Chapter 10
Concrete Masonry

Physical Properties of Expanded Shale, Clay & Slate Lightweight Aggregate And Lightweight Concrete Masonry Units

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Chapter 10

<u>Section B-Properties of Lightweight Concrete Masonry Units</u>

Chapter 10 Physical Properties of Expanded Shale, Clay & Slate (ESCS) Lightweight Aggregate and Lightweight Concrete Masonry Units (LWCMU)

10.0 Introduction

This chapter provides information on the properties and performance of concrete masonry units manufactured with ESCS Structural lightweight aggregate. Some of the specific subjects covered are:

- basic physical properties of structural lightweight aggregate
- basic physical properties of concrete masonry units made with structural lightweight aggregate
- proper methods of materials storage and handling,
- quality control testing requirements and procedures, and
- recommended methods of proportioning for mixture designs.

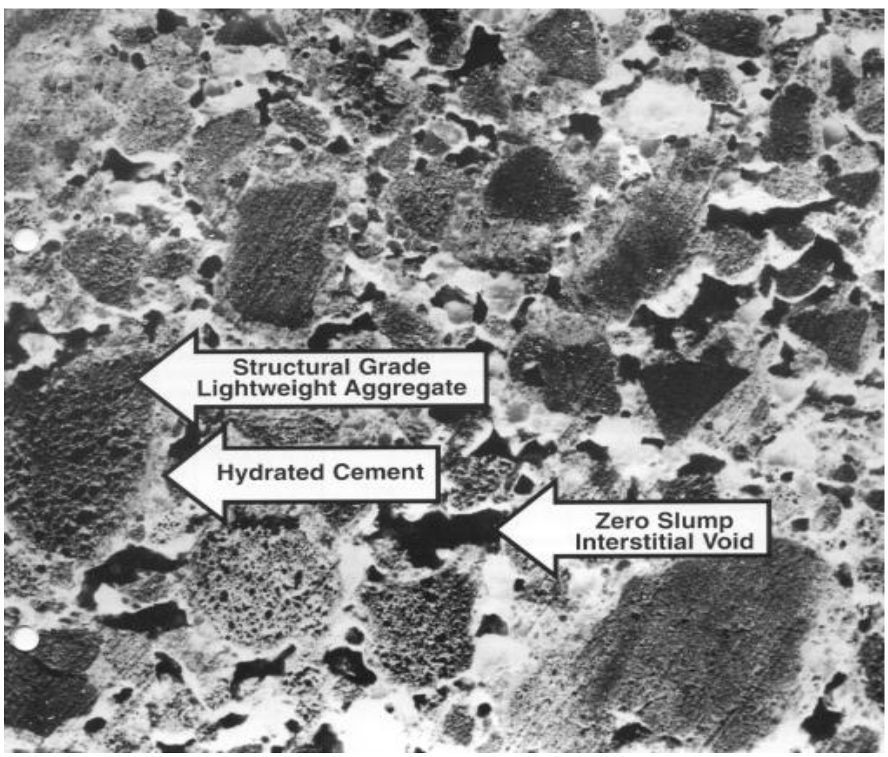


Figure 10.1 ***Cross-section of the lightweight Concrete used in a concrete masonry unit***

Concrete masonry units are a combination of portland cement, mineral aggregates, and water. Other ingredients, such as pigments, pozzolans, air entraining agents, and integral waterproofing agents may be added to achieve some desired features.

Aggregates constitute the major component of the masonry unit, occupying more than 70% of the total volume. The portland cement and water combine (Hydrate) to form a paste which binds the individual aggregate particles together into a solid zero slump cohesive mass with a small volume of unfilled interstitial voids (Figure 10.1).

Section A (10.1-10.8) "Properties of Lightweight Aggregate Used in Concrete Masonry

10.1 Relative Density of Particles of Lightweight Aggregate

Structural Lightweight Aggregates have a low particle density due to their internal cellular pore system. The cellular structure within the particles is developed by heating to high temperatures certain raw materials to the point of incipient fusion, at which time gases are evolved within the pyroplastic mass, causing expansion that is retained upon cooling. Strong, durable, ceramic lightweight aggregates contain a relatively uniformly distributed system of pores that have a size range of approximately 5 to 300 µm enveloped in a relatively crack-free, high-strength vitreous phase. Pores close to the surface are readily permeable and fill within the first few hours of exposure to moisture. Interior pores, however, fill extremely slowly. A fraction of the interior pores are essentially non-interconnected and may remain unfilled after years of immersion.

The particle density of an aggregate is the ratio between the mass of the particle material and the volume occupied by the individual particles. This volume includes the **PORES** within the particle, but does not include **VOIDS** between the particles (Fig. 10.2). In general, the volume of the particles is determined from the volume displaced while submerged in water. Penetration of water into the aggregate particles during the test is limited by the aggregate's previous degree of saturation.

