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SHRINKAGE CHARACTERISTICS OF CONCRETE BLOCKS

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ABSTRACT

Shrinkage strain data from tests of blocks from twenty-four block plants in Ontario shows that the majority of shrinkage occurs during later stages of drying. From a fully saturated state, it is generally necessary to remove much more than half of the water before significant shrinkage begins. From this data, it appears that water content as an absolute rather than a relative value may be a better indicator of the benefits of predrying as a measure to preshrink the block and limit the potential for shrinkage in situ. Questions are raised regarding the benefits of current specifications for moisture-controlled block.

INTRODUCTION

Background

Concrete is known to expand when it absorbs water and to shrink when it dries. For concrete block construction, particularly when it is unreinforced, significant shrinkage will cause unsightly cracks in the tension-weak masonry. Besides being unsightly, these cracks can negatively affect rain penetration and strength characteristics. Although use of movement joints at relatively close spacing is an effective way of reducing the stresses caused by shrinkage and thereby minimizing cracking, it is logical to reduce the problem itself by limiting the amount of shrinkage that can occur. In this way, standardized

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spacings for movement joints can be worked out and designer and owner satisfaction with concrete block construction can be protected.

The factors affecting the shrinkage of concrete, as we know them, are well explained in books on concrete technology. However, most shrinkage research has been done on normal weight concrete with densities ranging from 2300 to 2400 kg/m^3 (144 to 150 lb/ft^3), whereas concrete blocks produced in Ontario have densities ranging from 2000 to 2200 kg/m^3 (125 to 137 lb/ft^3). The difference represents additional void space in blocks, typically resulting from use of very low proportions of cement and the need for very dry mixes in the moulding process. As will be discussed later, the range of void space may be an important factor in the development of specifications to limit the potential for shrinkage in concrete block walls.

Current Specifications to Limit Shrinkage

CSA Standard A165.1 (CSA 1994) specifies maximum moisture contents as percentages of total absorption to limit the amount of shrinkage in what are known as moisture-controlled units. The maximum moisture content depends on the total linear shrinkage of the block (determined in accordance with ASTM C426 (ASTM 1994(b)) and the average annual relative humidity at the point of manufacture. Table 1 contains these specifications which are similar to the ASTM specifications (ASTM 1994(a)) except that the latter has a third category of relative humidities for average RH less than 50% corresponding to arid regions. The maximum moisture contents in this category are 5% less than the corresponding values in the under-75% R.H. category (Table 1) for each range of linear shrinkage.

Table 1. Maximum Moisture Content (% of total absorption)

Linear Shrinkage (%)	R.H.* over 75%	R.H.* under 75%+
Less than 0.03	45	40
0.03 - 0.045	40	35
Over 0.45	35	30

*In ASTM C90, the relevant R.H. is at the jobsite or point of use rather than the point of manufacture.
+In ASTM C90, these moisture contents apply to R.H. values between 50 to 75%

A related requirement is that the total absorption of block material with density greater than 2000 kg/m^3 (125 lb/ft^3) not exceed 175 kg/m^3 (10.9 lb/ft^3) which corresponds to a maximum of 8.75% absorption.

Experimental Approach
Earlier research at McMaster (Sandys-Wunsch, 1992) seemed to indicate that there was very little correlation between moisture content, expressed as a percent of absorption, and the amount of shrinkage yet to occur with further drying of block. Therefore, although total linear shrinkage is normally determined using the rapid drying method described in ASTM C 426 (ASTM 1994(b)), it was reasoned that measurements taken during slow drying shrinkage would provide better insight into the relationship between moisture content and shrinkage. Measurement of slow drying shrinkage from the green condition or after resaturation of mature blocks (Ferguson et al. 1957) allows the amount of shrinkage to be related to the existing moisture content.

Hollow 20 cm (8 in.) concrete blocks of normal weight concrete were obtained from 24 block plants in Ontario. Standard tests were done on samples of the mature blocks from each plant (Drysdale and Khattab, 1993). Then, conforming to the required number of shrinkage tests in ASTM C426 (ASTM 1994(b)), three blocks were randomly selected from each plant. Test procedure and results are presented in the next section.

