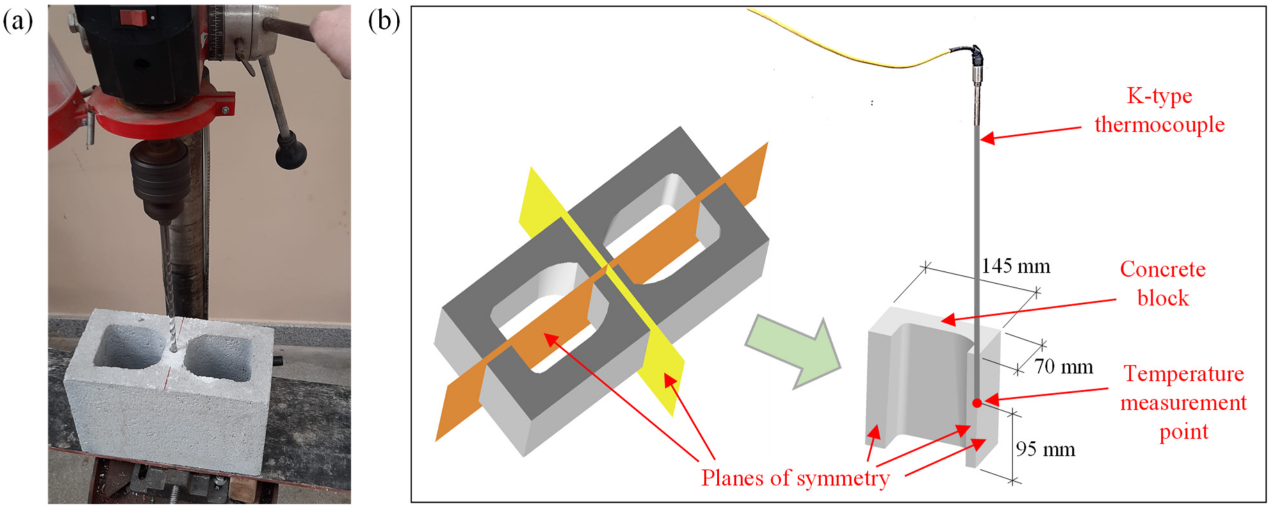


Figure 1. Hole drilled in the concrete blocks (**a**) and position and dimensions of the hole (**b**).

Dried concrete blocks were tested in a computer-controlled electrical furnace with inner dimensions of 750 mm × 750 mm × 600 mm (Figure 2a). The heating curve was defined by a linear temperature increase (rate of 7 °C/min) up to 300 °C, which was kept constant for 3 h. After that, the specimens were cooled naturally inside the furnace. Two scenarios were investigated: restricted access to air circulation inside the voids of the block (BC1) and easy access to air circulation inside the voids of the block (BC2). In the BC1 scenario, the block was placed on an insulating floor typically used in electrical furnaces (Figure 2b), as demonstrated by Bittencourt and Antunes [10]. In the BC2 scenario, the insulating floor was removed, and the block was positioned upright to facilitate air circulation within its voids (Figure 2c), mirroring the experimental methods used by Leal [6].

