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STRENGTH AND DEFORMABILITY OF HOLLOW CONCRETE BLOCKS AND THEIR CORRELATIONS WITH MECHANICAL PROPERTIES OF CONSTITUENT MATERIAL

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ABSTRACT

This paper deals with the correlations between the mechanical properties of hollow blocks and the concrete utilized in their production. Hollow blocks and test samples of different types and sizes were simultaneously cast with concrete having the same plastic consistency. Plastic consistency of concrete was used to assure the same characteristics in the blocks and test samples. Three different concrete strengths were defined to correlate the mechanical properties in compression and tension tests. In addition, two and three blocks high prisms without typical mortar joints were tested in axial compression. In these cases, the prisms were constructed with full blocks mortared together with a thin epoxy resin layer in the bed joints. Axial compression tests on blocks and prisms showed non-uniform stress and strain distribution in the mean cross section of these specimens. Even in the case of two and three blocks high prisms, a non-uniform distribution of strains was clearly observed. The influence of the platen effect was observed. It was also observed that geometry and slenderness of the tested specimens also influence the compressive strength correlation of cylindrical samples, blocks and prisms. Even minimizing the mortar joint effect on prisms, the relationship between prism and sample compressive strength reduced when increasing the height of the tested element.

KEYWORDS: Hollow concrete blocks, strength, deformability, properties of constituent materials.

INTRODUCTION

Despite the scientific evolution of structural masonry technology in recent years, the design methods and structural safety analysis are still based on empirical data. For example, the Allowable Stress Method is until now adopted by many design codes such as the Brazilian code for masonry structures,.

The current knowledge in some countries, does not clearly establish a group of strength and deformation parameters and their respective weighting and safety coefficients for a Limit State analysis. It is necessary to go forward detailing the factors that are related to the material's properties, to the unit production methods, to the construction procedures and quality control and to the assemblage behaviour.

To apply the concept of Limit States or other improved probabilistic methods, it is necessary to isolate and to have better knowledge of each parameter that influences the structural behaviour at service and ultimate stages. However, there are a number of challenges to be overcome, especially because many of these parameters are derived from tests and the test conditions are not unique. Block geometry is different from case to case, concrete mechanical properties inside the units are not characterized, confinement effects in block and prism tests are variable, steel plate stiffness affects the stress distribution in the tests, influence of mortar involves complex phenomena, etc.

Several researchers have reported work on numerical models for masonry structures, such as micro modelling (that details 3D blocks) of the masonry elements. Nevertheless, the theoretical methods usually assume constitutive equations or mechanical properties obtained from standardized tests of concrete samples. This assumption does not correspond to reality, because both concrete block and mortar are moulded and cured in different conditions. Various researchers have tried to determine the mechanical properties of concrete inside the block by extracting samples from them. However, this is not an easy method and some uncertainties may appear due to the small dimensions of the samples.

This paper reports a preliminary analysis of the correlations between the mechanical properties of concrete and the structural behaviour of hollow concrete blocks and prisms. Instead of analyzing blocks with unknown concrete properties, plastic consistency concrete was utilized to cast hollow blocks and test samples to assure the same material properties. Three concrete strengths were defined to simulate distinct deformability conditions.

The next steps of this ongoing research are to execute a new test series and to calibrate theoretical models for direct and reverse analyses. The preliminary results were obtained by Barbosa [1] in an MSc. research program.

MECHANICAL PROPERTIES OF CONCRETE BLOCKS AND SAMPLES

Several factors affect the compressive strength test results of masonry units, especially the confinement effect that changes significantly the strength of similar elements. Hendry compares test results of bricks and blocks made of the same material and tested under the same conditions [2]. Different strength values were observed since bricks have a more favourable geometric configuration looking at the platen effect in the test, which justifies that the external dimensions directly influence the behaviour of the unit.

The restriction caused by the test platens produces transversal confinement stresses that introduce a triaxial stress state in the block and consequently a higher compressive strength. So the compressive strength is related to block geometric characteristics like the aspect ratio – relationship between the height and thickness of the element. This means that increasing the block height and keeping constant the other dimensions, smaller compressive strength is to be expected.

