TEST PROCEDURE FOR SHRINKAGE OF CONCRETE BLOCKS

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ABSTRACT

In this paper, methods of testing the drying shrinkage of concrete blocks are evaluated. Tests were done on blocks of differing strengths, suppliers and curing procedures.

The shrinkage tests were carried out as recommended in ASTM C426 [1], using the whole block as specimens and with gauge discs attached to the sides. Three variations of this set-up were also tested: a face-shell prism cut from a whole block with gauge plugs attached to the sides, the same specimen with gauge discs attached to the top and bottom and whole blocks with gauge discs attached to the top and bottom. For the case of gauge discs attached to the sides, a Humboldt strain gauge was used to measure deformation. In the case of gauge discs attached to the top and bottom, a comparator was used. Deformations on control blocks left inside the laboratory, and not submitted to the saturated and dry conditions of the ASTM C426 test, were also measured for nearly 90 days.

The results of the concrete block shrinkage test were influenced very little by the different type of initial three-day cure, althought different shrinkage values were observed in the control blocks for each cure type. With regard to the test procedures, only small differences in results were obtained with whole blocks or face shell-prism, when readings were taken on the sides of the specimen. The use of whole blocks with gauge discs on the top and bottom was revealed to be inadequate. However, it may be possible to use top and bottom gauge discs on face-shell prisms, but more investigation into this test procedure is needed to improve results.

The work is still in progress, with deformation recordings continuing on a series of concrete block walls whose results will be divulged later.

KEYWORDS: Concrete block, shrinkage, moisture movement

INTRODUCTION

Concrete block shrinkage is an important phenomenon that causes most of the movement in concrete masonry. If care is not taken at the design stage, eventual damage is likely to occur.

Drysdale et al. [2] characterize two types of drying shrinkage for concrete blocks, one due to loss of moisture and the other due to carbonation. The first occurs by loss of moisture from the block in the attempt to come to equilibrium with drier surroundings. At lower or higher environmental humidity, the block will shrink or expand reversibly. Carbonation shrinkage occurs because of the reaction between Portland cement and the carbon dioxide present in the air. This type of shrinkage is irreversible and occurs over a long time.

According to ASTM C426 [1], the potential drying shrinkage test for a concrete block consists of measuring the change in size of the specimen due to drying from a saturated condition to an equilibrium condition at 17% relative humidity. Size readings are usually taken on a whole block or half face-shell specimens using gauge discs mounted on the side of the specimens. Alternatively, readings can be taken with gauge discs on the top and bottom of the specimen, usually face-shell specimens cut from a block.

Shrinkage values from 0.2 to 0.5 mm/m for low-pressure steam curing and from 0.1 to 0.4 mm/m for autoclave curing can be expected for dense gravel concrete blocks [2]. It should be noted that autoclave curing for concrete blocks is not common. The Masonry Society Designers Guide [3] indicates that wall-drying shrinkage should never reach these values, since the wall would never be exposed to such extreme conditions. The ACI-530/ASCE-5/TMS-402 [4] code indicates that 15% or 50% of the block test shrinkage should be used for design, depending on whether the blocks are moisture-controlled or not. According to The Masonry Society Designers Guide [3] a carbonation shrinkage equal to 0.25mm/m should be added to the wall-drying shrinkage to obtain total shrinkage.

Bryson & Waststein [5] compared test procedures in 1961, in order to standardize the test used to measure the drying shrinkage of concrete blocks.

These tests were perfomed on concrete blocks made of 5 types of aggregate and two different curing procedures. Four drying conditions were evaluated: RT-50 (23°C and 50% relative humidity), RT-30 (23°C and 30% relative humidity), Modified British (50°C and 17% relative humidity) and Rapid Method (105 to 113°C). Table 1 summarizes the study. The aggregates used were sand and gravel, cinders, expanded blast-furnace slag, expanded shale, and pumice. The nominal dimensions of the blocks tested were 200 x 200 x 400 mm. In addition to whole blocks, they also used face-shell sections and a thin horizontal lamina cut from the block. The authors reached the following main conclusions:

- The shrinkage obtained by the Rapid Method bore no consistent relationship to the values obtained by the RT-50 Method;
- The size of specimen had no important effect on the equilibrium values for autoclaved blocks tested by a given method. However, the average shrinkage of autoclaved blocks did vary from one method to another;
- For the low-pressure curing tested by the RT-50 Method and Modified British Method, the lamina showed the greatest shrinkage values, the half-shell intermediate values and whole block the smallest. In the case of the RT-30 Method, lamina shrinkage was still greater than that of half-shell and of whole block, but the differences were smaller;

- The rate of shrinkage for low-pressure steam-cured blocks was lower in the case of the RT-30 Method than in the RT-50 Method, but final shrinkage values were close;
- In the case of RT-30 Method, the use of lamina significantly reduced the time needed to attain equilibrium;
- Tests of a group of blocks by the RT-30 Method after prolonged storage indoors indicate that shrinkage of low-pressure cured blocks is significantly reduced, whereas shrinkage of autoclaved blocks is apparently unaffected by such storage.

Table 1 - Summary of the Test Conditions Used by Bryson & Waststein [5]

METHOD	RT-50	RT-30	RAPID	MODIFIED BRITISH
INITIAL STATE	SATURATED	SATURATED	SATURATED	SATURATED
DRYING OVEN (°C)	-	-	105 to 113 Initial 48 h Subsequent 24 h	50 ± 1 Initial 5 days Subsequent 24 h
R. H. (%)	50 ± 5	30 ± 5	-	-
COOLING (°C)	23 ± 1.7	23 ± 1.7	23 ± 1.7	23 ± 1.7
AIR-TIGHT DRUMS	NO	NO	YES	YES
COOLING PERIOD FOR EQUILIBRIUM	14 days	14 days	24 hours	48 hours
TEST STOPPED IF CHANGE LESS THAN (MM/M)	0.02	0.02	0.02	0.02

CONCRETE BLOCK POTENTIAL SHRINKAGE TESTS

The main aim of this work was to evaluate the test methods used to assess drying shrinkage of concrete blocks. Tests were done with a series of blocks of three strengths: 4.5, 8.0 and 14.0 MPa, supplied by two different manufactures and subjected to three different 3-day curing conditions: natural, moist, and steam.

The shrinkage tests were carried out in accordance with the ASTM C426 standard, using the whole block with gauge discs attached to each side. In addition, three variations of this set-up were tested: a face-shell prism cut from a whole block with gauge plugs attached to its sides, this same specimen with gauge discs attached to the top and bottom, and whole blocks with gauge discs attached to the top and bottom. For the case of gauge plugs attached to the sides, a Humboldt strain gauge was used for deformation readings. In the case of gauge discs attached to the top and bottom, a comparator was used. The reason for trying to perform top and bottom readings was to minimize operator influence on the test procedure, since specimens are placed inside the 4 indicates all the tests done and results. The Humboldt gauge had a sensitivity of $1x10^{-5}$ mm/mm (0.002mm at a 200mm length) while the comparator had a sensitivity of $0.25x10^{-5}$ mm/mm (0.001mm precision in a length of 390mm)

APPARATUS AND PROCEDURE

Test equipment followed the ASTM C426 [2] and ASTM C490 [6] specifications. A Humboldt multi-length strain gauge set was used for side readings (Figure 1). Figure 2 shows the comparator for top and bottom readings. Figure 3A shows the drying oven used. Specimens were cooled in a closed hermetic metal box (Figure 3B), which was placed in a temperature and humidity controlled room (Figure 3C). The controls of this room (Figure 3D) were set to

23 ± 1 ^{o}C and 50 ± 5 % relative humidity. Figure 4 shows the procedure for mounting gauge discs on the sides. Figure 5 shows the test procedure and Figure 6 shows a half-shell specimen ready to be tested.