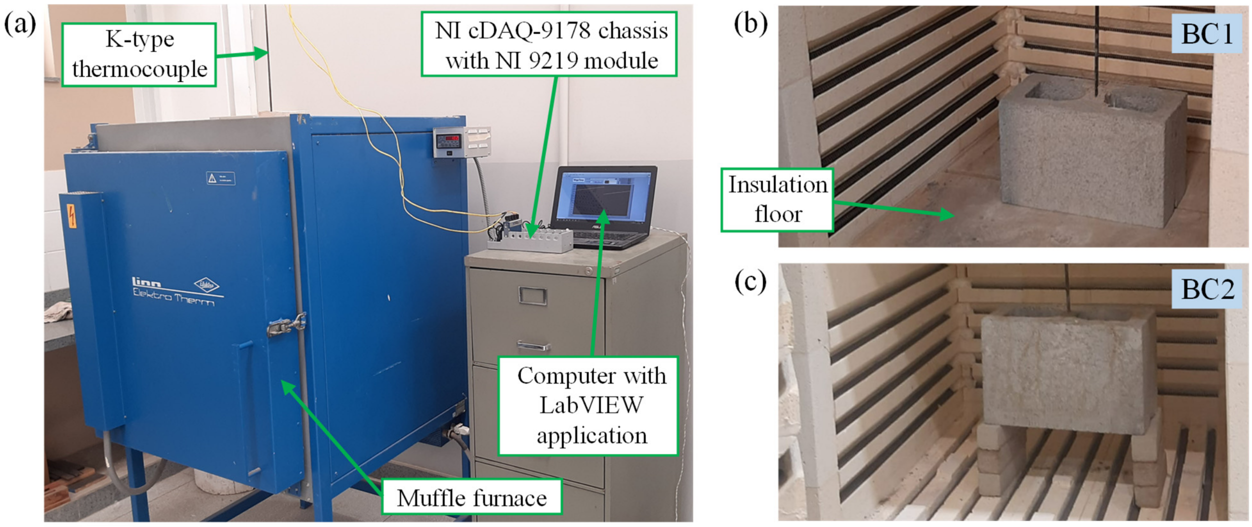


Figure 2. Experimental setup used to heat the masonry components (**a**), according to the BC1 (**b**) and BC2 (**c**) configurations.

Temperature measurements were acquired using the NI (National Instruments) data acquisition (DAQ) system cDAQ-9178 and a NI 9219 module (acquisition rate of 1 Hz) indicated in Figure 2a. One thermocouple was used to monitor the temperature inside the furnace chamber, and another thermocouple was used to monitor the temperature at the middle web and middle height of the concrete block.

2.2. Numerical Analysis

Numerical simulations of different masonry specimens were carried out in the Thersys 2.0 software (Universidade Federal de Minas Gerais, Belo Horizonte, Brazil), which is based on the FEM and enables the use of different types of bidimensional isoparametric elements (e.g., three-node triangle element, six-node triangle element, four-node quadrilateral element and eight-node quadrilateral element) or tridimensional isoparametric elements (e.g., 4-node tetrahedral element, 10-node tetrahedral element, 8-node hexahedral element and 20-node hexahedral element). This software deals with conduction heat transfer in the structure domain, in addition to radiation and convection mechanisms between hot gases and the surface of the structure. It supports the utilization of different fire curves, enables the modeling of solid structures, and incorporates non-linear thermal properties of materials. Further details regarding the implementation and validation of this software are discussed in previous works published by the authors of the present paper [27–30]. Additionally, practical applications of the software have been demonstrated by other researchers [31–34]. The elaboration of the graphical modeling environment, the generation of the FEM mesh and the visualization of results are developed using the GiD tool, a pre- and post-processor for numerical simulations developed by the International Center for Numerical Methods in Engineering [35].

Six distinct analyses were evaluated in the present work, whose characteristics are listed in Table 2. The heating curve of all simulations was defined by a linear temperature increase (rate of 7 °C/min) up to a maximum exposure temperature level (300 °C or 600 °C), which was kept constant until the end of each different analysis (Figure 3). The emissivity coefficient ε_m and the convection coefficient α_c were equal to 0.7 and 25 W/(m^2.°C), respectively [36–38]. The Galerkin scheme was used for temporal integration with a time interval Δt of 5 s.

Table 2. Characteristics of the models evaluated in the thermal analyses.

