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Influence of pores on the failure of structural ceramic blocks

Carlos E.F. Villar *, Ricardo E.F.Q. Nogueira, Luis A.M. Carvalho, Hamilton F.G. Abreu

Universidade Federal do Ceará, Engenharia Mecânica e de Produção, Rua Vilebaldo Aguiar 1160 apto 202, 60190-780 Fortaleza, CE, Brazil

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Abstract

The main goal of this work is to investigate the features of pores of structural ceramic blocks which determine their process of failure under compression. Eighteen ceramic blocks were subjected to compression up to failure. Samples were removed from specific blocks according to the results of the compression tests in order to characterize their microstructure. Investigation of microstructure was carried out by means of optical and scanning electron microscopy. Analyzing the results it was possible to identify the existence of a basic relationship between shape, distribution and alignment of pores present in the microstructure and the process of failure under compression.

Keywords: Structural masonry; Blocks; Pores; Microstructure; Compression; Ceramic

1. Introduction

Structural masonry is a sort of structure in which the walls are the supporting elements and are, also capable of resisting to other solicitations beyond their self weight [1]. The walls are composed by modular basics units, or blocks, which are joined by mortar joints [2]. The blocks are usually made of concrete or ceramics. They are responsible for about 80% of the total volume of wall and play a fundamental role in the wall strength [3]. The mortar has the function of correct the irregularities of block's surface and joins then [4]. It also has to transmit and to distribute stresses and to absorb small deformations [2].

Compression loads are preponderant in structural masonry buildings, making it very important to understand the block's behavior when it is subjected to this sort of loading.

Structural masonry is a composed material, non-homogeneous and anisotropic, in which, materials with different elastic features are joined together, resulting in a particular behavior [4]. Precise and detailed determination of microstructure is fundamental to the characterization of composition, structure and properties of any material [5].

Properties of ceramic materials are significantly influenced by their microstructure. Some of the features that contribute to the strength, and practically all of the features that initiate mechanical failure, can be identified through the study of the microstructure [6].

An important fact in the study of ceramic materials is that their properties are determined not only by the composition and structure of the phases present but also by the arrangement of these phases. Phase distribution or microstructure in the final products depends on the fabrication techniques, raw materials used, phase-equilibrium relationships, grain growth and firing burning process [6].

Some authors consider porosity as a phase, which is almost always present in ceramic materials [6]. Porosity can occur in a great diversity of sizes, shapes and distributions. The characteristics of porosities are determinant to the failure process of a material since it is from the pores that the nucleation and propagation of cracks starts.

2. Materials and methods

Eighteen structural hollow ceramic blocks (dimensions of $14 \times 29 \times 19$ cm, as illustrated in Fig. 1) were investigated.

* Corresponding author. Tel.: +55 85 32627760; fax: +55 85 32443939.
E-mail address: cefvillar@yahoo.com (C.E.F. Villar).

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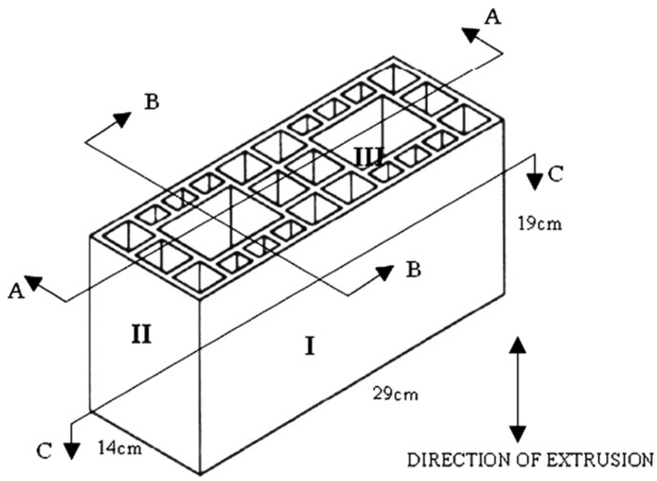

Fig. 1. Scheme used to remove the samples.

