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GEOMETRY DEPENDENCE ON THE BEHAVIOUR OF MASONRY CLAY BLOCKS AT HIGH TEMPERATURES

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Abstract. The development of different constructive techniques is somehow conditioned to the investment in scientific research, aiming at comprehend the behaviour of materials; not only as individuals, but also as a whole compound. One area that has growth, for its importance in structural integrity analysis, is the analysis of masonry structures in fire situations. However, there exists an inherent difficulty on performing real standard tests under fire situations. The present work has as its main objective the study of the thermal behaviour of clay blocks at high temperatures, having the geometry of internal cavities as the main reference parameter. For this purpose, four different geometric configurations were analyzed. The thermal analysis was accomplished by using the commercial software ABAQUS. It was considered radiation, convection and conduction as heat transfer mechanisms. Radiation and convection was accounted for heat transfer between fire and the fire-exposed face of the wall, and between the wall and the ambient. As a simplification, it was considered air as solid for the cavity representation. Thus, heat conduction was considered within the internal cavities. The numerical simulations were purely thermal, aiming at analyzing the dependence of the internal geometry of the cavities. Numerical results show that thermal behavior not only depends on the empty spaces, but also on their distribution along the block interior.

1 INTRODUCTION

Structural verification has a huge importance in structural design, this importance is magnified in a situation such as a in a fire. Reasons for this importance are diverse, some of them can be mentioned as follows:

- To minimize the risk to human life;

- To avoid premature structural failure, allowing users to escape and to apply correct proceedings in a fire situation [7];
- To guarantee permeability and thermal behavior of the components in sharing areas of buildings.

In Brazil, experimental investigations for determining fire resistance in structural components should be conducted following the normative NBR 5628:2001 [1]. In order to a masonry wall be considered fire resistant, it should fulfill three main criteria: Mechanical Resistance (R), Thermal Behaviour (T), and Permeability (P). This criteria are explained in details in the following section.

Experimental and semi-empirical studies have diverse limitations, as they are usually conservative and highly expensive. A complementary alternative is the use of advanced numerical models, in which several system configuration can be analyzed [5], [6], [9], [10].

Regarding the development of numerical models related to high temperatures, it is important to comprehend that thermochemical and thermophysical reactions are considered in an indirect manner, by relating to them thermophysical properties, that should vary as a function of temperature [3]. No less important are the correct consideration of heat transfer mechanisms that are fundamental in systems in which the temperature is different from the ambient temperature. Basically, three heat mechanism are herewith considered: conduction, convection and radiation.

Based on the above-mentioned considerations, the present work has as its main objective to analyze the thermal behaviour of blocks with different geometries. Results should be a good starting point for an initial study for evaluating fire resistance in more complex systems, such as prisms or masonry walls.

2 FIRE RESISTANCE CRITERIA

There exists several fire resistance criteria in the literature. Usually, each applicable to a specific region. However, for the present work, it will be considered the standard and fire resistance criteria in accordance to: Brazilian normative NBR 5628:2001 [1] and Eurocode 6 normative [2]. The criteria is detailed as follows:

- **Mechanical Resistance (R)**. the structure does not attain rupture during fire exposure, performing its mechanical function at a time interval.
- **Thermal behavior (T)**. Any point in the structure surface, not exposed to fire, should not exceed a temperature of 180 ^{o}C and the mean temperature should not be greater than 140 ^{o}C above ambient temperature.
- **Permeability (P)**. the constructive element capacity of preventing cracks or openings that allow fire or hot gases to pass across the structure.

3 METHODOLOGY

The numerical investigation was conducted using the FEM commercial software ABAQUS/CAE. Regarding the numerical model in ABAQUS, we used the Linear Solid Heat Transfer element DC3D8 for both, the prism and the air mass. Moreover, as all parameters are dependent on time, we used a transient analysis.

For representing the fire conditions as a precise replication of the real conditions, we used the heating rate proposed in the ISO 834-1:1999 normative [4], which is specially used to account for a accurate fire representation.

