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QUALITY ASSURANCE PROGRAM FOR CONCRETE BLOCK

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ABSTRACT

The development and introduction of the OCBA Quality Assurance Program is based on more stringent requirements than demanded by the material Standard. Key components of the program include increased geometric dimensions, higher design strength criteria, and decreased absorption and absolute shrinkage characteristics. A brief discussion of test results from standard tests is included and benefits of the program for producers and users are discussed.

BACKGROUND

One of the Ontario Concrete Block Association's stated aims, in common with other similar industry groups, is the increased acceptability and expanded use of its members' products. Management decided, some time ago, that conscious quality improvements would provide the means to help achieve this aim.

Further impetus was provided by the explicit trend to Quality Management, a policy to provide consistent quality and customer satisfaction. Membership product pride

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demanded that member companies provide a better quality than the minimum requirements of the block standard (CSA, 1994(a)) which is referenced in the Building Code and the masonry design standard (CSA, 1995). Over the years, the Q.A.P. has developed into a credible verification of the physical properties covered by the standard: aesthetic qualities such as colour, shade and texture variations are subjective and therefore difficult to standardize/establish and further may be influenced by design or application. Although on-going discussions have not established objective criteria as yet, general appearance and consistency of colour and texture are noted as part of the Q.A.P.

A brief review of the methods of describing the physical properties and standard requirements will establish the basis for comparison. The physical properties are described using a 4 facet system.

First Facet

H Indicates hollow unit: i.e. a unit having net cross sectional area less than 75% solid in any horizontal plane.

S Indicates a solid unit having a minimum net cross sectional area 75% solid in all horizontal planes.

S_f Indicates a solid coreless unit. This new clarification aims at removing all possible misunderstandings. By definition, a solid unit is permitted up to 25% void. Thus, in the rare cases where a fully solid unit is required, a conscious selection must be made and so indicated by the specifier.

Second Facet

The second facet indicates a minimum compressive strength based on **net area**. The strength is the average of 3 units with no unit less than 85% of the specified strength.

Third Facet

The third facet identifies specific densities with related absorption characteristics. Maximum permissible absorption measures the volume of all pores in the material (differential in unit weight between saturated and oven dry condition). As expected, concrete made with lower density aggregates containing a larger volume of pore, are permitted a higher absorption factor than the concretes made with higher density aggregates. Indeed, the primary purpose of this facet is to limit excess pore space in the manufactured material: thus, it is a measure of quality.

Fourth Facet - Moisture Content versus Shrinkage

The scope of this facet is to provide data to enable the designer to limit shrinkage as a means of controlling cracking. The maximum moisture content permitted depends on the total shrinkage of the unit and the humidity conditions at point of use. Units having lower shrinkage properties are permitted a higher moisture content than units with higher shrinkage strains. In addition, a higher moisture content is permitted for units used where Relative Humidity exceeds 75%. Where moisture controlled units (Type M) are required and specified, protection from rain or other moisture sources should be provided for both units and walls under construction so that moisture content remains unaffected.

Table 1 Physical Properties (CSA, 1994)

Facet	Symbol	Physical Properties		
1st		Solid content		
	H S S_f	Hollow Solid (as defined) Solid without voids		
2nd		Minimum Compressive Strength, MPa Based on Net Area		
		Average of 3 units	Individual unit	
	2.5 10.0 15.0 20.0 30.0	2.5 10.0 15.0 20.0 30.0	The compressive strength of any individual unit shall be not less than 85% of that specified average of 3 units	
3rd	Concrete Type	Density, kg/m^3	Absorption, kg/m^3	
	A B C D N	over 2000 1800-2000 1700-1800 Less than 1700 No limits	175 200 225 300 No limits	
4th		Linear Shrinkage	Maximum Moisture Content, %	
			RH over 75%	RH under 75%
	M M M	Less than 0.03% 0.03%-0.045% more than 0.045%	45 40 35	40 35 30
	O	No limits Not tested (where shrinkage is not of importance	No limits	

Type O units may be used where drying shrinkage is not a major consideration (e.g. interior partitions, inner wythe of cavity wall). The total shrinkage is the change in length which occurs as blocks are dried from the saturated to the oven dry condition; neither extreme is common and when combined with limitations on moisture content, actual deformation due to moisture (addition or loss) can be expected to be less than 0.04%.