Compressive strength obviously is the most important masonry parameter, because compression forces are the main actions in these kinds of structures. However, Medeiros, like other authors, emphasizes the importance of tensile strength of blocks, because the main structural limitations in masonry construction are caused by the tensile stresses [4].

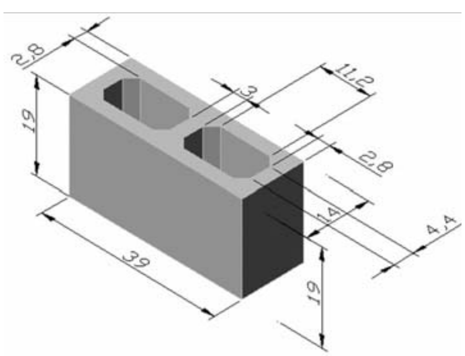
Usually, tests with three elements – blocks, prisms and walls – define the compressive strength of the masonry walls. However, the structural behaviour of prisms and walls is very different from that observed in isolated unit tests. Slenderness of prisms and walls and the presence of mortar joints change the failure mode and the average strength. Because of this, mechanical properties of masonry are related directly to the tested element (block, prism or wall), not to the properties of the constituent materials (concrete, mortar).

In numerical micro modelling, it is meaningful to have a closer evaluation of the mechanical properties of masonry constituent materials, e.g. concrete and mortar. Considering these factors, Hamid and Chukwunenye [5] conducted numerical simulations on prisms in which the block modulus of elasticity was obtained by tests on samples extracted from the concrete blocks tested by Becica and Harris [6]. Also Hawk et al [7] and Ganzerli et al [8] tested samples extracted from the hollow concrete blocks. Marzahn [9] extracted cylindrical samples from solid calcium silicate and concrete autoclaved aerated blocks.

Frasson Junior [10] tested cylindrical samples (5 x 10 cm) of no slump concrete used to manufacture hollow concrete blocks. The strength of the moulded sample was lower than of the blocks, based on the net area, and no detailed analysis was made about the results. Nevertheless, the main goal of this research was the development of a methodology for mixture design and production control in concrete block production plants.

PREPARATION OF HOLLOW CONCRETE BLOCKS

The typical hollow concrete block is 140 x 190 x 390 mm (width x height x length), with gross area 546 cm^2 and net area 306.63 cm^2 (Figure 1a). Series of blocks were moulded with plastic consistency of concrete and three concrete strengths were defined (about 17, 20 and 40 MPa). Steel moulds were utilized for production of the concrete blocks. Internal cores were provided by two EPS (Expanded Polystyrene) blocks fixed to the steel mould, as illustrated in Figure 1. The EPS units were extracted after 7 days.



(a)

(b)

Figure 1 – Block geometry (a) and steel mould utilized for production (b).

The two and three block high prisms, without typical mortar joint, were obtained from full blocks “mortared” together with a thin layer of epoxy resin. The goal of this arrangement was to simulate a variation of the height of a block, i.e., the prism was equivalent to a higher block. From another point of view, the prism should be seen as a "perfect" prism, with no influence of mortar (Figure 2).

(a) **(b)**

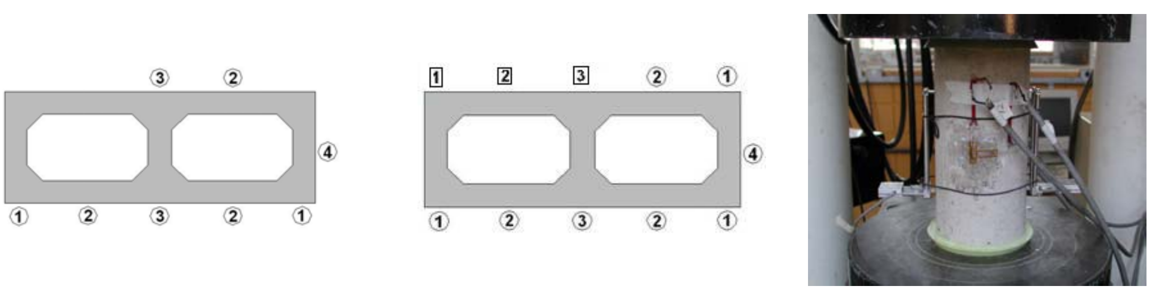
Figure 2 – Hollow concrete block with a thin layer fully bedded (a) and a prism with two blocks (b).