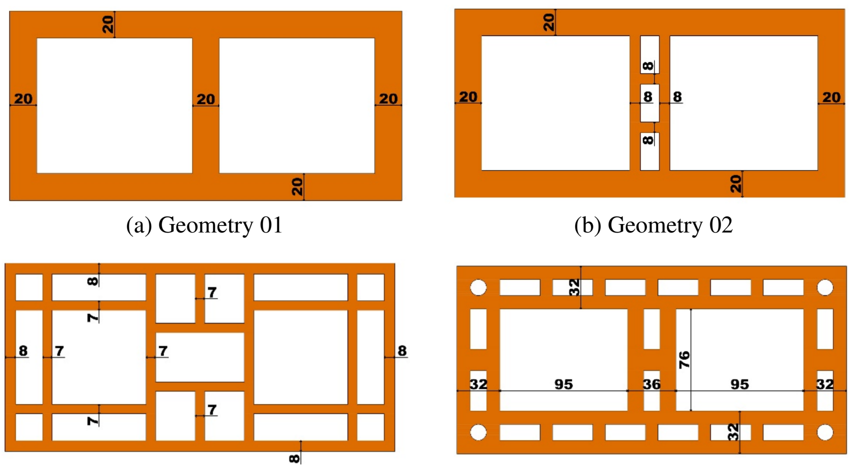
Material properties such as thermal conductivity and specific heat are dependent on temperature, following the line of the precise replication of real conditions we intended to reach. It is worth to mention that these properties were obtained from literature [8].

The following heat transfer modes were considered:

- **Face exposed to fire**. The fire was represented by the standard ISO curve [4]. Convection and radiation were considered as the heat transfer modes from the fire to the face exposed to fire.
- **Block interior**. The air mass was simplified by considering it as a solid, in this manner, conduction was considered for the interior of the blocks.
- **Face not exposed to fire**. Convection and radiation was considered for the heat transfer mode between the face that is not exposed to fire and the ambient.

All geometries considered have a clear symmetry, which we took advantage in our numerical model. The symmetry allowed us to have the same accuracy using less computational effort. Allowing, at the same time, the possibility of using finer meshes. Thus, several block geometries were analyzed, as can be seen in Figure 1.

From geometry 01 and 02, we can see that the big difference is the central voided wall. As for the geometry 03 and 04, all walls are voided and no special pattern is followed, however, it is important to mention that all geometries are commercial, and can be easily obtained in the Brazilian industry, for example.



(a) Geometry 01 (b) Geometry 02

(c) Geometry 03 (d) Geometry 04

Figure 1: Block geometries considered for the numerical models.

4 RESULTS

In order to properly evaluate the influence of the geometry in the thermal behaviour of the blocks, for each geometry was considered three cases: no coating, coating in one side (the side exposed to fire), and the case in which the coating is in both sides of the block. As a result the numerical study consists on twelve numerical models.

As mentioned before, symmetry was considered in order to have a more accurate result, as a consequence of the possibility of testing finer meshes. The symmetry plane is shown in Figure 2. Nodal points were considered in the exterior lateral plane and in the plane of symmetry, A and B, respectively. The total number of points depend on the geometry, and is, generally, different for each type of block.

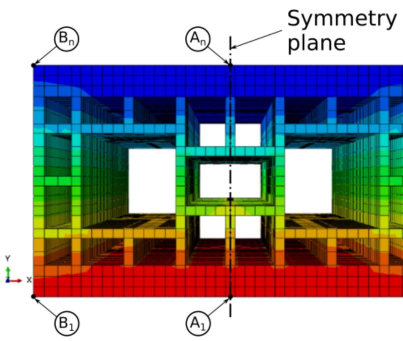


Figure 2: Symmetry plane for numerical models, showing the nodal nomenclature.

4.1 Geometry 01

The first geometry, denominated geometry 01, has a percentage of empty spaces of 56.65%. For this geometry were considered four, five and six nodes for the cases in which the block has no coating, has coating in one side and has coating in both sides, respectively. The nodes are used for evaluating the temperature distribution as a function of time. Figure 3 shows the temperature distribution for the case in which the block has coating in both sides. The fire distribution is in accordance to the ISO standard [4] and shown in red in the same figure.