QUALITY ASSURANCE PROGRAM

Geometric Properties

In the late 1970's, the conversion to metric dimensions led to the production of an Industry Manual (2), to assist users in the new language. In retrospect, this was a major undertaking involving new nomenclature, new dimensions and new approaches such as using mass rather than weight. The Industry Manual provided the opportunity to recognise the "defacto" dimensions rather than the "bare bones" minimum requirements of the standard (CSA, 1994). More substantial units with wider face shell and web dimensions provide increased capacity and thus reinforce user confidence.

Compressive Strength

Traditionally, North American standards, both ASTM and CSA, referenced compressive strengths in terms of gross area, and sometimes differentiated between hollow and solid and between loadbearing and nonloadbearing. In 1984, CAN3 A165.1 Concrete Masonry Units (CSA, 1984(a)) consolidated the various strength levels in terms of net area consciously paralleling the requirements of the masonry design standard (CSA, 1984(b)). Conformance to the strength requirement in the material standard had to be met by the average of 5 units (reduced to 3 in CSA, 1994) with no unit more than 15% below the strength specified. However, the design standard (CSA, 1995) requires capacities to be based on characteristic strength where the variability is considered using the following formula:

$$\text{characteristc strength} = \bar{x}\left(1 - \frac{1.5}{x}\sqrt{\frac{\Sigma(x - \bar{x})^2}{n - 1}}\right)$$

where

x = an individual test result
$\bar{x}$ = the average of individual test results
n = the number of specimens

The design standard (CSA, 1995) requires testing of 5 units, increased to 10 if the coefficient of variation exceeds 15%. The Association's Technical Committee selected 15 MPa as the minimum level of compressive, strength increased by 20% to provide a defined comfort zone for the user. This 18 MPa strength level is defined in terms of characteristic rather than average strength.

In addition, consistent quality is reinforced further by limiting the coefficient of variation to 10% rather than the 15% permitted by the Standard. The impact of the Q.A.P.

requirements compared to minimum requirements in the block standard (CSA, 1994) can be quite dramatic as illustrated in Table 2.

Table 2 Comparison of Minimum Standard Requirements versus those of the Quality Assurance Program. (Values are for hollow 20 cm units).

	Standard Requirement	Quality Assurance Program
Unit strength, MPa	15[1]	18[2]
Maximum Coefficient of Variation	15%	10%
Minimum Characteristic Unit Strength, MPa	11.62	18
f'_m Masonry Compressive Strength with Type S Mortar[3], MPa	7.57[3]	11.72[3]
Wall Capacity, kN/m (effective mortared area xf'_m	$30\times2\times7.57$ = 454[4]	$1.23(32\times2)\times11.72$ = 923[5]
Ultimate Design Load, kN/m $\phi_m(0.85\ ff'_m)$ $A_n=0.55(0.85\ f'_m)\ A_e$	212	368[6]

1. Average
2. Characteristic strength
3. From CSA S304.1
4. Based on minimum 30 mm face shell thickness
5. Based on minimum 32 mm face shell thickness and allowing fro increased effective mortared area due to thickened ends, webs and pear shaped cells
6. f'_m value of 10 MPa used instead of 11.72 MPa.

A concrete block with average strength of 15 MPa will have a characteristic strength of 11.62 MPa, based on the 15% C.O.V. As shown in Table 2, this translates into a masonry strength of 7.57 MPa. Using 30 mm thick face shells and the resistance factor $\phi_m = 0.55$ for masonry and the rectangular stress block, the axial capacity of 212 kN/m is achieved. For blocks from the Q.A.P., the specified minimum characteristic strength and 10% limit on coefficient of variability result in masonry compressive strength of 11.72 MPa. With appropriate quality control testing on site, this strength can be used. Alternatively, the masonry design standard (CSA, 1995) allows testing requirements to be waived (Clause 4.1.2) if the f'_m value is not greater than 10 and the producer provides satisfactory test data. Since the Q.A.P. satisfies the requirement for independent test data, there is sometimes an advantage to limiting the strength to 10 MPa in calculations. The resulting 368 kN/m ultimate load is still 66% greater than obtained following standard requirements.