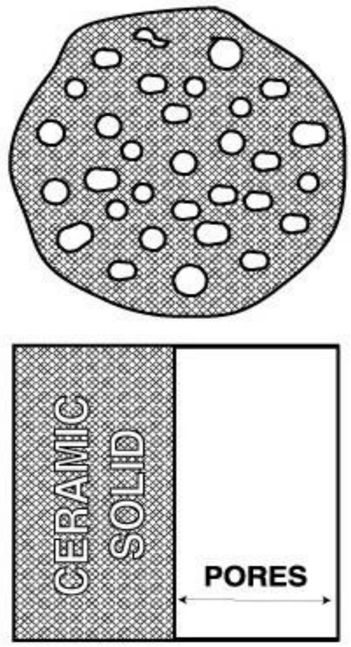


Figure 10.2. ***Schematic of Dry Structural Lightweight Aggregate***

The oven-dry density of an individual particle depends both on the density of the solid vitreous material and the pore volume within the particles, and generally increases when particle size decreases. After pulverizing in a jar mill over an extended period, the relative density of the poreless, ceramic material was determined to be 2.60 by methods similar to those used in measuring the relative density of cement.

It is important to understand that:

- Each LA has a unique pore system that controls the rate and amount of water absorbed. In order to accurately proportion concrete mixtures, the water absorption vs. time of moisture preconditioning may be established by a test program.
- Water absorbed within the lightweight aggregate does not immediately contribute to the water to cementitious material ratio; however, it reduces plastic shrinkage and enhances hydration through extended internal curing.
- During air drying of the CMU the small sized pore system in the cementitious matrix (< 1 μm) will wick out the moisture from the larger sized pores (5 to 300 μm) of the LA, thus providing for an extended period of internal curing.

10.2 Absorption Characteristics of a Lightweight Aggregate Particles

Due to their cellular structure, lightweight aggregates absorb more water than their heavy aggregate counterparts. Based upon a 24-hour absorption test conducted in accordance with the procedures of ASTM C 127 and ASTM C 128, structural-grade lightweight aggregates will absorb from 5 to more than 25 percent moisture by mass of dry aggregate. By contrast, normalweight aggregates generally absorb less than 2 percent of moisture. The important distinction in stockpile moisture content is that with lightweight aggregates the moisture is largely absorbed into the interior of the particles, whereas with ordinary aggregates it is primarily surface moisture. Recognition of this difference is essential in mixture proportioning, batching, and control. Rate of absorption of lightweight aggregates is dependent on the characteristics of pore size, continuity, and distribution, particularly for those close to the surface.

When the aggregate is used in concrete masonry internally absorbed water within the particle is not immediately available for chemical interaction with cement as mixing water. However, it is extremely beneficial in maintaining longer periods of hydration essential to improvements in the aggregate/matrix contact zone.

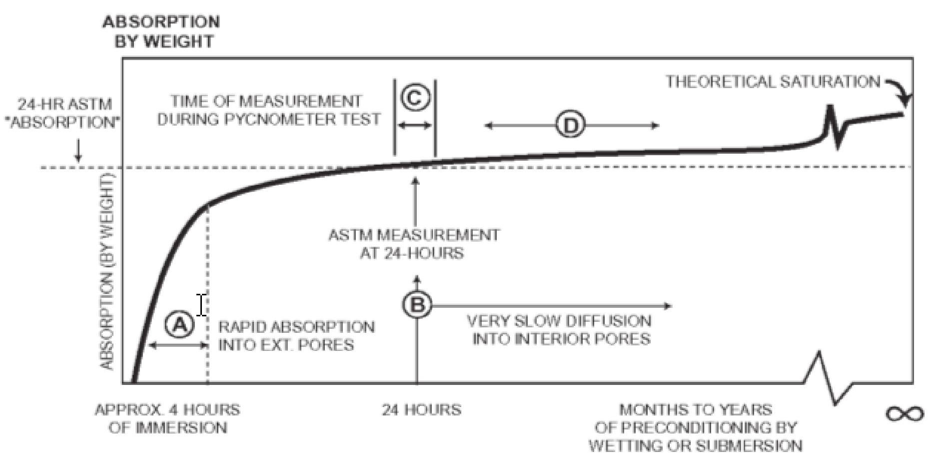


Figure 10.3. ***Absorption vs. Time for typical structural grade ESCS lightweight aggregate***

As can be seen in Figure 10.3, the rate of absorption can be divided into several regimes.

Region A. Rapid entry of water by capillary absorption by close to surface pores within first few hours.
Region B. Very slow diffusion into interior pores
Region C. When the moisture content is approximately equal to that obtained by ASTM procedure (24 hour immersion), then the slope of the line reflecting further

absorption is a very slow process of diffusion. This is the basis for providing accurate relative density values during the relatively short time used to conduct pycnometer tests at 24 hours

<u>Region D.</u> **A**bsorption developed over an extended period of time used to mix, transport and cube prior to initial set (6-8 hours ±) will be very small, and the strength making character of the matrix will be increased by a small amount.

Saturated Surface Dry

ASTM C 127 – C 128 procedures prescribe measuring the "saturated" (*inaccurately named in the case of lightweight aggregates; partially saturated after a 24-hour soak is more accurate)* particle density in a pycnometer and then determining the absorbed moisture content on the sample that had been immersed in water for 24 hours.. After a 24-hour immersion in water, the rate of moisture absorption into the lightweight aggregate will be so low that the partially saturated particle density will be essentially unchanged during the time necessary to take weight measurements in the pycnometer. After the moisture content is known, the oven-dry particle density may be directly computed. Figure 10.4 illustrates typical ESCS lightweight aggregate.