AXIAL COMPRESSION TESTS

Hollow concrete blocks, prisms and samples were submitted to axial compression force in a servo-hydraulic machine and tested in the linearly controlled displacement mode. The controlled displacement mode allows the acquisition of the stress-strain diagram, including its descending or softening branch.

The distribution of the applied force was made by means of 25 mm thickness rectangular steel platens (394 mm x 194 mm). On the top, the contact of this platen with the loading system was a 294 mm diameter rigid steel cylinder. On the base, the platen was fixed to a very rigid steel block. The platen dimensions fulfill the recommendations of Atkinson (1991) and the Brazilian codes. Every sample or block was capped with a thin sulphur layer.

Eight displacement transducers (base length = 100 mm) were positioned on the blocks along vertical reference lines to measure the average strain. In case of prisms, three additional mechanical extensometers were provided. Strain measurement in concrete samples was carried out with two displacement transducers. Locations of measurement lines are shown in Figure 3 (blocks and prisms). For example, reference line 2 locates a transducer that is located on the main face of the block, at the middle of the hollow cell.



(a) **(b)** **(c)**

Figure 3 – Locations of instruments to measure de longitudinal deformations in a block (a), prism (b) and a cylinder (c).

During the compression tests on blocks, cracks appeared typically at about 80% of the ultimate load, in a horizontal direction along the larger face of the blocks. These cracks appeared to be of crushing type and they were succeeded by progressive spalling. Internally to the block, the critical cracks proceeded along an inclined plane, towards the transversal webs.

The failure mode of the blocks can be characterized as diagonal shear (Figure 4a). This failure mode occurred due to the particular block geometry and the relationship between width and height, resulting in a significant confinement effect derived from the platen action.

The failure mode of cylindrical specimens, illustrated in Figure 4c, also can be characterized as diagonal shear.

In the prisms, the first crack appeared between 50% and 60% of the maximum force. The first crack was usually vertical and located on the larger face of the block, near the central web and the joint between blocks. The initial length of these cracks was not larger than 50 mm. Further on in the test, the crack length and opening tended to be enlarged. At the same time, new cracks showed up in the larger face of the block, always in the same direction or smoothly inclined.

The cracking configuration in prisms is shown in Figure 4b. The prism failure occurred by vertical cracking, started and intensified on the block face shells and sometimes on the transversal webs. On the transversal webs, cracking tends to split the face as it can be seen on Figure 4b. Cracking of the webs occurred at loading stages near to collapse, when the progressive loss of stiffness of the face shells takes place.

(a) (b) (c)

Figure 4 – Failure modes for elements under compression tests.

The mechanical properties of the blocks and samples obtained in the axial compressive tests are summarized in Table 1.