Absorption

The most commonly misunderstood property of masonry is absorption. Often equated with moisture permeance, absorption is actually an assessment of compaction by measuring the volume of voids in the material (weight differential between saturated and oven dry conditions). Thus, the purpose of this property is indeed a measure of quality control by limiting void space to an acceptable maximum for each density. Standard weight units (over 2,000 kg/m^3) are permitted 175 kg/m^3: conformance to the Quality Assurance Program limits the absorption to a maximum of 150 kg/m^3 (see Figure 1).

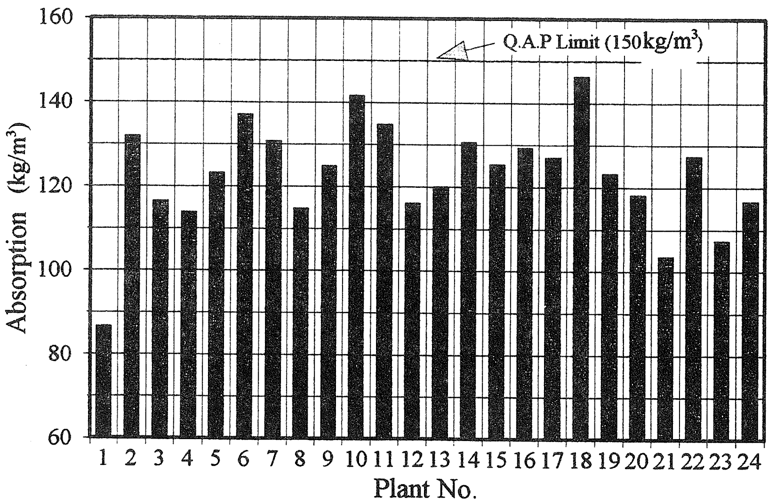

Fig. 1 Absorption of hollow 20 cm blocks.

The plot of absorption versus density in Fig. 2 confirms that absorption tends to decrease as density increases: an endemic property reflected in the requirements. As illustrated in Fig. 3, the densities varied from 2050 to 2240, reflecting the type of aggregate used in the preferred mix formula.

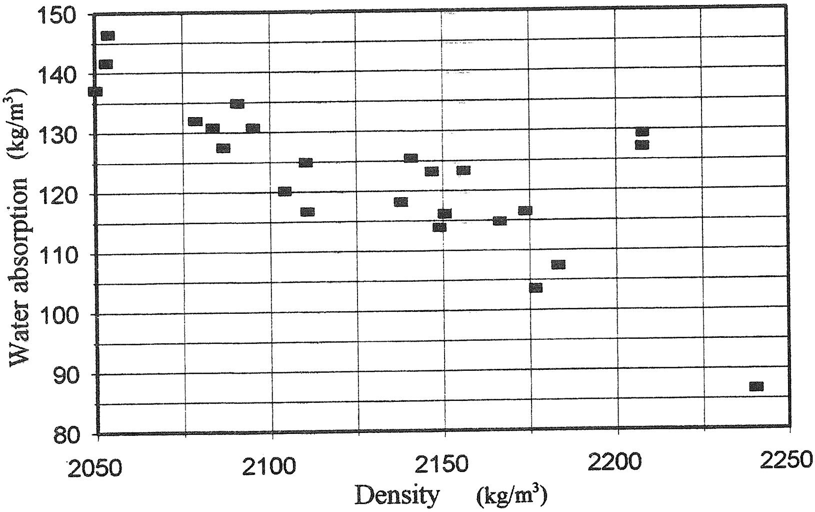

Fig. 2 Absorption versus density for hollow 20 blocks.