Table 1
Failure load obtained to the blocks

Block N°	Width (mm)	Height (mm)	Length (mm)	Failure load (kN)
0	135.9	190.0	285.9	810
1	135.8	189.3	282.5	575
2	135.1	188.5	281.5	560
3	136.4	191.0	285.5	570
4	136.1	190.0	281.5	555
5	134.8	189.5	279.0	840
6	136.3	190.0	282.5	510
7	135.3	188.8	283.8	370
8	136.2	190.0	285.5	535
9	135.8	190.5	284.0	625
10	135.6	188.5	283.0	530
11	136.9	190.3	285.5	530
12	137.5	191.0	288.0	465
13	137.0	188.7	284.3	625
14	136.7	189.5	284.6	410
15	136.8	189.3	285.2	390
16	135.8	188.0	284.2	640
17	135.6	189.0	283.2	475
Mean	136.1	189.5	283.9	556

They came from the same batch and were made in a factory of structural ceramic blocks localized in Jaguaruana, Ceará State - Brazil. The blocks were subjected to compression along the direction of the holes, up to failure, in a hydraulic machine VEB-Werkstoffprüfmaschinen-Leipzig, model 265/6 (maximum load 3000 kN). The tests were done according to the brazilian standard NBR 7184 [7]. Use of a sulfur cap ensured the flatness of the surface to which the load was applied.

Samples removed from three different blocks after the compression tests were used for observation of pores of the microstructure. The blocks chosen for the removal of samples were:

- Block 5 - exhibited the highest compression strength;
- Block 7 - exhibited the lowest compression strength;
- Block 2 - exhibited intermediate compression strength.

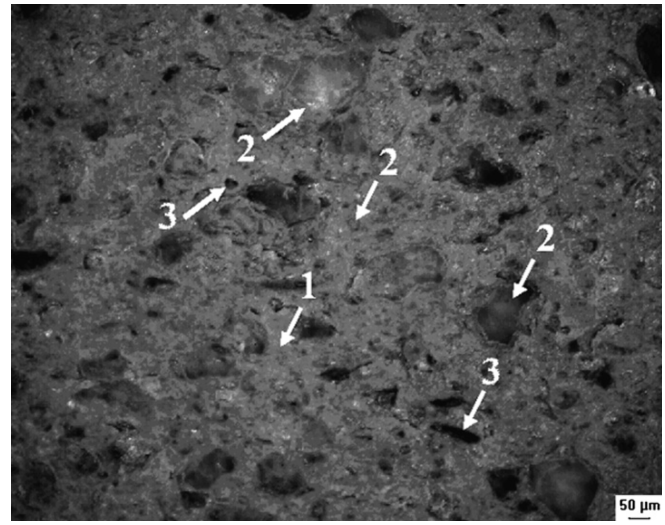

Fig. 2. Micrograph of block 7, section A–A in dark field (100×) showing: a matrix (1) silica inclusions of various sizes (2) and a little amount of pores without a preferential orientation (3).

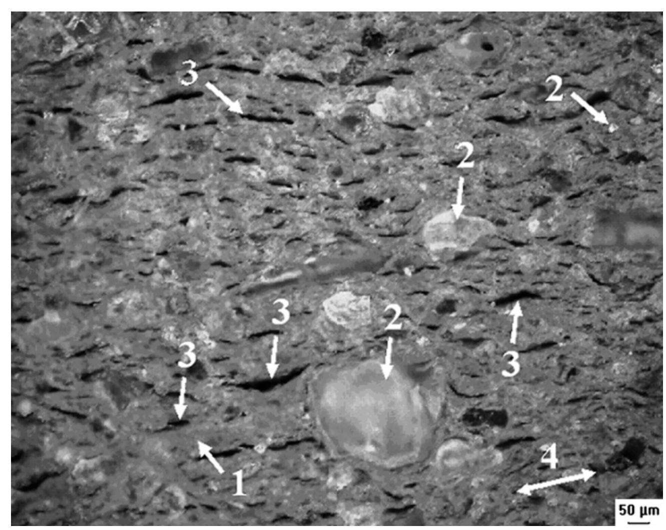

Fig. 3. Micrograph of block 7, section B–B in dark field (100×) showing: a matrix (1) silica inclusions of various sizes (2) and a great amount of elongated pores (3) along the direction of extrusion of the block (4).

Three samples were removed from each selected block according to the three directions shown in Fig. 1, as follows:

- Section A–A: Samples were taken along AA in order to investigate a plane parallel to face I, i.e., parallel to the direction of extrusion;
- Section B–B: Samples were taken along BB in order to investigate a plane parallel to face II, i.e., parallel to the direction of extrusion;
- Section C–C: Samples were taken along CC in order to investigate a plane parallel to face III, i.e., perpendicular to the direction of extrusion.