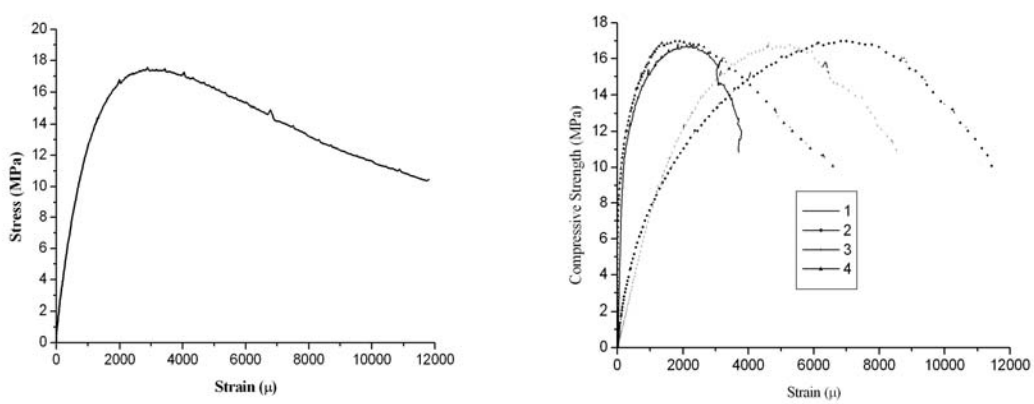
It can be noticed that strains were not uniform along the main face and webs of the block. Larger strain values were observed near the hollow cells, i.e., at the block main face approximately at the middle of the cell (reference lines 2, as shown in Figure 3). The points in the central web (reference lines 3) presented a little lower strains, but the lowest strains were observed at the lateral webs (reference lines 1 and 4).

Figure 5 presents stress-strain diagrams for cylindrical samples and blocks in case of Series B-1 (concrete strength about 17 MPa). It must be pointed out that the represented stress corresponds to the average stress in the net area. Figure 6 illustrates the strain variation along the face shell and webs of the block, in case of Series B-1. Strain curves are presented for five levels of average stress in the net area, where σ_u represents the maximum stress obtained in tests. Diagrams related to Series B-2 and B-3 were similar in shape.

Table 1 – Mechanical properties of blocks and samples

Series	Sample				Block		f_{bm}/f_{cm}
	f_{cm}[1] (MPa)	$f_{ct,sp}$[2] (MPa)	E_c[3] (MPa)	f_{bm}[4] (MPa)	Line[5]	ε (0,4 σ_u)[6]	
B-1	17.3 (2.51 ksi)	1.8 (0.26 ksi)	16,199 (2,349 ksi)	16.8 (2.44 ksi)	1	104	0.97
					2	821	
					3	917	
					4	138	
B-2	20.4 (2.96 ksi)	2.1 (0.3 ksi)	19,407 (2,815 ksi)	19.8 (2.87 ksi)	1	118	0.97
					2	834	
					3	1059	
					4	219	
B-3	41.5 (6.02 ksi)	3.3 (0.48 ksi)	25,484 (3,696 ksi)	35.7 (5.18 ksi)	1	173	0.86
					2	1094	
					3	919	
					4	187	

Notes:
[1] Average concrete compressive strength (cylinder 100 mm x 200 mm)
[2] Average concrete tensile strength (split test)
[3] Modulus of elasticity of concrete
[4] Average block compressive strength (net area)
[5] Location of measurement reference lines (as Figure 3)
[6] Average strain along reference lines, at 40% ultimate load



(a) **(b)**

Figure 5 – Stress-strain diagrams of cylinder (a) and block (b) – Series B-1

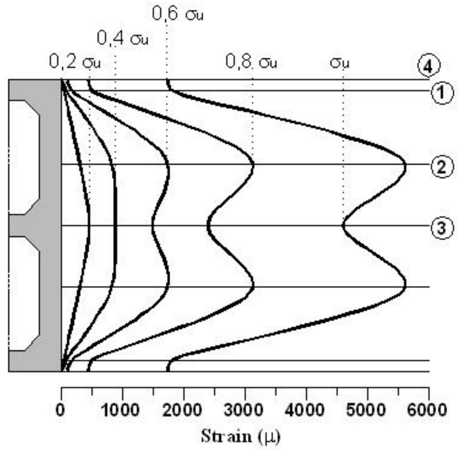


Figure 6 – Strain variation along the face shell and webs – Series B-1

It can be concluded from the analysis of Figure 6 that stress and strain distribution in the block is affected by several factors. These factors are mainly related to the confinement effects (derived from platen stiffness and contact conditions) and block geometry.

The mechanical properties of two and three block high prisms and corresponding cylindrical samples obtained in the axial compressive tests are summarized in Table 2 and Table 3.