Figure 1 - Multi-Length Strain Gauge

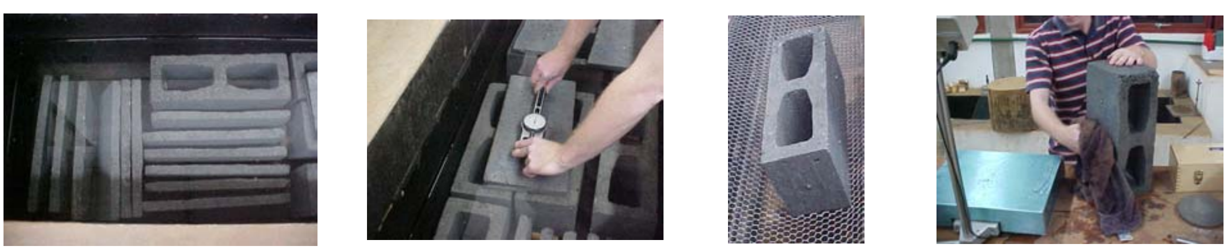
Figure 2 - Comparator For Top Readings

(A) drying oven **(B) cooling chamber** **(C)controlled room** **(D)temperature and humidity controls**

Figure 3 - Test Apparatus

(A) **(B)** **(C)**

Figure 4 - (A) Central Axis Positioning; (B) 200mm Length Gauge Punch Bar; (C) Gauge Plugs Glued With Epoxy



(A) specimens inside water tank **(B) initial saturated reading** **(C) block draining over a steel mesh** **(D) block blotting with damp cloth before weighing**

Figure 5 - Test Procedure

Although the ASTM C426 procedure permits top and bottom gauges, they are not used very often for concrete blocks. Hence, few experiments with this kind of reading have been reported. During the several phases of this study, some care was taken to improve the procedure. The whole-block specimen with top and bottom gauges was shown to be inadequate. Testing a face-shell specimen with top and bottom gauges seems to be adequate if care is taken. Figure 7A shows a gauge disc glued to the top of a whole block and Figure 7B shows a gauge disc on the tops of face-shell specimens.

Figure 6 - Half Face-Shell Specimen With Side Gauge Points

(A) **(B)**

Figure 7 - Gauge Disc Glued To (A) Top of a Whole Block and (B) Tops of Face-Shell Specimens

The main difficulty with this reading procedure was how to get the saturated reading, since placing a comparator in the water did not seem to be a good idea. The procedure established was to remove the specimens from water, to dry only the gauge points (Figure 8) and to place the specimens in the comparator (Figure 9) as quickly as possible. Readings were taken with water still draining from specimens. After these precautions, tests on this type of specimem gave consistent results, but the shrinkage values were greater than those obtained with side gauges. This difference may have occurred because of the high face-shell length-to-width ratio (390 to 25 mm) that may have caused specimen bending. Further tests with shorter specimens are needed.

Deformations on control blocks left inside the laboratory, and not submitted to the saturated and dry conditions of the ASTM C426 test, were also measured for nearly 90 days.

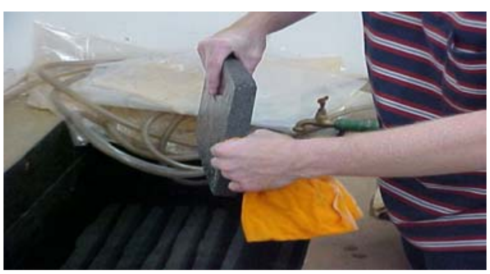


Figure 8 - Top Gauge Blotting Only

(A) **(B)**

Figure 9 - Comparator Reading of (A) Whole Block and (B) Face-Shell Specimen

CURING CONDITIONS AND SUPPLIERS

In this test program, blocks were supplied from two very different manufacturers. Supplier #1 had a big automated plant with a high technical level and factory control. This manufacturer commonly cures blocks with steam. For this study only, besides steam curing, blocks were produced with a moist cure and a natural cure. For moist curing sprinklers were installed in the roof of the curing chamber and the units were showered with cool water. “Natural” cure consisted of placing the blocks inside the curing chamber and doing nothing. The time inside the chamber was two days for all cases. Figure 10 shows photos of this plant.

Factory overview

Block machine

Curing chamber

Figure 10 - Manufacturer #1

Manufacturer #2 was a small supplier from a medium-sized city (Figure 11). This supplier did not have steam curing and the factory control was poor. The curing condition, also called “natural”, consisted of spreading units over the floor and wetting them for one day. On the second day the blocks were stored in stockpiles. Although this is not the best procedure, it was the normal factory procedure over which we had no influence. Thus, condition of the blocks at the time of test was the same as that of the blocks usually supplied by this manufacturer.