Analysis	Model Composition	Boundary Conditions	Maximum Exposure Temperature
BC1-300	B + AM	BC1	300 °C
BC2-300	B	BC2	
PC1-300	P + AM	PC1	
PC2-300	P	PC2	
PC1-600	P + AM	PC1	600 °C
PC2-600	P	PC2	

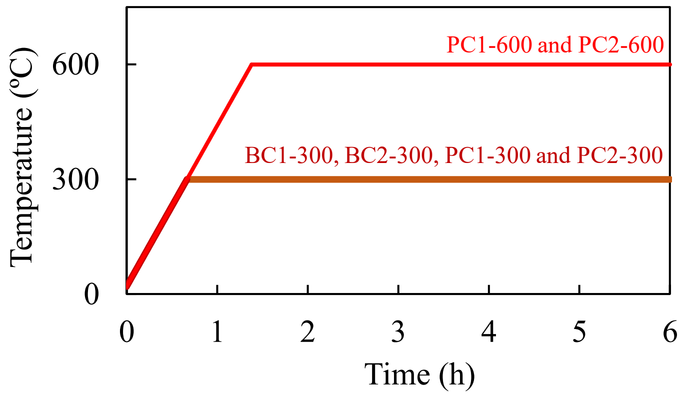


Figure 3. Heating curves used in the BC1-300, BC2-300, PC1-300, PC2-300, PC1-600 and PC2-600 numerical analyses.

To reduce computational efforts, the finite element models were simplified based on the thermal symmetries of hollow concrete blocks and stack-bond prisms composed of three blocks and two mortar joints. The geometry of the blocks and joints and the position of the longitudinal and transversal planes of symmetry are represented in Figure 4, in addition to the simplified models evaluated in the numerical analyses.

The models were composed of a single hollow concrete block (B), single hollow concrete block + air mass in its voids (B + AM), stack-bond prism (P), or stack-bond prism + air mass in its voids (P + AM), as indicated in Table 2 and illustrated in Figure 5. Four-node tetrahedral elements and full integration were used in all models. Full integration is commonly preferred for the development of tridimensional finite elements to address numerical instabilities and convergence problems by providing the exact integrals for the elements' stiffness matrix [39–41]. Some analyses were conducted to obtain viable and useful FEM models in terms of accuracy and computational time. They resulted in the mesh configurations, number of elements and nodes, and resolution of FEM elements indicated in the models represented in Figure 5.

One of the objectives of the thermal analyses was to investigate the effects of different specimen boundary conditions due to the formation of convection currents inside the voids of blocks and prisms. Four different situations were investigated: restricted access to air circulation inside the voids of the block (BC1) and the prism (PC1), and easy access to air circulation inside the voids of the block (BC2) and the prism (PC2). Figure 6 illustrates the thermal exposure faces and thermal insulation faces of BC1, BC2, PC1 and PC2 boundary conditions, which were applied to the B + AM, B, P + AM, and P models, respectively. In the BC2 and PC2 boundary conditions, convection currents were formed inside the voids of the specimen and heat transfer also occurred by radiation between the hot gases and its internal surfaces. On the other hand, it did not happen in the BC1 and PC1 boundary conditions because only heat conduction was considered in the air mass. The insulation areas represented in Figure 6 are associated with (i) the insulation floor of the furnace or (ii) the longitudinal and transverse planes of symmetry, where there is no contact between the specimen and the hot gases of the furnace.