Table 2 – Mechanical properties of two blocks high prisms and samples

Series	Sample				Two Blocks High Prisms		f_{p2m}/f_{cm}
	f_{cm}[1] (MPa)	$f_{ct,sp}$[2] (Mpa)	E_c[3] (MPa)	f_{p2m}[4] (MPa)	Line[5]	ε (0,4 σ_u)[6]	
P2-1	15.9 (2.31 ksi)	1.7 (0.25 ksi)	16,847 (2.443 ksi)	13.3 (1,93 ksi)	1	153	0.84
					2	490	
					3	780	
					4	275	
P2-2	20.1 (2.92 ksi)	2.0 (0.29 ksi)	16,974 (2,462 ksi)	18.2 (2,64 ksi)	1	179	0.91
					2	585	
					3	912	
					4	252	
P2-3	37.1 (5.38 ksi)	3.0 (0.4 ksi)	24,961 (3,620 ksi)	26.3 (3,81 ksi)	1	227	0.71
					2	534	
					3	699	
					4	541	

Notes:
[1] Average concrete compressive strength (cylinder 100 mm x 200 mm)
[2] Average concrete tensile strength (split test)
[3] Modulus of elasticity of concrete
[4] Average two block high prism compressive strength (net area)
[5] Location of measurement reference lines (as Figure 3)
[6] Average strain along reference lines, at 40% ultimate load

Table 3 – Mechanical properties of three blocks high prisms and samples

Series	Sample				Three Blocks High Prisms		f_{p3m}/f_{cm}
	f_{cm} [1] (MPa)	$f_{ct,sp}$ [2] (Mpa)	E_c [3] (MPa)	f_{p3m} [4] (MPa)	Line[5]	ε (0,4 σ_u)[6]	
P3-1	13.7 (1.99 ksi)	1.6 (0.23 ksi)	17,424 (2,527 ksi)	7.9 (1.15 ksi)	1	226	0.58
					2	408	
					3	616	
					4	392	
P3-2	20.0 (2.9 ksi)	2.0 (0.29 ksi)	20,861 (3,026 ksi)	14.4 (2.09 ksi)	1	220	0.72
					2	426	
					3	615	
					4	349	
P3-3	34.1 (4.95 ksi)	2.9 (0.42 ksi)	25,770 (3,737 ksi)	20.2 (2.93 ksi)	1	188	0.59
					2	432	
					3	646	
					4	81	

Notes:
[1] Average concrete compressive strength (cylinder 100 mm x 200 mm)
[2] Average concrete tensile strength (split test)
[3] Modulus of elasticity of concrete
[4] Average three block high prism compressive strength (net area)
[5] Location of measurement reference lines (as Figure 3)
[6] Average strain along reference lines, at 40% ultimate load

As can be seen, the relationships between prism strength and sample strength are different from those obtained for isolated blocks. Figure 7 presents a comparison of the observed correlations for blocks and prisms.