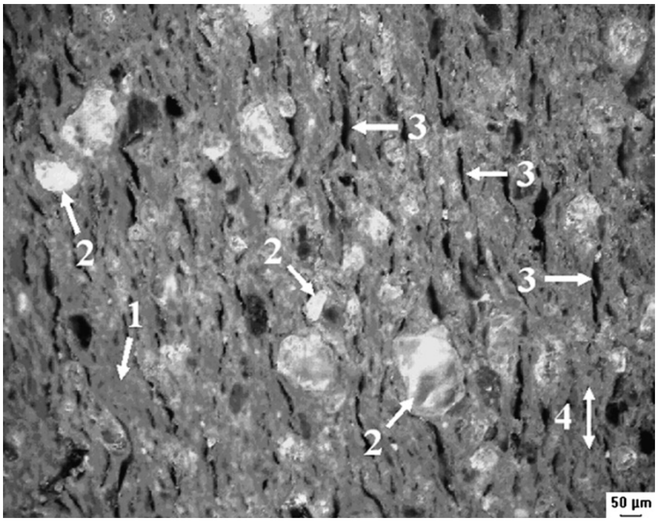

Fig. 4. Micrograph of block 7, section C–C in dark field (100×) showing: a matrix (1) silica inclusions of various sizes (2) and a great amount of elongated pores (3) along the direction of extrusion of the block (4).

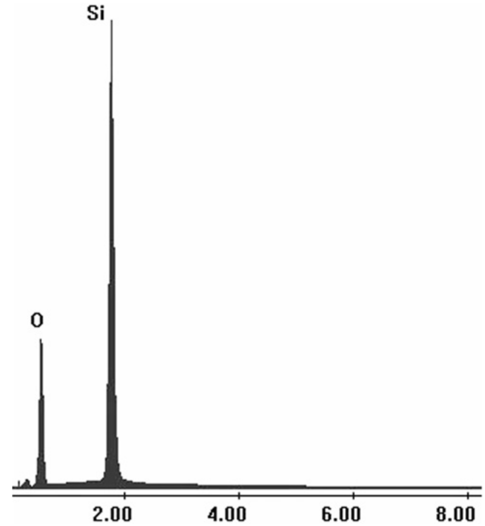

Fig. 6. EDS spectrum of the inclusions in blocks 2, 5 and 7.