EXPERIMENTAL PROGRAM

Test Method
Brass strain indicator points were glued on both face shells of each of the three blocks selected for shrinkage measurement. The pattern shown in Fig. 1 was followed to provide 200 mm (8 in.) gauge lengths for use of a DEMEC™ demountable mechanical strain indicator which has an accuracy of 0.00001. The initial weight was recorded to the nearest gram and initial DEMEC™ strain readings were taken. The

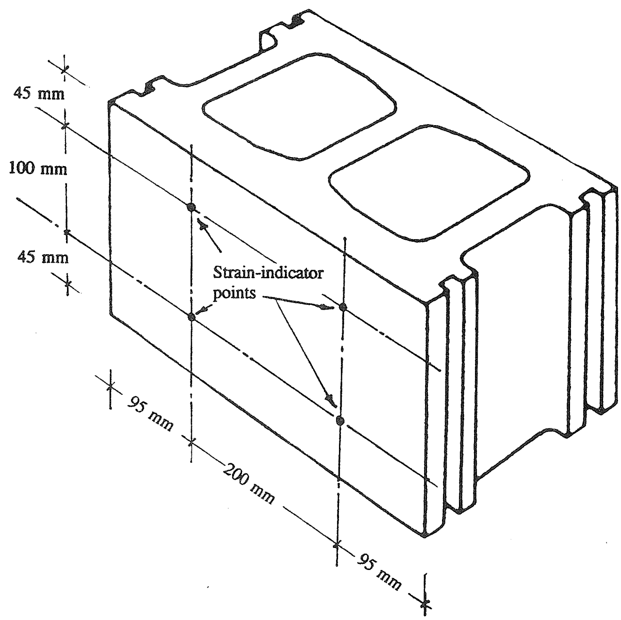


Fig. 1 Position of the strain indicator points on a face shell of the block.

blocks were then immersed in water at room temperature for three days, after which they were removed from the water and drained for 1 minute on a 10 mm (3/8 in.) mesh while the visible surface water was removed with a damp cloth. At this moisture condition, defined as saturated surface dry, the strain readings and weights were recorded.

The blocks were moved to air dry in a humidity and temperature controlled room. The humidity was controlled at 42 $\pm$ 4% using household humidifier and dehumidifier appliances. Over the next two and a half months, shrinkage and weight measurements were taken at regular intervals. At the end of this period shrinkage values and weights had stabilized. The blocks were then oven dried and final readings and weights were recorded.

Test Data

Table 2 contains a summary of the test data in columns 2, 3 and 5. Examples of shrinkage strain versus time and water content (expressed as a percent of the dry block weight) are plotted in Figs. 2 and 3 for Plant Numbers 1 and 9, respectively. These two plants represent the extremes of water absorption from a low of 4.16% for Plant 1 to a high of 7.89% for Plant 9. Otherwise, the shapes of the data plots are typical. The increment of shrinkage between the last two strain measurements in Figs. 2(a) and 3(a) represent shrinkage caused by oven drying of the blocks. This component of shrinkage is not included in the values listed in column 5 of Table 2. Similarly, the increment of water content between the last 2 sets of readings in Figs. 2(b) and 3(b) represent oven drying and this component of water content is included in the absorption values (fully saturated) listed in columns 3 and 4 of Table 2.

Figures 2(c) and 3(c) are plots of shrinkage versus water content. What is obvious from these two plots and similar plots for the other 22 plants is that no significant shrinkage occurs until the water content is less than at point B. Therefore, removal of a substantial portion of the water from the fully saturated condition at point A to point B does not have any significant effect. However, for water contents less than the value corresponding to point B, shrinkage increases nearly linearly in proportion to decreases in water content to point C. Point C represents the end of the shrinkage measurements where shrinkage strain and water content were nearly constant for the controlled environment of 42% relative humidity and temperature of 22°C.

Column 6 in Table 1 lists the water contents at point B in grams per block. However, for moisture controlled block (Table 1), the limits on moisture content are expressed as a percent of the Absorption. The calculated percentages are listed in Column 7 and, depending on the block plant, range from 24 to 51% of total absorption. As can be seen, in many cases, drying the block to a prescribed moisture content between 30 and 45% of the absorption may not accomplish much in terms of preshrinking the block to avoid high shrinkage in the wall.