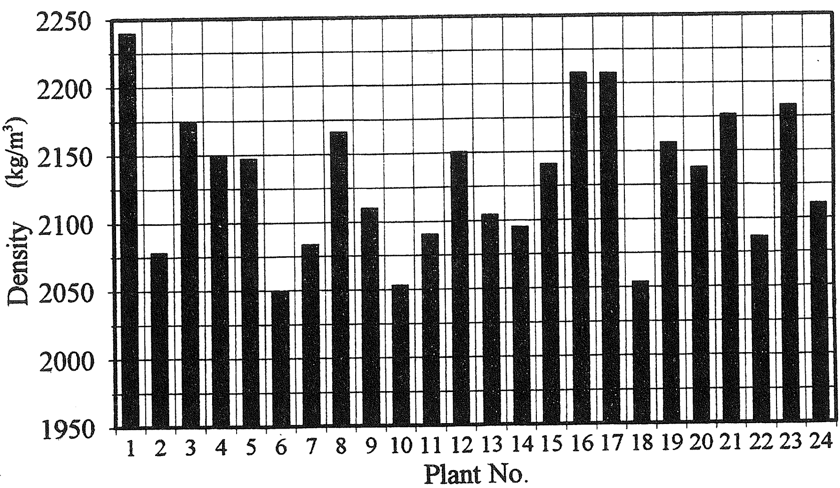

Fig. 3 Densities of hollow 20 cm blocks.

Moisture Content

The block standard requires that moisture content be limited in relation to the shrinkage of the unit (i.e. this facet combines requirements for two separate though related properties: moisture control and shrinkage/expansion.) Both properties are initially within the control of the manufacturer. However, the significance of this requirement and the potential benefits have not been clearly understood by designers and producers. Research regarding the effectiveness of this requirement is underway.

On-site protection of concrete masonry units is generally known to be desirable. In fact, it is a Code requirement but the same protection is seldom extended to work underway. Moisture content limits may be frustrated further by the mistaken though well meaning extension of pre-wetting recommended for clay units with high initial absorption rates. The test program measured absolute deformation from fully saturated to oven dry conditions. The qualifying maximum was limited to 0.065% (6.5 mm/10 m). In addition, a maximum real life deformation was assumed from saturated surface dry (SSD) to 42% relative humidity (a more arid condition than occurs in Ontario). Conformance was limited to 0.05% (5 mm/10 m). Quality Assurance requires meeting both strict limits made even stricter by the requirement of total immersion of units for 72 hours to produce a more saturated condition and allow full expansion to occur. Immersion for 72 hours rather than the standard requirement of 24 hours is likely to cause greater subsequent shrinkage than would result from wetting during normal use. The Quality Assurance Program establishes absolute rather than relative data and thus more accurate detailing for movement points is possible.

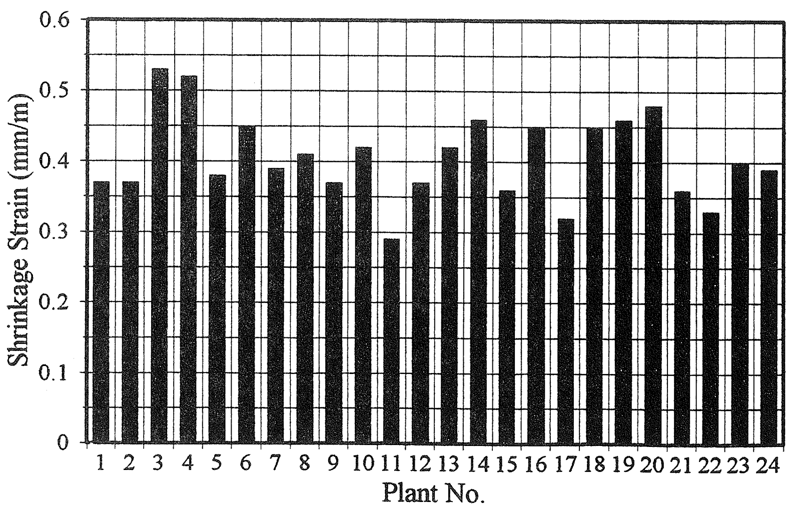

Fig. 4 Total shrinkage strains of hollow 20 cm block from SSD condition to a balanced condition of 42% R.H.