LABORATORIES

The shrinkage tests were done in two different laboratories. The first laboratory is located at the Brazilian Portland Cement Association (ABCP). In this laboratory tests are usually done with whole-block specimens with gauge discs on the sides. Blocks were dried to an equilibrium condition inside a temperature and humidity controlled room (23 ± 1 ^{o}C temperature and 50 ± 5 % humidity) but without using a hermetically sealed steel box. The second laboratory is located at the Civil Engineering Department of the Federal University of Sao Carlos (UFSCar), SP, Brazil. In this laboratory it was possible to cool blocks inside a similar room, but a hermetic steel box was used in some cases.

Block machine

Blocks spread over the floor for “wet” cure

Stockpiles

Figure 11 - Manufacturer #2

RESULTS

Table 2 shows test results for the concrete blocks used in each phase for compression strength, absorption and humidity. Shrinkage of control blocks after 83 days, not submitted to the saturated and dry conditions of the ASTM C426 test procedure, is shown in Table 3. Table 4 shows all the drying shrinkage results.

Table 2 - Block Characterization for Each Phase

Phase	Cement type	Curing condition	Compression strength (MPa)	Absorption (%)	Humidity (%)
1	ASTM type I	natural	7.3	7.6	21.5
		moist	7.5	7.2	35.3
		steam	8.7	6.6	27.2
2	ASTM type I	natural	15.1	5.3	53.8
		moist	15.7	5.4	56.5
		steam	13.8	5.2	57.5
3	ASTM type III	natural	5.4	6.2	67.5
4	ASTM type I	natural	8.4	5.5	29.0
		moist	7.2	7.0	24.2
		steam	7.2	6.8	24.5

Table 3 - Shrinkage in Control Blocks Not Submitted To the Saturated and Dry Conditions of the ASTM C426 Test Procedure

BLOCK STRENGTH	CURE PROCEDURE	SHRINKAGE AFTER 83 DAYS
14.0 MPa	Steam	0.040
	Moist	0.059
	Natural	0.059
4.5 MPa	Natural – test started after 5 days	0.061
	Natural – test started after 19 days	0.040
8.0 MPa	Steam	0.033
	Moist	0.039
	Natural	0.027

DISCUSSION

From the test results it was clear that using an entire block specimen with top and bottom readings was not a good option. For this type of set-up, results were scattered and should not be taken into account. This occurred because it was very difficult to place a whole block inside the comparator, since the block was very heavy. The use of a whole block in a comparator is not recommended.

Table 4 - Concrete block drying shrinkage results (mm/m)

Phase	1									2														
Supplier	#1									#1														
Compression strenght	4.5									14														
Test age	5									5														
Cure procedure	steam			moist			natural			steam	moist	natural	steam				moist				natural			
Use of hermetic sealed box	no									no			yes											
Laboratory	abcp									abcp			ufscar											
Specimen type	face-shell		block	face-shell		block	face-shell		block	block	block	block	face-shell		block		face-shell		block		face-shell		block	
Reading type	top & bottom	sides	sides	top & bottom	sides	sides	top & bottom	sides	sides	sides	sides	sides	top & bottom	sides	top & bottom	sides	top & bottom	sides	top & bottom	sides	top & bottom	sides	top & bottom	sides
Result	-0.87	0.21	0.26	-0.81	0.24	0.26	-0.29	0.22	0.27	0.25	0.26	0.26	0.96	0.53	0.55	0.45	0.097	0.47	1.19	0.43	0.96	0.50	0.86	0.48