Another way to look at the influence of drying the block to a prescribed moisture content is to look at the amount of shrinkage that has occurred when a specific moisture content is reached. For instance, the shrinkage strains at 35% moisture content are listed in

Table 2 Shrinkage and Water Content Test Data

Plant No. (1)	W_{od} Oven dry weight of block (grams) (2)	Total Absorption		Total shrinkage at 42% R.H. $(\varepsilon_{sh})_T \times 10^{-6}$ (5)	Water Content at B	
		Moisture content grams/block (3)	% of W_{od} (4)		grams/ block (6)	% of Absorption (7)
1	17718	737	4.2	370	330	45
2	16260	1101	6.8	370	423	38
3	16774	909	5.4	530	463	51
4	17213	1005	5.8	380	347	35
5	16486	1123	6.8	450	528	47
6	16752	1032	6.2	390	335	32
7	17129	826	4.8	410	379	46
8	17222	990	5.8	370	327	33
9	15912	1255	7.9	420	383	31
10	16326	1054	6.5	290	250	24
11	16986	876	5.2	370	305	35
12	16976	1039	6.1	420	363	35
13	16611	1043	6.3	460	309	30
14	17375	881	5.1	360	306	35
15	17624	1017	5.8	450	449	44
16	17412	963	5.5	320	336	35
17	16012	1098	6.9	450	431	39
18	17037	1000	5.9	460	273	27
19	16795	815	4.9	480	336	41
20	17179	830	4.8	360	308	37
21	16326	1058	6.5	330	260	25
22	17141	893	5.2	400	379	42
23	16378	960	5.9	390	272	28
24	17328	859	5.0	520	372	43

Table 2 (continued)

Plant No. (1)	Water Content at C (g/block) (8)	Shrinkage at 35% moisture content $(\varepsilon_{sh})_{35} \times 10^{-6}$ (9)	$\frac{(\varepsilon_{sh})_{35}}{(\varepsilon_{sh})_T} \times 100$ (10)	Water Content (g/block) for Specific Remaining Shrinkage Strains		
				300×10^{-6} (11)	200×10^{-6} (12)	100×10^{-6} (13)
1	135	213	58	312	253	194
2	140	69	19	346	277	209
3	191	288	54	354	300	245
4	107	75	20	325	252	180
5	228	297	59	428	361	295
6	116	0	0	284	228	200
7	82	125	30	299	226	191
8	91	56	16	282	218	155
9	143	22	5	328	266	204
10	78	131	47	250	250	174
11	105	53	14	293	230	168
12	141	59	15	326	264	202
13	125	42	9	263	217	171
14	96	56	17	287	223	160
15	176	213	47	393	321	248
16	96	47	15	344	261	179
17	133	100	23	351	278	206
18	106	78	17	253	204	155
19	81	136	28	254	197	139
20	82	88	25	308	233	157
21	85	38	11	279	214	150
22	130	128	32	325	260	195
23	95	38	10	246	196	146
24	99	125	25	262	208	154