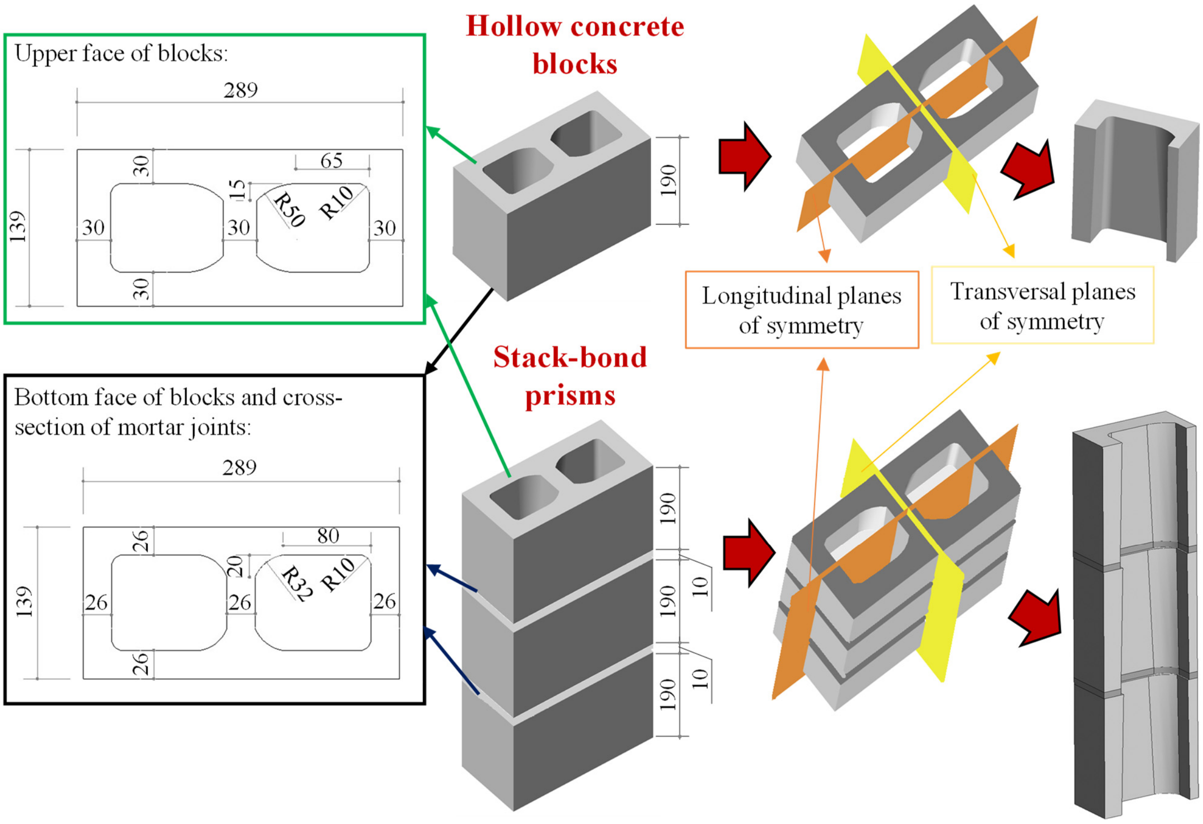


Figure 4. Dimensions (in millimeters) and thermal symmetry conditions used in the definition of the numerical models.

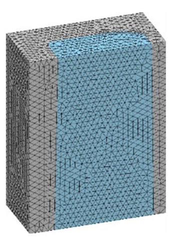
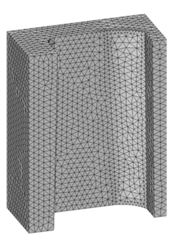
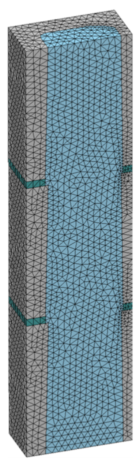
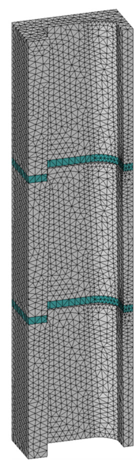
B + AM (single block + air mass)	B (single block)	P + AM (stack-bond prism + air mass)	P (stack-bond prism)
			
Nodes: 16,297 Elements: 86,644 Resolution: 6 mm	Nodes: 10,412 Elements: 51,167 Resolution: 6 mm	Nodes: 15,701 Elements: 81,185 Resolution: 10 mm	Nodes: 12,172 Elements: 56,955 Resolution: 10 mm

Figure 5. Finite element mesh, number of nodes and elements of the different numerical models.

Values of specific heat, thermal conductivity and specific mass of the concrete units (Figure 7a) were those tabulated in EN 1992-1-2 [42] for dry normal-weight concrete with siliceous aggregates.

For the mortar joints, the values of specific heat, thermal conductivity and specific mass (Figure 7b) were those tabulated in previous papers [21,43]. For the BC1 and PC1 models, data reported by Incropera and DeWitt [44] was used to define the specific heat, thermal conductivity, and specific mass of the air (Figure 7c) inside the hollows of concrete blocks and prisms.