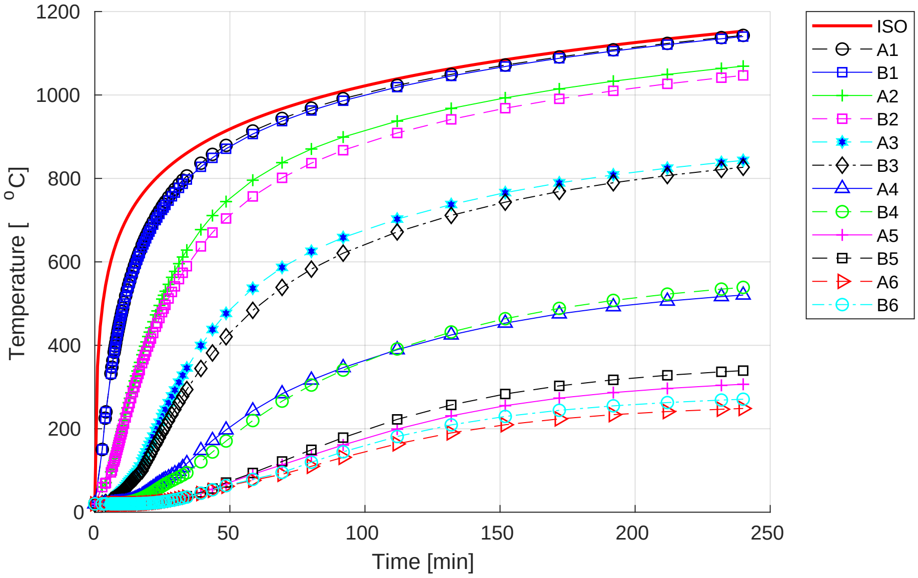


Figure 3: Temperature distribution as function of time for the geometry 01.

Nodal temperatures for the face that is not exposed to fire are also shown in Table 1.

Table 1: Nodal temperatures as function of time. All temperatures are in °C.

Time	No coat.		One-side		Both-sides	
[min]	A4	B4	A5	B5	A6	B6
30	55	73	42	51	30	30
60	146	179	119	124	79	82
90	193	236	183	199	127	140
120	212	260	214	236	175	193
180	228	280	236	264	228	248
240	235	289	245	275	248	270

For the case that we have no coating the temperature reached was 289 °C. When there was coating at one side the temperature reached was 275 °C, representing a reduction of 4.84% compared to the worst case, case in which there was no coating. Finally, in the case with coating on both sides the temperature reached was 270 °C, representing a reduction of 6.57% compared to the worst case.

4.2 Geometry 02

The second geometry, denominated geometry 02, has a percentage of empty spaces of 57.08%. For this geometry were considered eight, nine and ten nodes for the cases in which the block has no coating, has coating in one side and has coating in both sides, respectively. The nodes are used for evaluating the temperature distribution as a function of time. Figure 4 shows the temperature distribution for the case in which the block has coating in both sides. The fire distribution is in accordance to the ISO standard [4] and shown in red in the same figure.

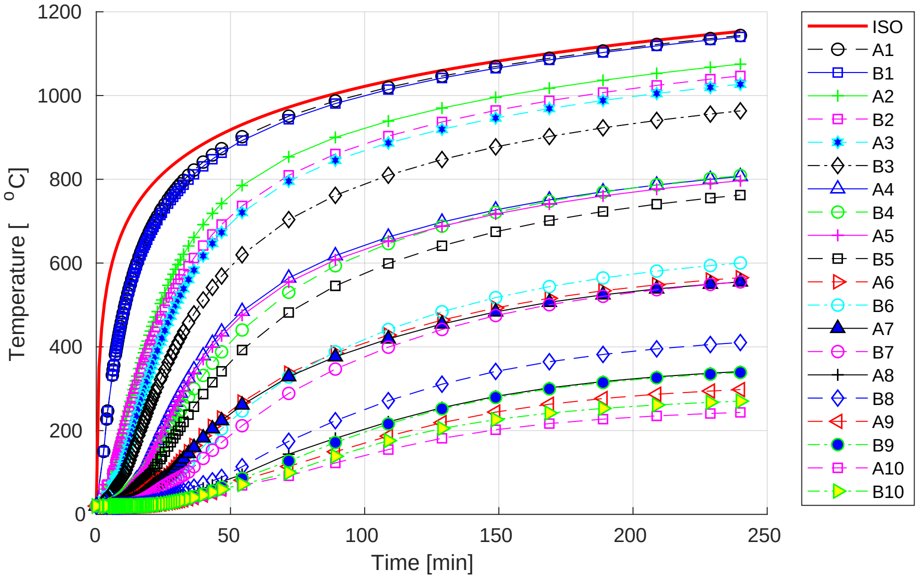


Figure 4: Temperature distribution as function of time for the geometry 02.