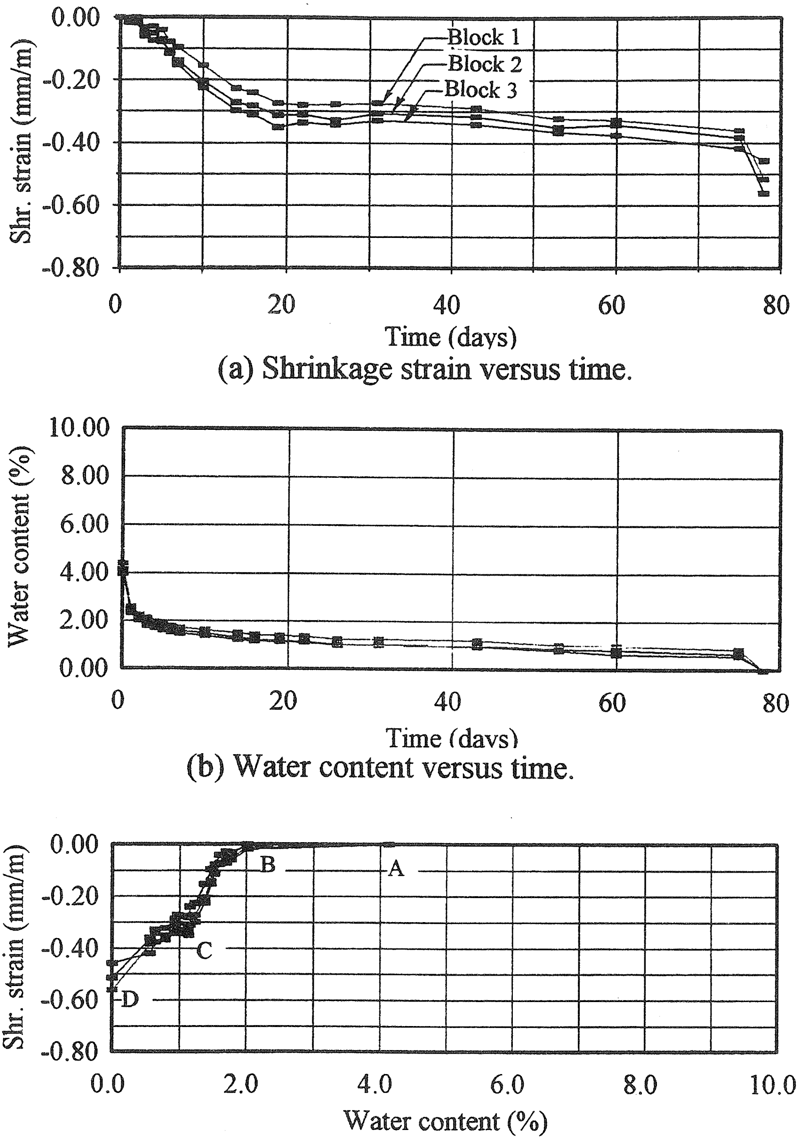
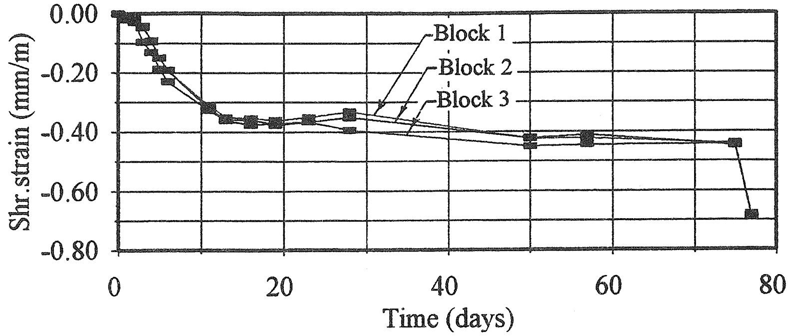
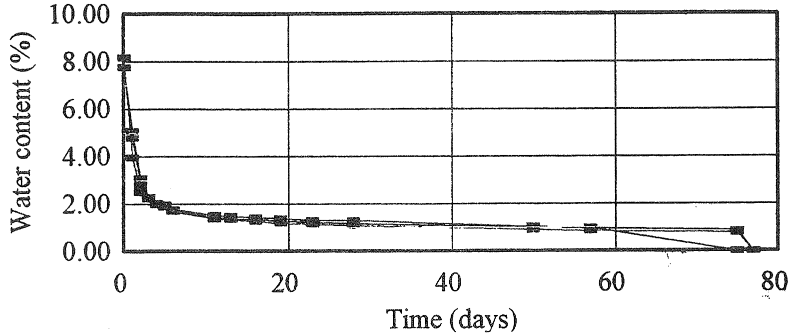


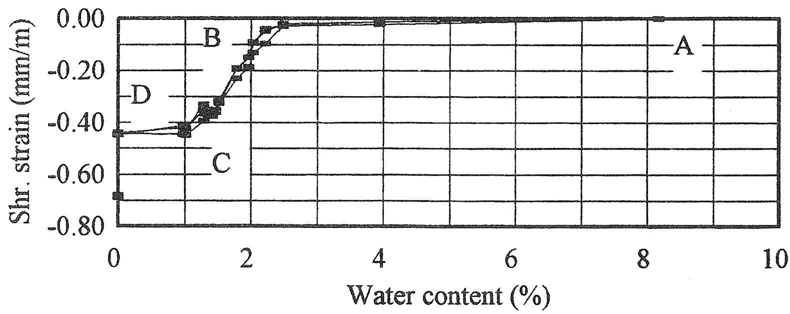
Fig. 2 Shrinkage versus Water Content Data for Plant 1



(a) Shrinkage strain versus time.



(b) Water content versus time.



(c) Shrinkage strain versus water content.