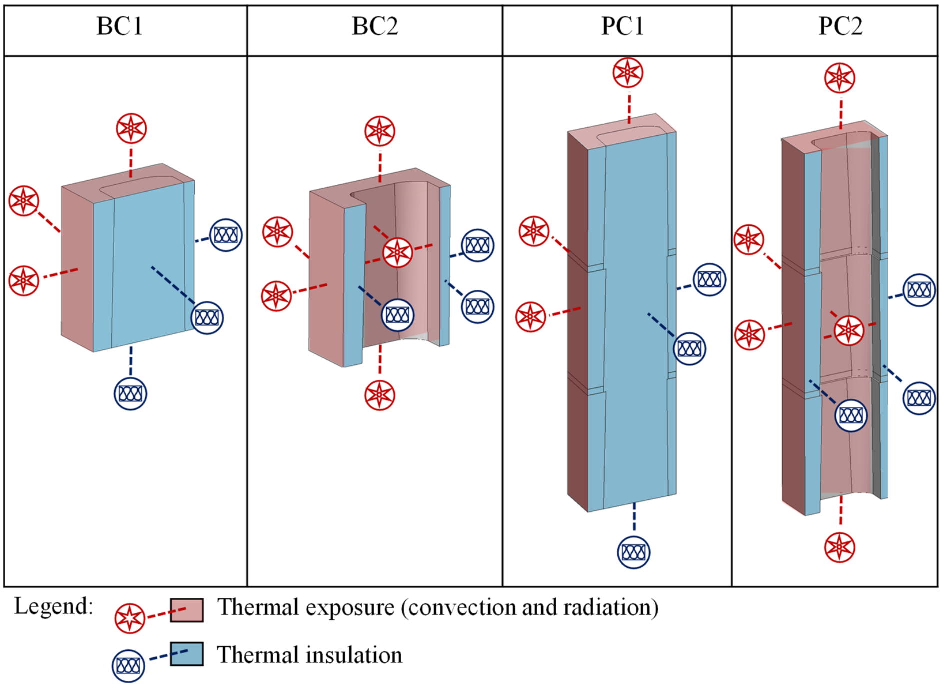


Figure 6. Schematic of the boundary conditions of the finite element models.