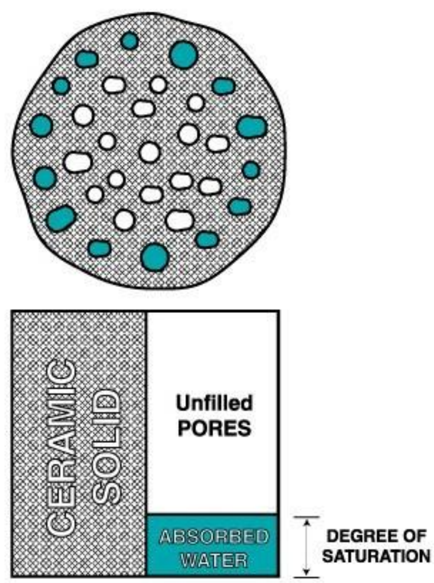


Figure 10.4. ***"Saturated" Surface Dry as defined by ASTM C 127 and C 128 after a 24-hour submersion***

Following ASTM procedures the measured physical properties of a typical lightweight aggregate are as follows:

Relative density, RD_{24} = 1.80
Moisture Absorption, M_{24} = 9%
Relative density soilid, RD_{SOLID} = 2.6
Bulk density, BD = 55 pcf (880 kg/m³)

That after 24-hour immersion in a pycnometer, measurements result in a relative density of 1.80 with an associated "absorption" of 9% by mass. Then, the oven-dry particle density (PD_{OD}) may be back calculated to be as follows:

$$PD_{OD} = \frac{1.80}{(1+.09)} = 1.65$$

It follows then that the fractional volume of ceramic solids (with an assumed density of the solid ceramic fraction of the aggregate 2.60) **,** $V_S = \frac{1.65}{2.60} = 0.63$

Fraction Volume of pores, $V_p = 1.00 - .63 = 0.37$

The degree of saturation (DS: the extent to which the pores are filled)

$$DS = \frac{.09 \times 2.60 \times .63 \text{ (Fractional volume* of absorbed water)}}{.37 \text{ (Fractional volume of pores)}} = .40$$

10.3 Aggregates Bulk Density

According to ASTM C 331, the loose bulk density of lightweight aggregates when measured in an oven dry condition utilizing the shoveling procedures contained in ASTM 29, shall conform to the requirements of Table 1.

Table 10.1 Maximum Bulk Density (Dry Loose) Requirements of Lightweight Aggregates for Concrete Masonry Units

Nominal Size Designator	Maximum Dry Loose Bulk Density kg/m³ (lb/ft³)
Fine Aggregate 4.75 mm (No. 4) to 0, Coarse Aggregate	1120 (70)
9.5 to 2.36 mm (3/8 in to No. 8)	880 (55)
Combined Fine and Coarse Aggregate	1040 (65)

The dry loose bulk density of lightweight aggregate shipments sampled and tested shall not differ by more than $\pm$ 3 lb/ft³ (50 kg/m³) or 7% whichever is greater from that of the sample submitted for acceptance testing, and shall not exceed the limits of Table 10.1.

10.4 Grading of Lightweight Aggregates

There are a number of reasons why recommendations for the grading of lightweight aggregates used in concrete masonry units should NOT follow the practice suggested for normalweight aggregates. This is because that, contrary to the essentially unchanging relative density for all ordinary aggregate particle sizes, there is a continuous increase in the relative density of lightweight aggregate particles with decreasing smaller sizes. This well known fact has been used in calculations for mixture proportions in cast-in place structural lightweight concretes incorporating lightweight fine aggregate for more than 40 years and has been documented in American Concrete Institute publications.

In a manner similar to fully compacted cast-in-place structural concrete mixtures, aggregate gradings exert a profound influence on the physical properties of machine manufactured, *zero slump, and incompletely compacted block concrete*. Intentionally incompletely compacted block concrete employs a mixture with insufficient mortar so that the finished product has unfilled voids. When used in cast-in-place concrete, a well graded aggregate will provide a mixture with a minimum void content and consequently require minimum paste content to fully coat and bridge between all particles. Mixture proportions based upon a minimum void approach lead to optimized strength making properties and minimize volume changed due to drying shrinkage in both ready mix and concrete masonry. Here too, there are differences brought about by the unique characteristics of structural lightweight aggregate. Reports studying the influence of differing gradings clearly indicate that highest strengths were obtained with mixture that incorporated finer gradings of lightweight aggregate (Menzel).

In contrast to cast-in-place concrete that is highly workable, fully compacted and contains cementitious paste volumes significantly in excess of the volume of intra particle voids; concrete masonry mixtures are proportioned to zero slump characteristics that results in unfilled interstitial voids. Due to the zero slump requirement the resulting unfilled voids are absolutely essential to provide the wet dimensional rigidity essential for molding, stripping, and handling of fresh masonry concrete on a pallet.

In addition the attractive surface texture available with lightweight aggregate concrete masonry units (CMU) that is so crucial to developing superior sound absorption characteristics, is also a direct result of an aggregate gradings that develops an optimum system of interstitial voids.

Fineness Modulus

As mentioned earlier, the relative density for a usual natural aggregate type is essentially constant for all sieve sizes and as a result, the fineness modulus on a weight basis will directly reflect the volumes occupied by each particular size. In contrast, the relative density measure on each sieve size in a typical commercial lightweight aggregate blend reveal a progressive numerical increase in relative density as the particle size diminishes. It is the volume occupied by each size fraction and NOT the weight of material retained on each sieve that ultimately determines the void structure, paste requirements and workability characteristics. To further understand this difference between the weight and volume occupied by particles on each sieve for a particular lightweight aggregate an example is included and shown in Table 10.2.