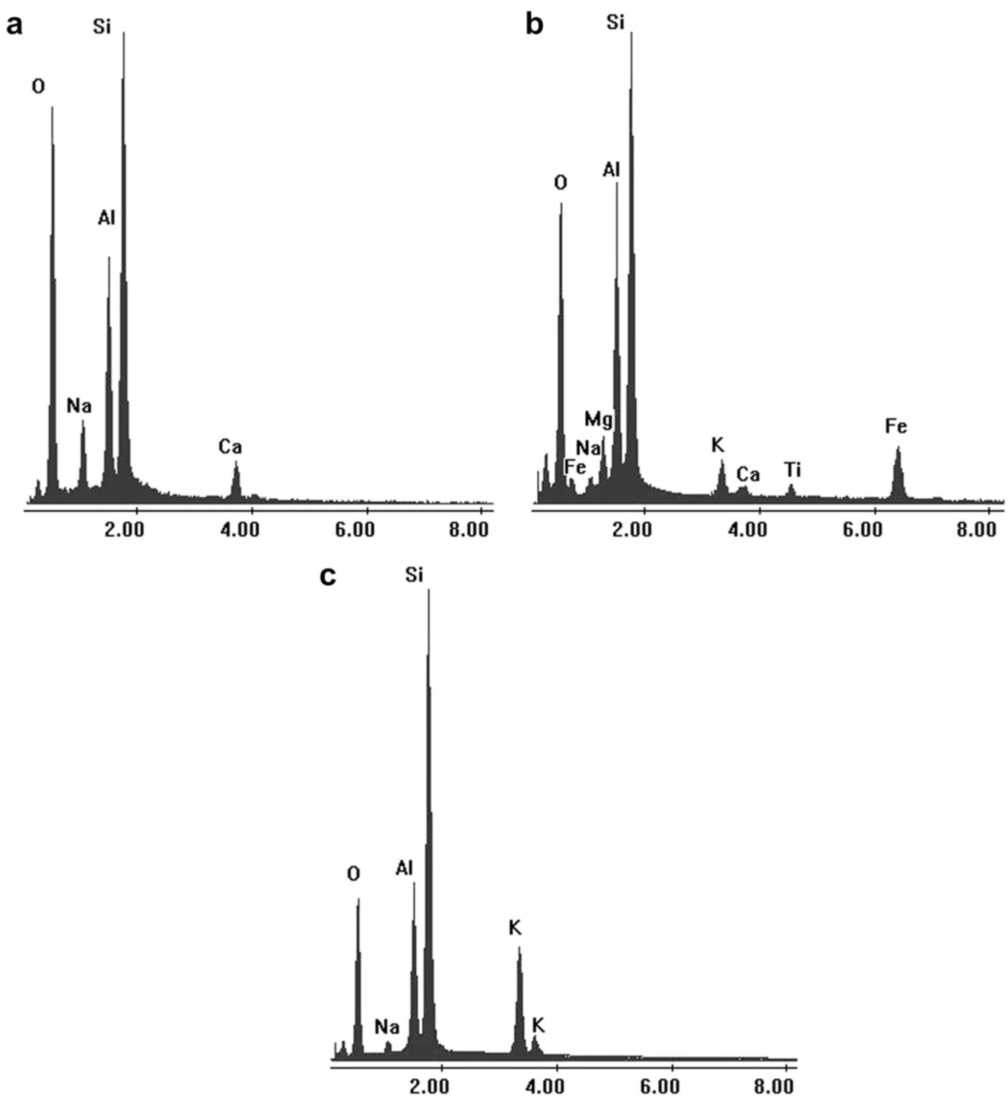

Fig. 5. EDS spectrum of the matrix of three different blocks. (a) Block 2; (b) Block 5; (c) Block 7.

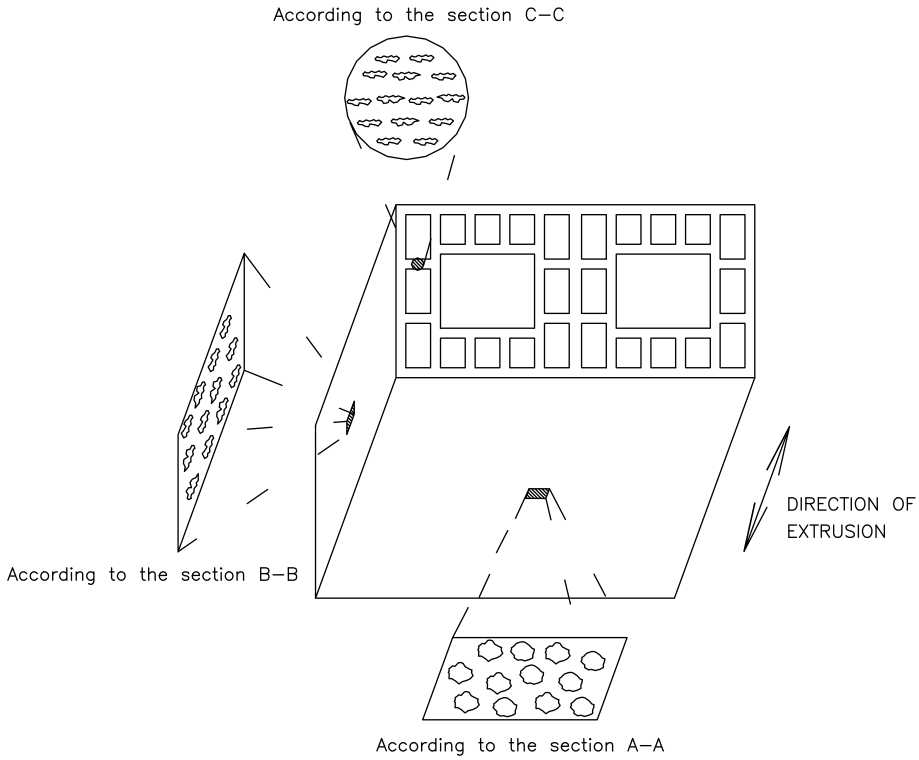

Fig. 7. Schematic representation of the distribution of pores in the blocks according to the sections A–A, B–B and C–C.