Fig. 3 Shrinkage versus Water Content Data for Plant 9

Column 9 of Table 2. They are also shown as percentages of the total shrinkage strains in Column 10. For 15 of the 24 block plants, this degree of predrying resulted in shrinkage from 0 to 25% of the total shrinkage. This means that removing 65% of the moisture content did not have much effect. An alternate way to look at this is that, at 35% moisture content, the average shrinkage strain remaining to occur to reach point C was 303×10^{-6} with a coefficient of variation of 25%.

From the above analysis and general review of the results, it is apparent that drying concrete blocks to a specific moisture content, expressed as a percentage of the total absorption (i.e., saturated condition), does not produce consistent results, and in many cases, has negligible effect on reducing the shrinkage which will occur with further drying. Therefore, the idea of using an absolute value of water content rather than a ratio was investigated to see if improved correlation with shrinkage could be obtained.

Using a straight line representation of the shrinkage versus water content relationship between points B and C, the water contents for residual shrinkage strains of 300×10^{-6}, 200×10^{-6} and 100×10^{-6} were calculated and are listed in Columns 11, 12 and 13, respectively, in Table 2. For the 200×10^{-6} level of residual shrinkage strain, the average water content was 247 g/block with a coefficient of variation of 16%. Similarly, for the 300×10^{-6} and 100×10^{-6} residual shrinkage strains, the average water contents were 295 and 187 g/block respectively with coefficients of variation of 16 and 20%, respectively. Two sets of data have particularly high values (Plants 5 and 15) and if these were arbitrarily ignored, the average water content would decrease slightly but more significantly, the coefficients of variation would drop to about 12%.

DISCUSSION OF TEST RESULTS

It seems that moisture content, expressed as a percentage of the total absorption, is not a good indicator of the remaining shrinkage. As was clearly evident (Figs. 2(c) and 3(c)) for blocks from all manufacturing plants, the initial drying out of the block from the saturated condition (Point A) to point B had little effect on shrinkage. The absorption varied from 4.16 to 7.89% of the block weights, and because the water content (grams per block) at the onset of the main shrinkage (point B) was reasonably consistent, it naturally was very inconsistent when expressed as a ratio of the total absorption.

For normal weight concrete blocks, expressing water content in grams per block or proportionally as a percent of the block weight, appears to provide a better indication of the desirable water content needed to limit the remaining shrinkage strain to some chosen value. For example, if a shrinkage strain of 200×10^{-6} after predrying is acceptable for point of use conditions of 42% R.H. and 22°C temperature, limiting the water content to 247 grams/block would ensure that most blocks were close to or below this value of remaining shrinkage. Alternatively, for the 24 block plants, limiting the moisture content to 200 grams/block would mean that all blocks would have 200×10^{-6} or less residual shrinkage strain.

For moisture controlled blocks, the previously mentioned limits on moisture content have existed in concrete block standards for more than 30 years. Perhaps it is time to take another look at what is being accomplished by compliance with these requirements. For example, if there are no corresponding requirements to keep the blocks dry on the job site prior to placing them in the wall, the potential benefits of predrying the blocks may not be realized because wetting of the blocks will reverse the initial shrinkage which occurs during the predrying. In this case, it makes more sense to limit the total shrinkage that can occur from the saturated conditions to stable conditions in the environment at the point of use.

If blocks are kept dry before they are put into the wall, then predrying, resulting in preshrinking, can have significant benefits provided that the shrinkage which is left to occur in the wall conforms to some prescribed limits. In this regard, we noted that the shrinkage occurred in a relatively short period of time. For this reason, the practice of basing the requirements on the average annual relative humidity also may be questionable. If there is a dry season, the critical shrinkage and greatest potential for cracking are likely to be related to these conditions rather than average conditions.

Finally, another factor to consider is whether using relative humidity as an indicator of potential for shrinkage is valid. Movement of moisture through a material or from one material to another is driven by vapour pressure difference, not relative humidity. Because saturated vapour pressure is a function of temperature and because relative humidity is expressed as the percentage of saturated moisture content that exists in air at a particular temperature, the vapour pressure at high relative humidity and low temperatures can be much lower than for lower relative humidities at higher temperatures.

The data reported in the paper originated as part of the Quality Control Program of the Ontario Concrete Block Association. The intent of this discussion is to encourage the block industry, appropriate standards committees and other researchers to take another look at the long standing specification for moisture controlled block. Is what is currently being done a waste of time and money and should the requirements be changed?

ACKNOWLEDGEMENTS

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