Nodal temperatures for the face that is not exposed to fire are also shown in Table 2.

Table 2: Nodal temperatures as function of time. All temperatures are in °C.

Time	No coat.		One-side		Both-sides	
[min]	A8	B8	A9	B9	A10	B10
30	73	73	41	41	29	30
60	159	178	124	123	76	80
90	205	235	179	201	125	142
120	224	260	207	237	171	194
180	238	279	228	264	223	248
240	246	289	236	275	243	270

For the case that we have no coating the temperature reached was 289 °C. When there was coating at one side the temperature reached was 275 °C, representing a reduction of 4.84% compared to the worst case, case in which there was no coating. Finally, in the case with coating on both sides the temperature reached was 270 °C, representing a reduction of 6.57% compared to the worst case.

4.3 Geometry 03

The third geometry, denominated geometry 03, has a percentage of empty spaces of 65.38%. For this geometry were considered four, five and six nodes for the cases in which the block has no coating, has coating in one side and has coating in both sides, respectively. The nodes are used for evaluating the temperature distribution as a function of time. Figure 5 shows the temperature distribution for the case in which the block has coating in both sides. The fire distribution is in accordance to the ISO standard [4] and shown in red in the same figure.

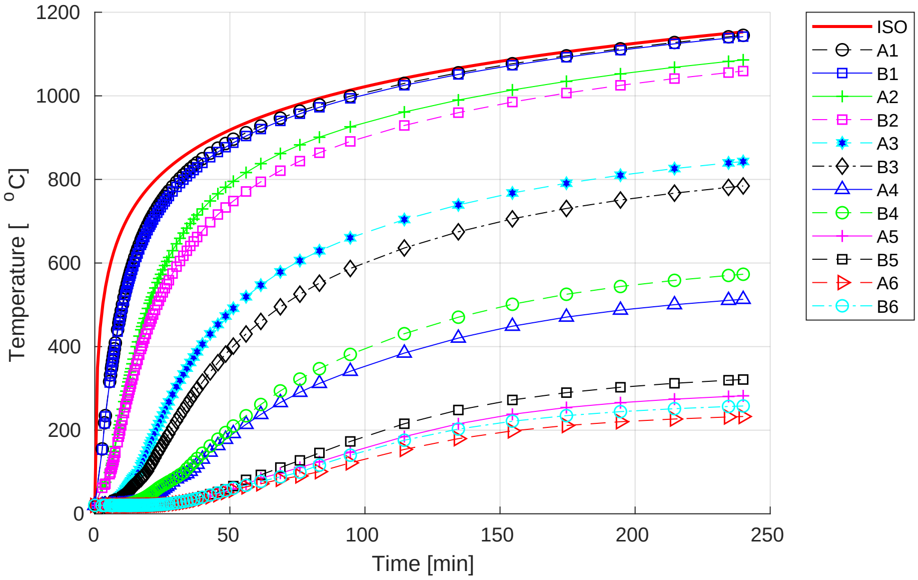


Figure 5: Temperature distribution as function of time for the geometry 03.

Nodal temperatures for the face that is not exposed to fire are also shown in Table 3.

Table 3: Nodal temperatures as function of time. All temperatures are in °C.

Time	No coat.		One-side		Both-sides	
[min]	A4	B4	A5	B5	A6	B6
30	56	63	32	35	24	26
60	145	165	102	117	69	74
90	189	220	165	189	114	132
120	207	244	192	223	162	184
180	221	262	212	249	214	238
240	229	271	220	260	232	257

For the case that we have no coating the temperature reached was 271 °C. When there was coating at one side the temperature reached was 260 °C, representing a reduction of 4.06% compared to the worst case, case in which there was no coating. Finally, in the case with coating on both sides the temperature reached was 257 ºC, representing a reduction of 5.17% compared to the worst case.