Table 10.2 Fineness Modulus by Weight and Volume of lightweight aggregate

Sieve Size	Percent Retained by Weight	Cumulative Percent Retained by Weight	Relative Density @ SSD	Percent Retained by Volume	Cumulative Percent Retained by Volume
3/8	0	0	___	___	___
#4	5	5	1.5	5.9	5.9
#8	25	30	1.6	27.8	33.7
#16	25	55	1.7	26.1	59.8
#30	10	65	1.8	9.9	69.7
#50	10	75	1.9	9.3	79.0
#100	10	85	2.0	8.9	87.9
PAN/FM	15	FM by Weight	2.2	12.1	FM by Volume
	Total 100	3.15		Total 100	3.36

From the above, it can be seen that fineness modulus (by volume) of 3.36 indicates a considerably coarser grading than that computed by standard FM by weight...3.15. Therefore, because of their unique characteristics, lightweight aggregates require a significantly larger percentage of material retained on the finer sieves when computed on a weight basis than do their heavier counterparts in order to provide a comparable void system. Furthermore, minus #100 sieve expanded shale, clay and slate fines are extremely beneficial because they serve a dual role as both aggregate and pozzolan.

It is important to understand the fact that Fineness Modulus is a single number index that suggests an average particle size and that identical fineness modulii may be arrived at using fundamentally differing gradings. FM's may be useful as an overall qualitative index, or for QC control of an individual supplier providing a specific standard grading, but it should not be given an undeserved respect for providing any scientific insight. From the data shown in Table 10.3 it can be seen that an aggregate producer could supply three different gradings that have IDENTICAL FM's that would produce CMU's with three significantly different textures. Since FM methodology reflects an average particle size, one can manipulate the computations by keeping the percent retained constant on the #16 sieve for all gradings the numbers and arrive at the same FM's for all three fundamentally differing products.

Table 10.3 Fineness Modulus

% Retained Sieve Size	ASTM C 331 (#4-0)	Texture			ASTM C 331 (3/8-0)
		Fine	Medium	Coarse	
3/8	(0)	0	0	0	(0-10)
#4	(0-15)	5	10	15	(10-35)
#8	____	35	40	45	(35-65)
#16	(20-60)	55	55	55	____
#30	____	75	70	65	____
#50	(65-90)	85	80	75	(75-90)
#100	(75-95)	90	90	90	(85-95)
FM	___	3.45	3.45	3.45	____

Theoretical vs. Practical Gradings

Long-term practical experience in the production of millions of tons of properly graded lightweight aggregate used in billions of high quality lightweight aggregate CMU's takes precedence over any attempt to impose any pseudo scientific methodology, as for example, the attempt to replicate a grading based on an exponential curve (.45 Power) appropriate for a different purpose: asphalt gradings. Theoretical grading curves generated decades ago based on exponential ratios of sieve openings are inappropriate for direct application to production of lightweight aggregate CMU's because all theories based on a minimum void approach inherently presume a constant relative density for every particle size. It is essential that manufacturers of structural lightweight aggregates assume responsibility for providing optimized gradings without any further reference to inappropriate, theoretically based methodology or for that matter obsolete gradings recommendations that have origins in a cinder block mentality. These older industry recommendations were used in the production of low quality, "pop corn" type lightweight aggregate CMU's that are no longer acceptable in today's market.

Influence of Grading on Strength Making Considerations

Early works clearly showed that the influence of grading (expressed in terms of FM) on the strength making characteristics of concrete masonry units molded with structural lightweight aggregate differed from units incorporating sand and gravels. The compressive strength of CMU's made with ESCS lightweight aggregate was essentially constant over a wide range of FM's up to approximately 3.5, after which there was a decline in strengths with coarser gradings. This behavior was opposite to sand and gravel CMU's which showed a continuous increase of strength, ultimately reaching a maximum at an FM above 4. Compressive strength levels for lightweight aggregate CMU's significantly greater than ASTM C 90 minimums are best achieved when finer gradings of structural grade lightweight aggregate are used (Menzel). Systematically eliminating large particles that have an inherently higher ceramic porosity, and as a consequence a lower particle strength, will significantly increase the strength making potential of the composite system in a manner similar to that learned years ago when developing high strength cast-in-place structural lightweight concrete. Lowering the aggregate top size will also reduce the internal bridging characteristics of particles within the mass, indirectly call for more water and thus improve the overall compactibility of the fresh concrete masonry mixture.

All porous materials (concrete, ceramics, gypsum...) follow the natural law of decreasing strength with increasing porosity and structural grade lightweight aggregate CMU's are no exception to that rule. When mixtures are readily compactable, both the size and the volume of the interstitial voids are reduced and as a consequence the average strength making character is significantly improved. The influence of the degree of compaction: (1 – interstitial void volume) has been observed to parallel other concrete strength gain scenarios...approximately 5% increase in strength (compression and tensile) for every 1% decrease in interstitial voids.

High strength concrete masonry units incorporating structural grade lightweight aggregates have been successfully used in hundreds of high rise, load bearing concrete masonry buildings. Figure 10.5 from reference (Holm) indicates the profound affect of strength making influence of compaction as opposed to merely increasing cementitious binder. In yet another departure from cast-in-place concrete technology in the manufacture of CMU's, it has been observed that the influence of the water to cementitious material ratio is completely overshadowed by compactibility issues.