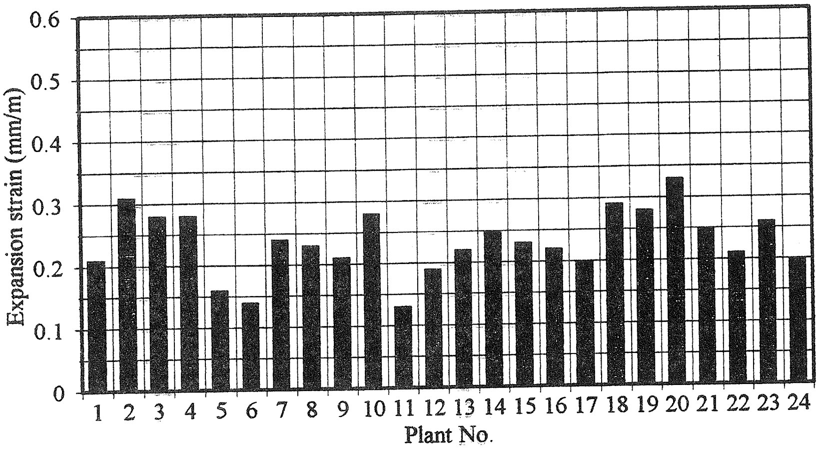

Fig. 5 Expansion strains of hollow 20 cm blocks from natural condition to SSD condition.

Total shrinkage strains and expansion strains are shown in Figs. 4 and 5 for the 24 block plants participating in the Q.A.P. Moisture deformation control in concrete masonry production and design has concentrated mainly on shrinkage effects. In order to expand knowledge of the material, it was decided to measure expansion strains occurring when the units in their partially dried state were resaturated. When compared to Fig. 4, there is some correlation between lower expansion related to lower shrinkage but the natural condition of the blocks when they arrived at the laboratory could vary significantly depending on how they were protected during transportation.

Non-Standard Tests

The Q.A.P. was expanded further to include other not required tests to broaden the data base for research on the behaviour of masonry walls.

Splitting Tensile Strength. The face shells of six half blocks were subjected to two opposite line loads applied through 15 mm diameter bars. A strip of plywood was used between each bar and the block to reduce the stress concentration along the loading lines. Loads at failure were recorded and the splitting tensile strength (f_t) was calculated from $f_t = 2P/\pi A_n$. P is the splitting failure load and A_n is the sectional area along the splitting plane. The test set-up is shown in Fig. 6 and the distribution of average splitting tension strengths is shown in Fig. 7 for the 24 block plants.

The Initial Rate of Absorption (I.R.A.). Another not required test, though commonly used in clay masonry, is the I.R.A. determined by performing the ASTM C67 test on 5 blocks. For this test, a dry unit is immersed in water to a depth of 3.2 mm for a period of 60 seconds. The amount of water thus absorbed is measured. These values may be

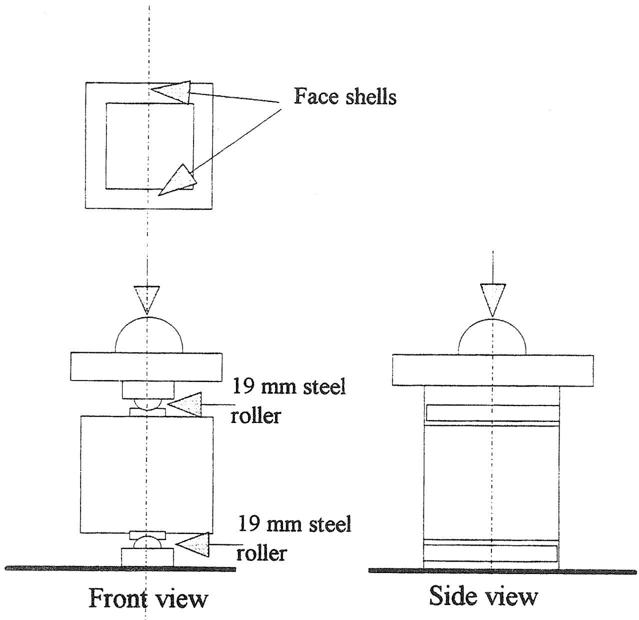

Fig. 6 Splitting tension test set-up.