$$f_{bm} = 0.6\, f_{cm} + 6.73\ \text{(MPa)}$$

$$f_{p2m} = 0.57\, f_{cm} + 5.28\ \text{(MPa)}$$

$$f_{p3m} = 0.57\, f_{cm} + 1.27\ \text{(MPa)}$$

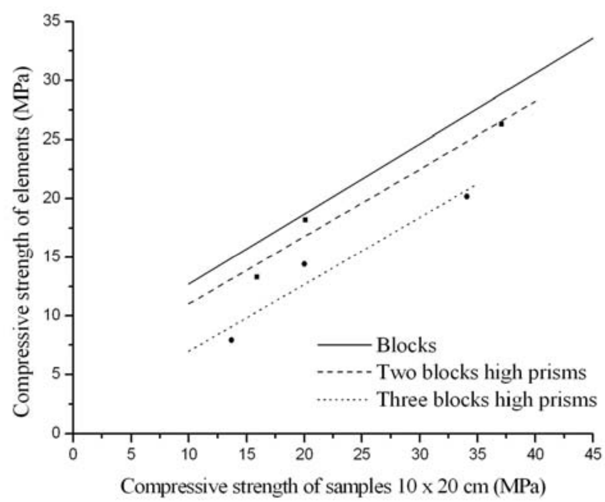
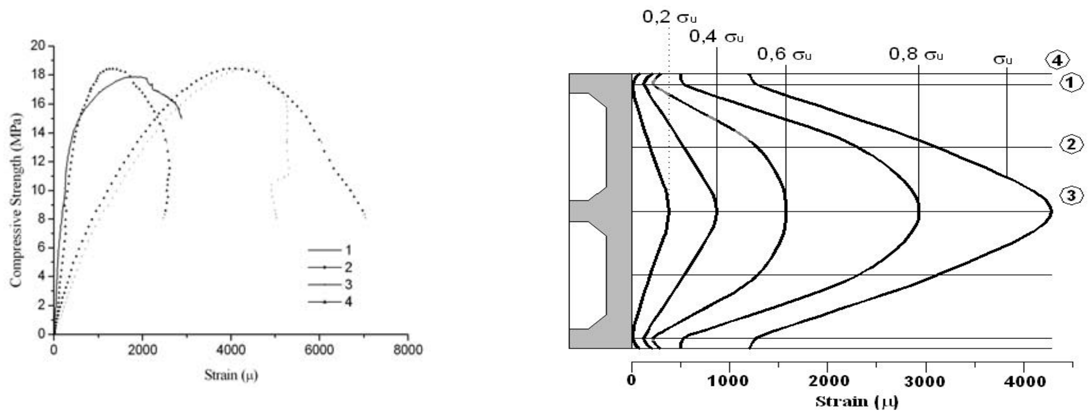


Figure 7 – Correlation of compressive strength of cylinders, blocks and prisms.

The main cause of smaller correlation coefficients in case of prisms is the reduction of the confinement effect due to the test platens and the increasing of the element slenderness.

Figure 8a presents stress-strain diagrams for prisms in case of Series P2-2 (concrete strength about 20 MPa). The represented stress corresponds to the average stress in the net area. Figure 8b illustrates the strain variation along the face shell and webs of the block, in case of Series P2-2. Strain curves are presented for five levels of average stress in the net area and σ_u represents the maximum stress in tests. Diagrams related to the other prism series were similar in shape.



(a) **(b)**

Figure 8 – Stress-strain diagrams (a) and deformation lines (b) for 2 blocks high prisms – Series P2-2.

Like the behaviour of the isolated block, the smallest strains were observed in reference lines 1 and 4. However, strains at the reference lines 3 were observed to be the larger ones, in all loading levels.

CONCLUSIONS

Strain and stress distribution in concrete hollow blocks and prisms is strongly dependant on the block geometry and the confinement conditions in the test. The confinement effect is imposed by the stiffness of the steels platens and the contact conditions between the platens and tested element.

Axial compressive tests on blocks and prisms showed non-uniform stress and strain distribution in the mean cross section of these specimens. Even in the case of two and three blocks high prisms, a non-uniform distribution of strains was clearly observed.

Despite the utilization of steel platens conforming to Brazilian codes and suggested values by Atkinson [11], the influence of the platen effect did not seem to be negligible. Numerical simulations, not presented here, showed that platen deformation contributed to the non-uniformity of loading and therefore the stress distribution. Further studies must be done to eventually revise codes or test recommendations.

Geometry and slenderness of tested specimens also influence the compressive strength correlation of cylindrical samples, blocks and prisms. Even though the mortar joint effect was minimizing in the prisms, the prism compressive strength was reduced compared to the sample strength with increasing height of the tested element.

The failure mode in samples and blocks are similar due to the confinement effect produced by the test platens and was characterized by diagonal shear. Prism failure typically occurred by vertical cracking on the block face shells and webs, and block splitting. This last situation is similar to that observed in block tests with brush platen, without confinement effect.

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