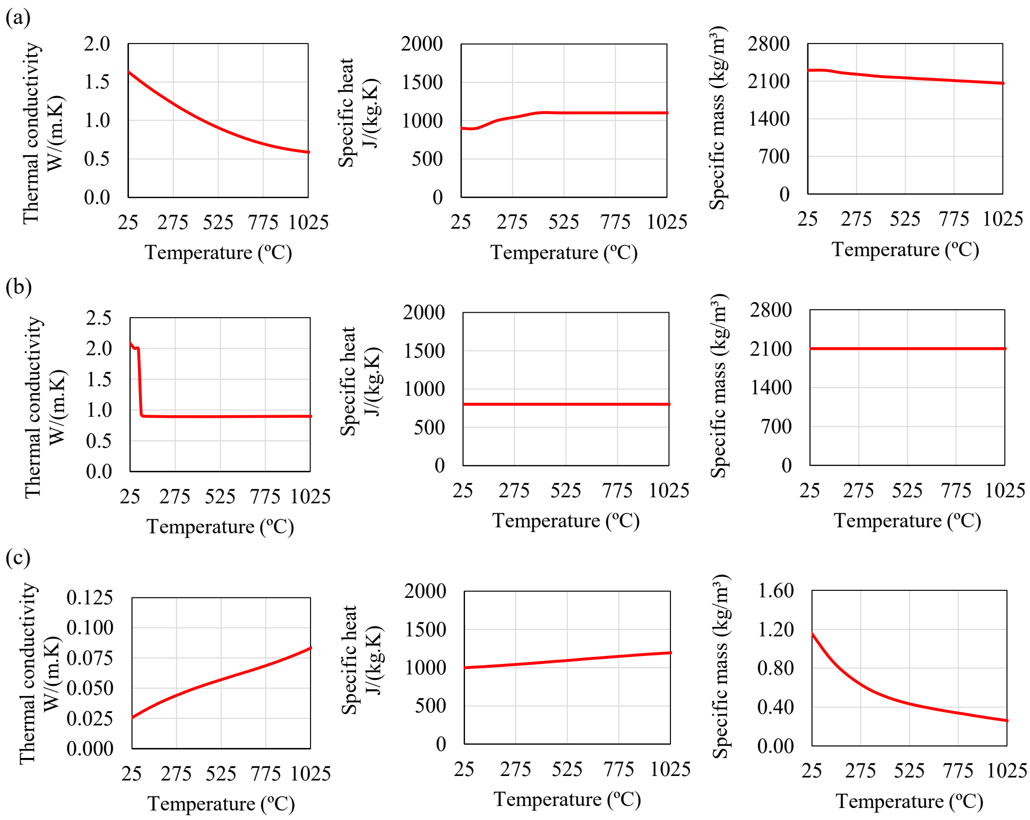


Figure 7. Variations of thermal conductivity, specific heat, and specific mass with temperature for concrete (**a**), mortar (**b**) and air mass (**c**).

3. Results and Discussion

3.1. BC1-300 and BC2-300 Thermal Analyses

Figure 8 shows a comparison between numerical and experimental results obtained in the present work. It includes the results of temperature evolution at the node located at the middle web and middle height of the numerical models BC1-300 and BC2-300, in addition to the results of the thermocouple measurements used to validate the numerical model.

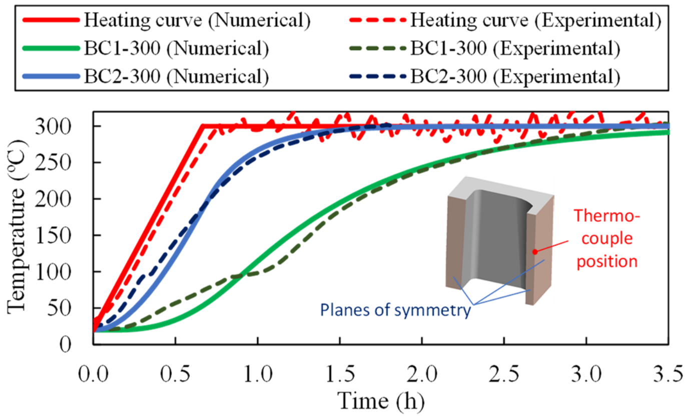


Figure 8. Experimental and numerical results of BC1-300 and BC2-300 thermal analyses.

Before 100 °C, the experimental model revealed a higher temperature increase rate than the numerical model. It can be attributed to the presence of some residual amount of water in the pores of the cementitious matrix around the block's thermocouples, which increased the thermal conductivity of the material. At about 100 °C, a small plateau was observed in the experimental curves, which was associated with the pore water evaporation. After 100 °C, the numerical and experimental models provided a very similar response so that the temperature vs. time curves were close to each other in the range of 150–300 °C. Therefore, results indicated that the numerical simulation approach had a high predictive ability to represent the temperature evolution of dry hollow concrete blocks.

The boundary conditions significantly affected the time required for temperature homogenization in the blocks, as results of BC1-300 and BC2-300 analyses reached the maximum temperature (300 °C) after exposure periods of about 3 h 30 min and 1 h 45 min, respectively. Therefore, it is possible to conclude that the formation of convection currents inside the voids of blocks was able to decrease the time required for temperature homogenization.

3.2. PC1-300, PC2-300, PC1-600 and PC2-600 Thermal Analyses

Results of PC1-300, PC2-300, PC1-600 and PC2-600 thermal analyses indicated the nodes of the prisms that exhibited the highest and lowest values of temperature during the numerical simulations. The identification number and position of these nodes in the prisms and their temperature vs. time curves are presented in Figure 9.