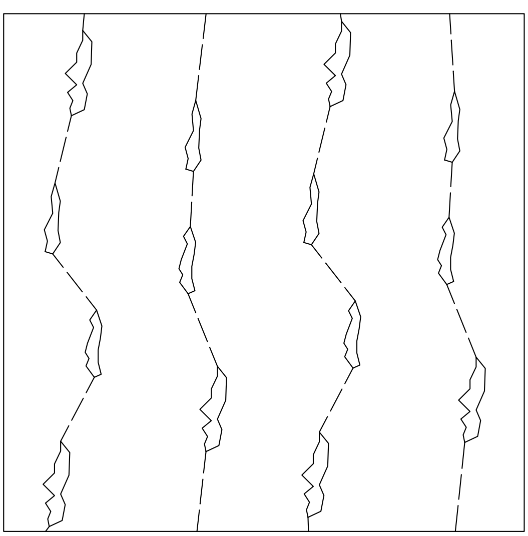

Fig. 8. Scheme of nucleation and propagation of the cracks between pores.

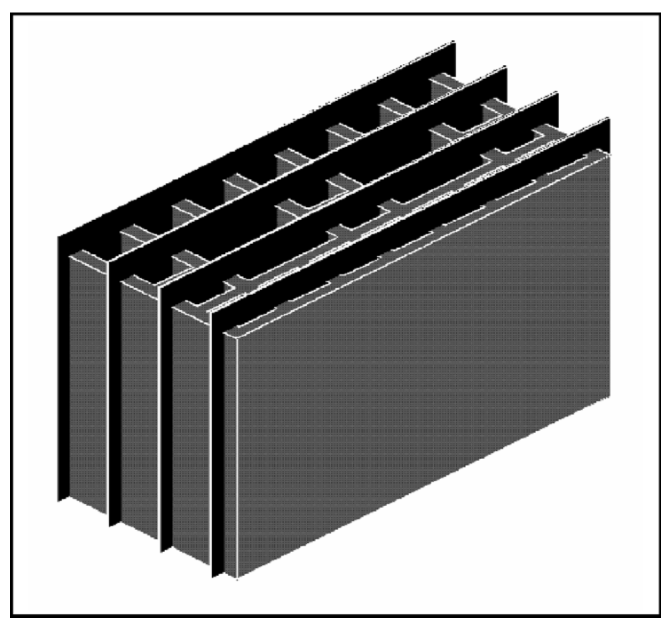

Fig. 9. Theoretical scheme proposed for the formation of failure planes.

Each sample was prepared by mounting in bakelite and then grinding for 5 min in each of a series of SiC abrasive papers (220, 320 and 600) [8]. Chemical etching was not necessary because the present phases could be fully revealed in an optical microscope after grinding. Observations were made using an optical microscope Olympus BX51 M equipped with a camera (Evolution LC Color model PL-A662) for the image capture.

Determination of chemical composition of specific points of the samples was realized by energy dispersion spectrometry (EDS) analysis in tandem with a scanning electron microscope Philips XL-30, in order to identify the phases present in the blocks.

3. Results and discussion

Results of compression tests are shown in Table 1. The blocks presented a mean failure load of 556 kN and a standard deviation of 125 kN.

Figs. 2–4 are micrographs of block 7 which show the general features of pores, observed in all the analyzed samples. Micrographs done for the sections B–B and C–C (Figs. 3 and 4), reveal the existence of a matrix where the presence of O, Si, Al, Na, Ca, Mg, Fe, Ti and K was detected. Elongated pores aligned to the direction of extrusion and some silica inclusions dispersed along the matrix are also observed. Fig. 5 shows the EDS results for the matrix. Fig. 6 presents EDS spectrum (spectra were similar for blocks 2, 5 and 7) for the inclusions, confirming that they are basically silica.

The micrograph of the section A–A, Fig. 2, shows the existence of the matrix, a great amount of silica grains (inclusions) and only a few pores. In fact, it could be verified, according to the observations of the sections B–B and C–C, that in section A–A, the samples were removed parallel to the pores. The pores, therefore are very flat and, when visualized by this angle, could not be identified easily, since they are being sectioned longitudinally. Fig. 7 shows schematically, the distribution of pores in the blocks.