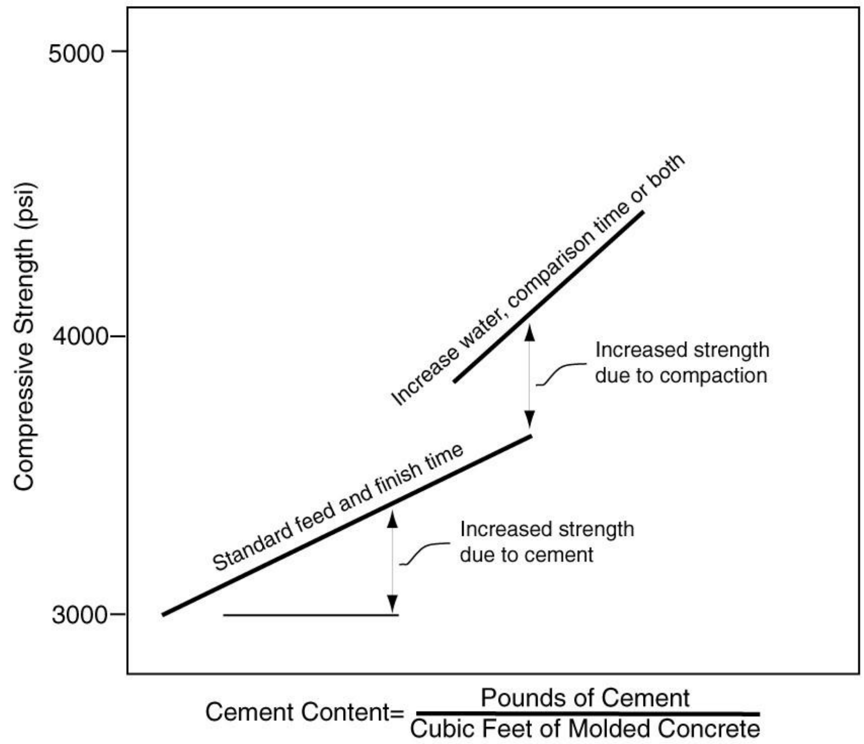


Figure 10.5. ***Impact of Compaction vs. Cement Content on Compressive Strength***

ASTM C 331 Grading Suggestion

The finely tuned, practical gradings developed by lightweight aggregate manufacturers that have been time tested over decades will result in a workable concrete mixture that will machine well in a modern high speed block machine, compact to an optimum strength/density ratio, as well as provide a uniform, aesthetic texture. Use of optimized gradings will result in a balance of qualities that include machining characteristics (smooth feeding, compactibility, green strength) as well as superior hardened concrete properties. What is truly important in achieving the consistent quality standards required of high quality lightweight aggregate CMU's is close attention to specific individual screen sizes of aggregate, and in particular, the material retained on the #4 and #8 sieves (essential for texture control) and that passing the #100 (critical for molding and handling characteristics). Following the grading recommendations shown in Fig. 10.6 ASTM C 331 Appendix 10A will result in a uniform, fine textured surface with an optimum interstitial void system within the block concrete. This will, in turn, maximize the thermal, acoustical, and fire resistance as well as the strength making properties of the finished product...high quality structural grade lightweight aggregate CMU's.

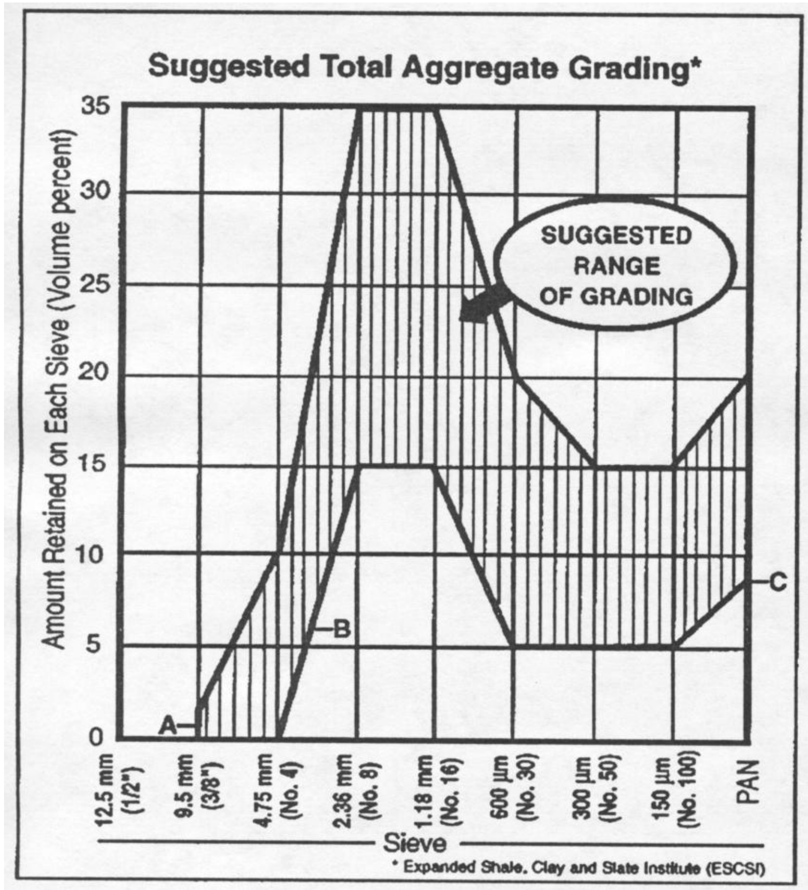


Figure 10.6. ***Recommended lightweight aggregate particle size distribution to produce high quality structural grade lightweight aggregate concrete masonry units.***

10.5 Aggregate Contamination and Impurities

Impurities and Deleterious Substances

In order for aggregate particles to be bound together by portland cement paste into a solid cohesive mass, they must be free from any impurities. This includes such deleterious materials as clay, loam, silt, and organic materials such as lignite, coal, sticks, and leaves.