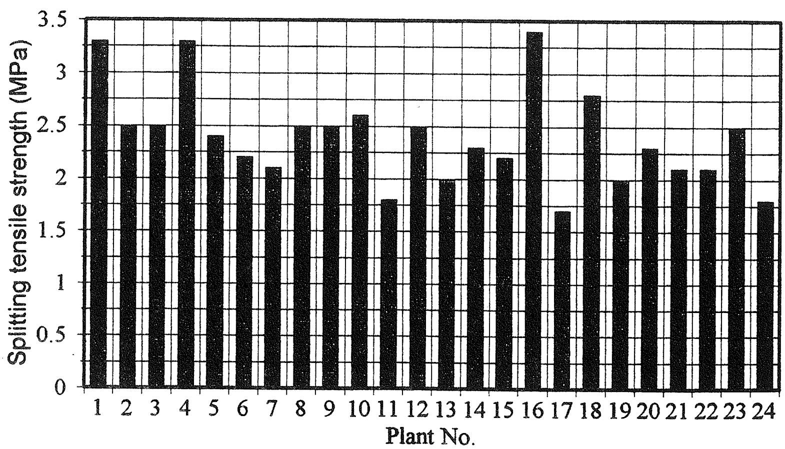

Fig. 7 Splitting tensile strengths of hollow 20 cm blocks.

useful in research on absorption related properties of concrete block and their effect on mortar bond. At this time no strong relationship has been found between the I.R.A. value (Fig. 8) and other properties such as absorption.

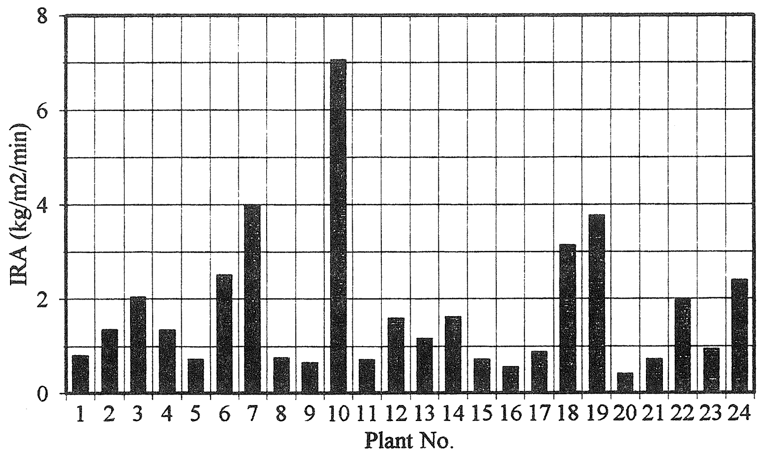

Fig. 8 Initial Rates of Absorption of hollow 20cm blocks.

CONCLUSIONS

1. The increasing reference to the Q.A.P. in construction specifications is evidence that designers place value on member product quality.

2. The existence of the Q.A.P. was a key factor leading to of the code provision to waive testing if other satisfactory evidence was available. The independent test program provides credible data which satisfies this requirement, thereby allowing owners to avoid extra testing costs for compressive strength (f'_m) not greater than 10 MPa.

3. Inevitably, research is never conclusive but answers some questions while raising others. Spin-off research from the Q.A.P. include evaluation of test procedures for measuring density and evaluation of the benefits of predrying block to specified moisture content.

ACKNOWLEDGEMENT

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