Phase	3								4								
Supplier	#2								#1								
Compression strenght	4.5								8								
Test age	19		5						5								
Cure procedure	moist		moist						steam	moist	natural	steam		moist		natural	
Use of hermetic sealed box	yes		no			yes			no			yes					
Laboratory	ufscar		ufscar			ufscar			abcp			Ufscar					
Specimen type	face-shell		face-shell		block	face-shell		block	block	block	block	face-shell		face-shell		face-shell	
Reading type	top & bottom	sides	top & bottom	sides	sides	top & bottom	sides	sides	sides	sides	sides	top & bottom	sides	top & bottom	sides	top & bottom	sides
Result	0.38	0.38	0.40	0.39	0.31	0.45	0.46	0.37	0.13	0.17	0.17	0.36	0.12	0.37	0.15	0.50	0.29

The tests with face-shell specimens with top and bottom readings were also subject to some scattered readings in the first phase (results from this phase should be disregarded). From this first experiment it could be seen that the mistake was in the reading procedure, especially in the first saturated reading. In the first phase, the specimens were blotted with a damp cloth before reading, and this caused a fast shrink in the specimens before they were placed in the comparator. In later phases, specimens were removed from the water and only the top and bottom gauges were dried, after which they were placed in the comparator as quickly as possible. Examining results for this type of specimen and reading from this point, it can be observed that they were close to each other, indicating consistent results. However, if these results are compared to those from side readings, on both the whole block or face-shell, a great difference is noted, in all phases except for phase 3 when blocks from supplier #2 were tested. The conclusion is that although the procedure seems to be good there may be some problems with the specimens. The leading hypothesis is that the specimen is too long in relation to its thickness, 39x2.5 cm, and may bend during the test. Further tests with smaller specimens must be performed in order to clarify this point. The side gauges gave more consistent readings in both types of specimen.

Comparing the results for specimens from manufacturer #1 made under different curing conditions, no significant differences were observed. It should be noted that all curing was performed at low pressure and the units were produced in a highly automated plant. It must also be remembered that the blocks were immersed in water for two days prior to the first reading, which changed the curing conditions. Results from this test procedure indicate the maximum *potential* shrinkage. Blocks cured under different conditions did have different shrinkage values when they were submitted to normal environmental conditions, as can be seen in the results for control blocks (Table 3). Shrinkage tests on concrete masonry walls made from all the types of units described in this paper are being carried out and future results may better clarify this issue.

By examining the results from the two laboratories differences can be seen between results for the same specimen type. This could be explained by the use of the hermetically sealed box, the operator procedure and equipment differences (the ABCP lab uses a demec gauge similar to but not the same as that used in the UFSCar lab).

Blocks of nominal compression strength of 4.5 MPa were supplied by both manufacturers. In this case, it can be clearly noted that blocks from manufacturer #2, produced under poor control and a poor curing procedure, had a considerably higher shrinkage value. Moreover testing after 19 days instead of 5 days reduced the shrinkage of blocks from manufacturer #2 by about 17%.

CONCLUSIONS

From the test program it can be concluded:

- Shrinkage tests on whole blocks with top and bottom gauge points tested in a comparator gave large readings. It was also difficult to handle the block. It is recommended that this test procedure not be used;
- Face-shell specimens with top and bottom gauge points gave comparable results to face-shell specimens with side gauge points in phase 3, when blocks from supplier #2 were tested, but much larger readings in phases 2 and 4;

- More investigation of the test procedures is needed to explain the differences observed;
- Block and face-shell specimens with lateral gauge points gave similar results in phase 3. In phase 3 the face-shell specimens had higher readings while in phase 1 the opposite occurred. Conclusions from Bryson and Waststein [5] also indicate face-shell shrinkage results greater than whole block shrinkage results for the RT-50 and Modified British Method and similar results for the RT-30 Method;
- Since side readings on face-shell or whole block specimens led to differences not greater than 0.08 mm/m and since shrinkage tests usually tend to give rather scattered results, we understand that either specimen type can be used;
- Different curing conditions at low pressure for blocks supplied from a highly automated plant did not lead to different *potential* shrinkage results tested according to the ASTM C426 standard, but differente shrinkage values were oberserved for different curing conditions in control blocks submitted to normal environmental conditions;
- Blocks produced in a small and poorly controlled plant with poor curing conditions had higher shrinkage results. The shrinkage was reduced when the blocks were tested at an age of 19 instead of 5 days.

Work is still in progress on deformation recordings on a series of walls. The results will be divulged later.

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