Aggregates should be structurally sound, properly graded, and inert. Organic materials can retard or disrupt the hydration process of cement and thus adversely affect the strength and durability of the concrete. A film of any sort on the surface of the aggregate particles will adversely affect the bond between the aggregate particles and the cementitious material, resulting in reduced concrete strengths.

Impurities in aggregates may also adversely affect non-structural properties of masonry units such as aesthetics by creating pitting, popouts, and staining on the surface of the masonry.

Test methods to identify impurities in aggregates are contained in the following ASTM specifications:

ASTM C 40	Test Method for Organic Impurities in Fine Aggregate for Concrete
ASTM C 123	Test Method for Lightweight Pieces in Aggregate (Chert, Coal, Lignite)
ASTM C 142	Test Method for Clay Lumps and Friable Particles in Aggregates
ASTM C 114	Test Method for Chemical Analysis of Hydraulic Cements
ASTM C 641	Test Method for Staining Materials in Lightweight Aggregates

Popouts

Popouts normally occur shortly after the masonry units are placed in the wall, although there have been many instances where the expansive reaction has not taken place until after many years.

Popouts are unsightly non-structural blemishes caused by the expansion of particles beneath the surface of the concrete. These particles may increase considerably in volume when in contact with water. This increase in volume can create a force sufficient to disrupt the surface of the concrete. Popouts typically assume a conical shape, with the apex of the cone located at the expansive particle and the base of the cone at the surface of the concrete. According to the physical property section, ASTM C 331 "Standard Specification for Lightweight Aggregates for Concrete Masonry Units", concrete specimens shall show no surface popouts.

Common offenders are particles of unsound chert and lignite and un-hydrated lime. Cinders may contribute to popouts if the cinders are not aged sufficiently, and if particles of unburned or partially burned coal, hard-burned free lime, magnesia, or calcium sulfate are present. This problem may be minimized by storing the aggregate in a continuously wet stockpile for several weeks.

10.6 Sampling and Testing of Lightweight Aggregate

In order for any test results to be reliable, samples should be tested according to appropriate ASTM procedures to be truly representative of the entire supply. Experience has shown that stockpile and bin samples show more variation than exists in the material before transporting and depositing. This is especially true for surface dry aggregate. Test samples may be obtained from:

- Conveyor belts
- Stockpiles

- Aggregate bins
- Rail cars and trucks

Conveyor Belts
The preferred location for sampling aggregates is from conveyor belts.

To obtain samples from conveyor belts, representative samples should be taken from at least 3 locations along the belt. In order to do this, stop the belt and insert 2 templates, the shape of which conforms to the shape of the belt, at each of the three locations such that the weight of the material between them will be an increment of the required weight.

Carefully remove all of the material between the templates and place into a suitable container. Using a dust pan and brush, collect the fines on the belt and add them to the container.

Stockpiles
Samples should consist of materials taken from locations near the top third, midpoint, and bottom third sections of the stockpile.

At each sample point make a "dam" by driving a 2' x 2' sheet of plywood vertically into the pile. Below the dam, be careful to discard all material to a depth of approximately 6 in. below the surface. Take one shovelful from the top of the pile, four at random from the midpoint of the pile, and four at equally spaced points around the bottom.

Combine the individual sample into one composite sample.

Aggregate Bins
Bin samples should be taken at random intervals, preferably when the bin is full or nearly full. One method of obtaining samples is to discharge the bin into the bucket of a front end loader. Another method is to obtain the samples by passing a bucket or bag through the entire cross section of the aggregate discharge stream to obtain a representative sample. The individual samples are then place on a hard, flat surface and combined into on composite sample.

Rail Cars and Trucks
Samples should be obtained from rail cars and trucks by excavating three or more trenches across the load at points which give a reasonable estimate of the materials in the load.

The trench bottom should be approximately level, at least one foot in width and in depth. Obtain samples by pushing a shovel downward into the material at a minimum of 3 locations spaced equidistant along the trench. Combine the individual samples into one composite sample.

Sample Preparation

The sample to be tested should be placed on a hard clean surface to prevent loss of material and contamination.

The sample should then be thoroughly mixed by turning the entire lot over three times with a shovel, beginning at one end and taking alternate shovels of the material the length of the pile.

After the last turning, shovel the entire sample into a conical pile by depositing each shovelful on top of the preceding one. This conical pile is then flattened to a uniform thickness and diameter. The flattened mass is then marked into quarters by two lines that intersect at right angles at the center of the pile.

Then two diagonally opposite quarters are removed and discarded and the cleared spaces brushed clean. The remaining material is remixed as described above and the process repeated until the sample is reduced to the desired size for testing.