According to the shape, distribution and alignment of pores observed, when the blocks are subjected to compressive forces, the region between pores is submitted to a stress concentration, nucleating cracks that join the pores, as illustrated in Fig. 8, contributing to the formation of a series of preferential parallel failure planes along the direction of extrusion. In Fig. 9, a theoretical scheme is proposed to explain the formation of these failure planes. In fact, during the compression test it was possible to verify that the blocks failed as a consequence of the formation of big vertical cracks, which can be seen in Fig. 10.

When the block is built into a wall subjected to compression, stresses will be transmitted through the components of the wall by different modes. The mortar has a much lower elastic modulus than the block. Due to this behavior, when block and mortar work together, under compression, the mortar suffers more deformation than the block and in a wall, composed by blocks and mortar, the actions on components will occur according to the scheme shown in Fig. 11 [3]. It can be seen that the block is subjected to a tension stress perpendicular (σ_{xb}) to the preferential planes of failure proposed, enhancing the separation between then and consequently the failure of the block. Therefore, the formation of preferential planes of failure due to the shape, distribution and alignment of pores are determinant to the failure process of structural ceramic blocks investigated.

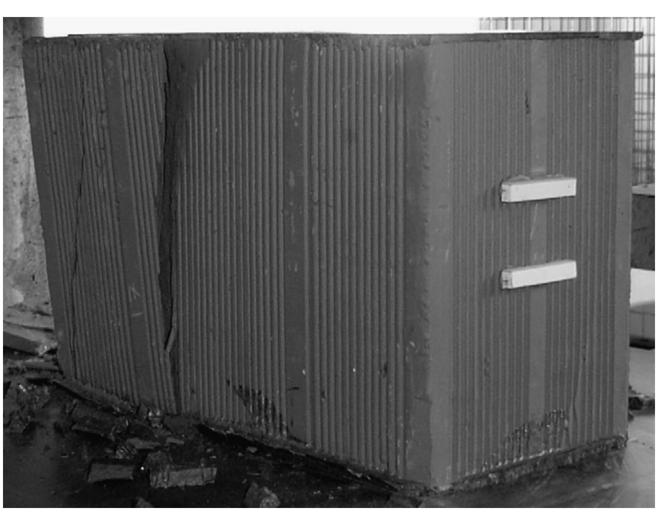

Fig. 10. Single block failure under compression. Failure occurred according to a vertical plane through the separation of "layers".

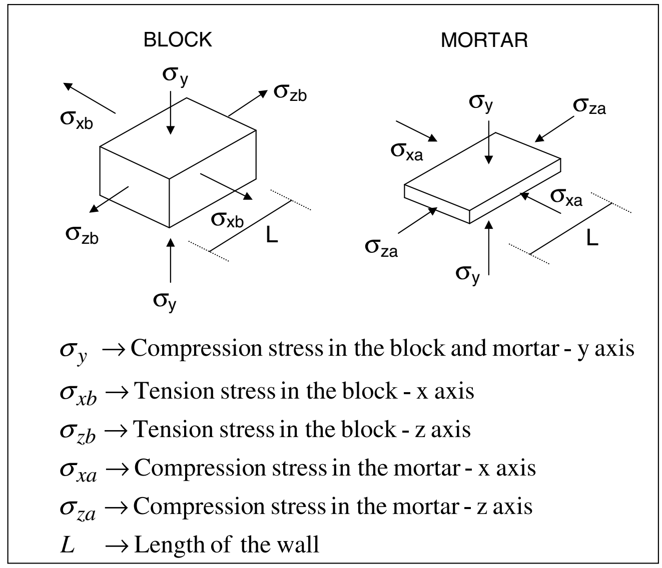

Fig. 11. Scheme for stress distribution in block and mortar on a portion of a compressed wall.

4. Conclusions

The microstructure of the structural ceramic blocks investigated was composed of:

- Flattened pores oriented according to the direction of extrusion;
- A matrix where the presence of O, Si, Al, Na, Ca, Mg, Fe, Ti and K was detected;
- Inclusions of various sizes composed mainly of O and Si.

Shape, distribution and alignment of pores contribute to the formation of a series of preferential parallel failure planes along the direction of extrusion, when the blocks are subjected to compression.

Failure of the blocks occurs due to the separation of layers or planes that were formed along the height of the blocks and in the direction of extrusion.

Formation of preferential planes of failure due to the shape, distribution and alignment of pores are determinant to the failure process of structural ceramic blocks investigated.

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