4.4 Geometry 04

The forth geometry, denominated geometry 04, has a percentage of empty spaces of 52.64%. For this geometry were considered six, seven and eight nodes for the cases in which the block has no coating, has coating in one side and has coating in both sides, respectively. The nodes are used for evaluating the temperature distribution as a function of time. Figure 6 shows the temperature distribution for the case in which the block has coating in both sides. The fire distribution is in accordance to the ISO standard [4] and shown in red in the same figure.

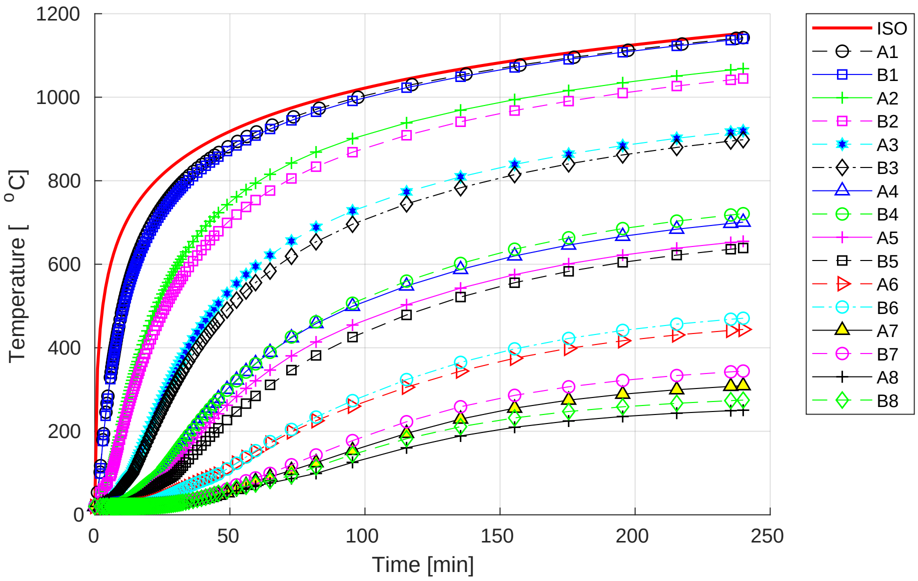


Figure 6: Temperature distribution as function of time for the geometry 04.

Nodal temperatures for the face that is not exposed to fire are also shown in Table 4.

Table 4: Nodal temperatures as function of time. All temperatures are in ºC.

Time	No coat.		One-side		Both-sides	
[min]	A6	B6	A7	B7	A8	B8
30	56	63	32	35	24	26
60	147	166	98	112	68	74
90	203	231	172	193	115	133
120	228	260	207	234	166	188
180	247	283	234	266	227	249
240	256	293	245	278	250	274

For the case that we have no coating the temperature reached was 293 ^{o}C. When there was coating at one side the temperature reached was 278 ^{o}C, representing a reduction of 5.12% compared to the worst case, case in which there was no coating. Finally, in the case with coating on both sides the temperature reached was 274 ^{o}C, representing a reduction of 6.48% compared to the worst case.

5 CONCLUSIONS

In the present work, the dependence on the thermal behavior was accounted using FEM and the commercial software ABAQUS. The block interior voids were simplified by considering them as solid elements with air properties, in that manner, conduction was considered for void representation. The following conclusions can be mentioned about block thermal response:

- The geometry 03 (voided walls) was the best in terms of thermal behaviour, due to the high percentage of empty spaces (65.38%).
- The geometry 03 without coating represented a reduction of 11.07 % in terms of temperature, compared to geometry 01 without coating.
- The geometry 04 was the worst in terms of thermal behaviour, this could be related to its low percentage of empty spaces (52.64 %).

Finally, The air mass plays an excellent insulating function, however, the overall result depends also on the percentage of empty spaces and their distribution along the block. Better results are expected if the voids are represented by fluid elements, nonetheless, this kind of analysis could be highly computationally demanding. In this way, the present work exposes a good starting point for design purposes when dealing with blocks at high temperatures.

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