Sieve Analysis

Equipment requirements

1	set of sieves 1/2 in., 3/8 in., No.4, No. 8, No. 16, No. 30, No. 50, No. 100, Pan
1	Portable sieve shaker (optional)
1	Riffle sample (optional)
1	Balance scale
1	Set of weights for scales
6	10" square cake tins
1	Hot plate (electric)

Procedure:

The first step in conducting a sieve analysis is to dry the test sample to a constant weight at a temperature of 230 + 9º F (110 + 5º C).

The sieve sizes selected for testing shall be those applicable (fine or coarse) to the type of aggregate to be tested.

Nest the sieves in decreasing opening size from top to bottom and place the sample on the top sieve. Agitate the sieves by hand or by mechanical apparatus for a sufficient period and in such a manner that, after completion, not more than 1% by weight of the residue on any individual sieve will pass that sieve during 1 minute of continuous hand sieving performed as follows:

Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute. Turn the sieve about one sixth of a revolution at intervals of about 25 strokes.

Determine the weight of each size increment by weighing on a scale or balance to the nearest 0.1% of the total original dry weight. The total weight of the material after sieving should check closely with the original weight of the sample place on the sieves.

Calculate percentage passing, and total percentages retained to the nearest 0.1% on the basis of the original dry sample.

10.7 Thermal Expansion of Lightweight Aggregates and its Effect on Lightweight Concrete Masonry Units

Volume change may lead to shrinkage cracking (see Fig. 10.7). Cracks can result from excessive stresses induced either by restrained thermal shrinkage or restrained drying shrinkage or a combination of both. Cracks occur when these effects exceed the strength of the stressed section. The relative importance of these two factors varies considerably with the service environment and the intrinsic properties of the concrete. Thus, in northern climate where the temperature may exceed 100 deg. F., and then drop suddenly, the thermal volume change properties of the concrete may dominate. On the other hand, where a fairly uniform temperature and low relative humidity predominate, drying shrinkage may be more important.

On the first issue – thermal volume stability, lightweight aggregates have an advantage over most heavyweight units. While the variations of thermal expansion coefficients vary widely for natural aggregates depending on mineralogy, however, ESCS aggregates are fairly consistent with 3.9. Table 10.3 and Fig. 10.7 show typical values:

Table 10.3.

Aggregate	Coefficient of thermal expansion (x 10^{o})
Expanded shale, clay, slate	3.9
Crushed limestone	5.1
Sand and gravel	5.5

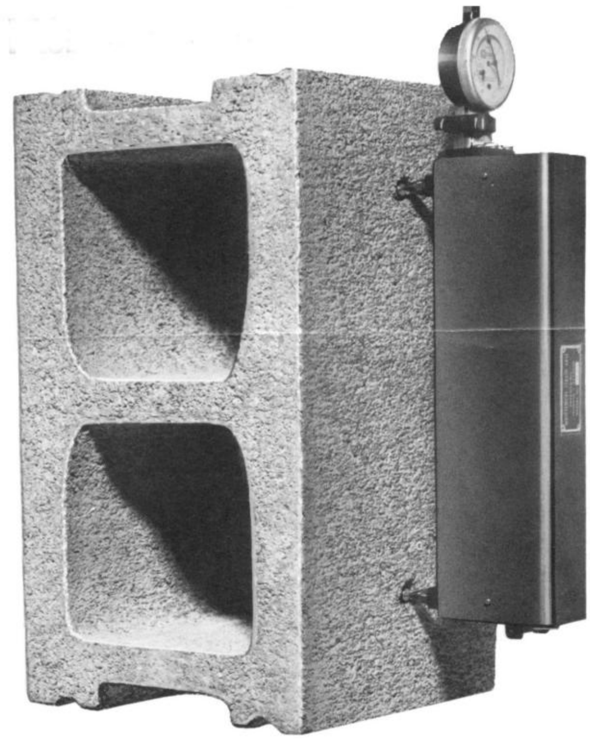


Figure 10.7. ***Measurement of Volume Change of Lightweight Lightweight Aggregate Concrete Masonry Unit***

10.8 Thermo-Structural Stability of ESCS Aggregates

General

Thermo-Structural performance of concrete products is significantly enhanced by the superior dimensional stability characteristics of ESCS aggregates. Exposure to the extremely high and rapidly developing temperatures experienced in fires can cause serious micro-structural damage to concrete products that contain aggregates that expand excessively. The rapid increase in the coefficient of linear thermal expansion in concrete products that contain certain natural aggregates may also be due to phase changes in thermally unstable minerals due to transformation from Alpha quartz to Beta quartz at about 1060ºF causes severe micro-cracking within the concrete and is beyond the scope of this reference manual. For further detailed documentation and explanation, study of the papers by Zoldners and Dougill are recommended.

The following section is a reprint of "*Thermo-Structural Stability of Concrete Masonry Walls",* Holm T.A. and Bremner T.W. from the proceedings of the Fourth North American Masonry Conference, August 1987.

Containment of building fires is crucial to both life safety and property protection. In order to offer adequate containment characteristics, fire walls must be composed of materials that possess structural resistance to the thermal forces developed by restraint of expansion while simultaneously providing insulative resistance to limit the rise of temperature on the unexposed side. This dual capacity mandate fire walls to be composed of thermally stable materials of high structural integrity. Trade offs of containment qualities, through the use of non-structural, thermally unstable building components that undergo excessive shrinkage due to chemical dehydration compromise building codes, put fire fighters at risk and contribute to the national scandal of loss of life and property.