Figure 9 shows that the highest temperatures were observed in the hollow concrete blocks. They were always identified in the surface nodes positioned at the corner of the concrete units located at the ends of the masonry prisms (15,412, 2412, 15,414 and 2412 nodes in PC1-300, PC2-300, PC1-600 and PC2-600 analyses, respectively). The temperature vs. time curves for these nodes were very close to the temperature curves obtained for the hot furnace gases, as the nodes were located at the surface of the prisms. In contrast, results presented in Figure 9 indicate that the lowest temperature levels of the prisms were observed in nodes of the interior web of blocks (5168, 6631, 4365 and 6631 nodes in PC1-300, PC2-300, PC1-600 and PC2-600 analyses, respectively) and mortar joints (6241, 7819, 6241 and 7819 nodes in PC1-300, PC2-300, PC1-600 and PC2-600 analyses, respectively).

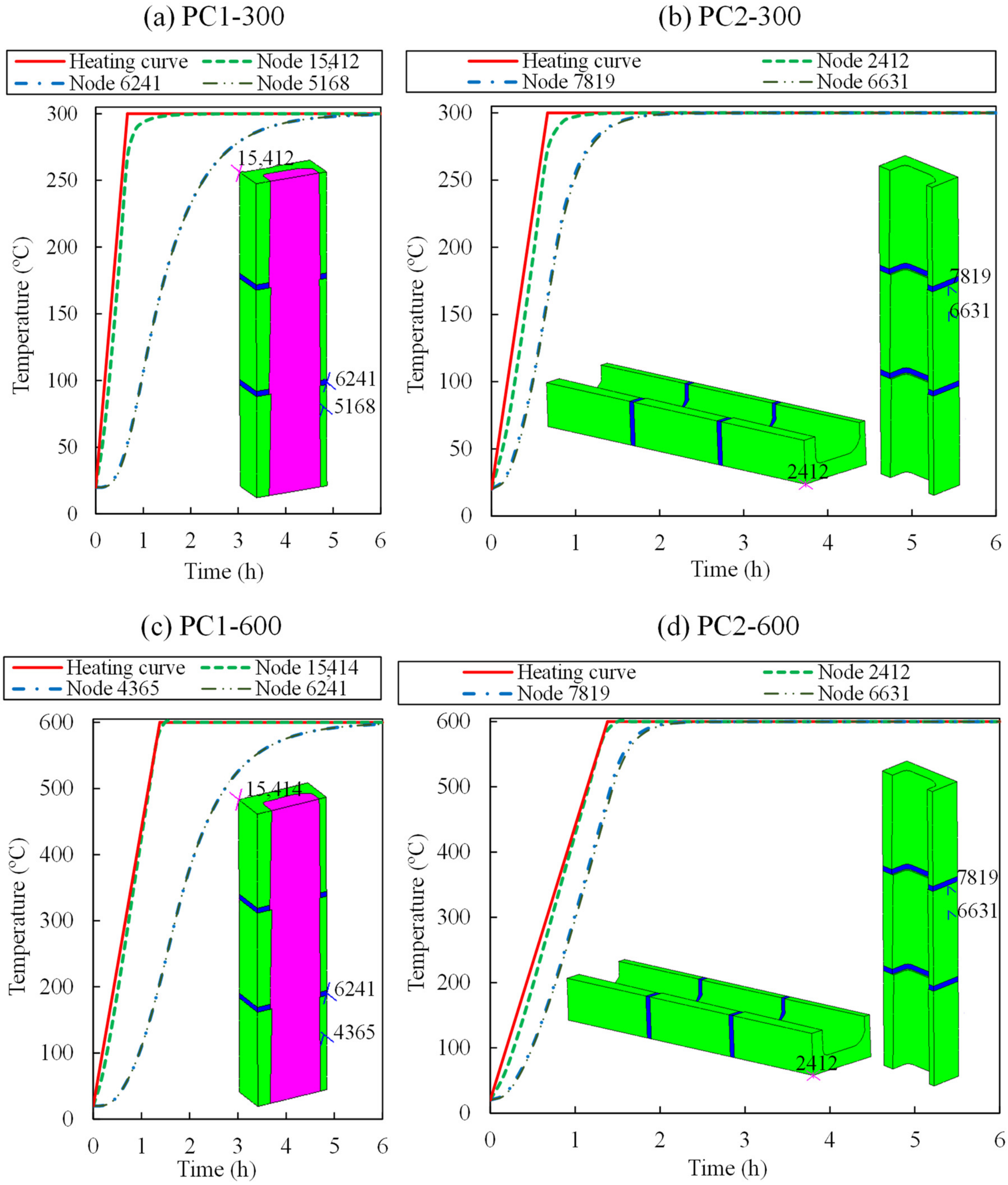


Figure 9. Results of (**a**) PC1-300, (**b**) PC2-300, (**c**) PC1-600 and (**d**) PC2-600 thermal analyses.

The boundary conditions also affected the time required for temperature homogenization in the prisms. For example, the prism of the PC1-300 analysis reached ($300 \pm 0.5\% \times 300$) °C after an exposure time of about 5 h 20 min, whereas the prism of the PC2-300 analysis took about 2 h to reach the same temperature range. In contrast, the prism of the PC1-600 analysis reached ($600 \pm 0.5\% \times 600$) °C after 6 h, whereas the prism of the PC2-600 analysis took about 2 h 10 min to reach this temperature range. Then, the convection currents formed inside the voids also decreased the time required for temperature homogenization in the prisms, regardless of the maximum exposure temperature.

4. Conclusions

In conclusion, this study has advanced the understanding of temperature distribution mechanisms within masonry materials. The thermal analyses provided the temperature vs. time curves of concrete blocks and stack-bond prisms exposed to different temperature levels.

The boundary conditions (restrict or easy access to air circulation inside the voids of the block and prisms) significantly affected the time required for temperature homogenization in blocks and prisms. The examination of intricate effects arising from these distinct boundary conditions contributed to the refinement of fire testing methodologies for masonry prisms exposed to high temperatures.

The investigation into the often-neglected aspect of convection currents within voids of masonry specimens added a novel dimension to the scientific discourse, filling a critical gap in previous studies. Results indicated that the formation of convection currents was able to decrease the time required for temperature homogenization.

Novel practical orientation for fire tests was offered in this study, particularly in relation to the time required for temperature homogenization in concrete masonry materials, which can improve fire testing protocols. In terms of operational aspects, easy access to air circulation inside the voids of test specimens may be recommended for fire tests, as it provides a faster temperature homogenization. When access to air circulation within the voids of the prism was unrestricted, it reached temperature ranges of $(300 \pm 0.5\% \times 300)$ °C and $(600 \pm 0.5\% \times 600)$ °C after exposure times of 2 h and 2 h 10 min, respectively. In contrast, when the airflow within the voids of the prisms was restricted, the same temperature ranges were achieved after exposure times of 5 h 20 min and 6 h, respectively. It is essential to note that altering the heating rate would lead to variations in the time required for temperature homogenization, which is a well-established fact in the existing literature. The decision to limit the heating rate to 7 °C/min in this study was intentional, focusing on facilitating the exploration of aspects not previously covered in the literature.

The present research has revealed an important perspective in the current understanding of the temperature distribution of masonry elements based on the demonstration of the impacts of different boundary conditions on the time needed for temperature homogenization within blocks and prisms. These findings highlight the importance of evaluating the boundary conditions associated with different equipment used in fire tests, thus opening new avenues for exploration in this scientific field.

The intent of the present paper was not to engage in a broad parametric analysis but rather to assess the effects of convection mechanisms and temperature homogenization under predefined test conditions. However, comprehensive parametric analyses could be developed to provide a deeper understanding of the underlying dynamics in fire-exposed masonry materials. In addition, the thermal analyses developed in the present paper may be complemented with numerical simulations for the investigation of the effects of different boundary conditions on the thermal response of stack bond prisms made of hollow blocks with different materials or thicknesses of coating systems. It is essential to acknowledge that the scope of this study did not encompass all possible variations in heating scenarios. Future investigations in the realm of innovative heating treatments could be developed to explore advanced techniques such as tailored heat distribution systems or innovative heating equipment for fire tests of masonry specimens.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/constrmater4010004/s1, Table S1: Numerical parameters, Table S2: Results of thermal analyses.

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