Restraining forces acting on walls exposed to elevated temperatures are related to the expansion characteristics of the wall materials. Structural analysis of thermal forces requires an understanding of the thermal expansion characteristics of the wall components. Most construction materials, however, exhibit behavior that is not constant over the temperature ranges developed in building fires. Therefore behavior of these materials can not be characterized by a single coefficient but rather by a series of coefficients that reflect the variation of the materials, thermal response characteristics dictated by physio-chemical changes.

Philleo brought attention to the change in rate of expansion and provided a comprehensive analysis of the behavior of several cast-in-place concretes. Philleo measured the linear coefficients of thermal expansion of structural concretes with differing types of aggregates and also compared the influence of curing.

Test Equipment

Apparatus used for the determination of the thermal characteristics of 1/2" diameter by three inch long cylindrical concrete specimens consisted of four components: a dilatometer, an electric furnace, a temperature controller-recorder, and an X-Y recorder. The dilatometer consists of instruments for measuring expansion of specimens during temperature changes. During testing the specimen was located at the closed end of fused silica tube inserted into the electric furnace, as shown in Fig. 10.8.

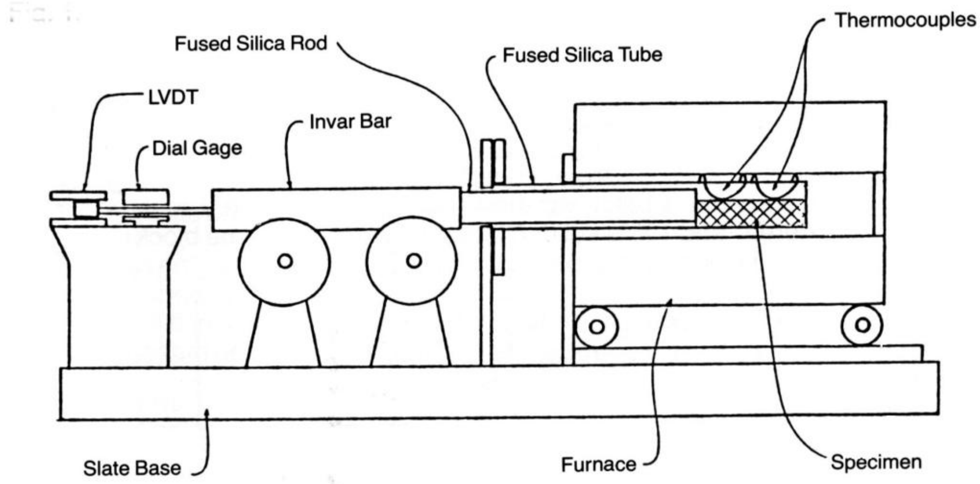


Figure 10.8. ***Schematic of Dilatometer***

Test Procedures

All tests were conducted in general compliance with ASTM Designation E 228-71 (Re-approved 1979) "*Standard Test Method for Linear Thermal Expansion of Solids With a Vitreous Silica Dilatometer"*. Details of specimen preparation, testing apparatus and procedures are described in the reports of Shirley.

Each specimen was positioned in the fused silica tube of the dilatometer with a fused silica rod seated against the end of the specimen. The temperature of the electric furnace was increased by the automatic temperature controller at a rate of 10ºF/Min. from room temperature to approximately 1800ºF for thirty minutes. At that time the specimen was cooled to room temperature at a rate of 10ºF/min. or less. After reaching room temperature, the specimen was subjected to a second heating/cooling cycle identical to the first. Temperature and thermal expansion were recorded at two minute intervals by the HP9845B desk top computer.

Test Materials

Two separate investigations were completed at the Construction Technology Laboratory in Skokie, IL. In Series "A" the primary thrust was to compare the reproducibility of multiple tests taken from the same specimen. This would develop confidence in the data used in theoretical analysis of walls composed of concrete masonry units of differing thermal stabilities. Accordingly six cores were tested from a single specimen of one commercially produced lightweight aggregate concrete masonry. Three specimens were taken from a commercial concrete masonry unit made with natural aggregate. A further set of three specimens were taken from a commercial concrete masonry unit made with a second lightweight aggregate.

The Series “B” tests were devised to document the thermal behavior of concrete masonry units of varying mix composition currently being commercially produced. These are either all lightweight aggregates, all normalweight aggregates or a combination of lightweight and normalweight aggregates in the same masonry unit. In the masonry units made from a combination of lightweight and normalweight aggregates, one unit used normalweight sand for the material finer than the No. 4 sieve. Another unit was made with the minus No. 4 sieve material being lightweight aggregate and the No. 4 to 3/8 inch material being normalweight aggregate. This normalweight coarse aggregate fraction is referred to in the trade as “grits”.

All mixes in Series “B” were proportioned on the basis of approximately 400 pounds of cement in a 50 cu. Ft. batch and the 4" x 8" x 16" masonry units produced were all “tight textured” and 100% solid. A laboratory one-at-a-time block machine was used to produce the units for the Series “B” specimens. The machine has proved in the past to develop sufficient compactive effort that simulates the performance of commercial block manufacturing equipment. Samples, one half inch in diameter and three inches long (1/2" x 3") were obtained by core drilling the masonry units in the four inch direction.

To evaluate the contribution of the lightweight aggregate, expansion tests were conducted on a one half inch diameter by three inches long cylinder of rotary kiln produced lightweight aggregate. In rotary kilns, a small percentage of lightweight aggregate is produced in the form of “clinker” consisting of an agglomerated mass of lightweight aggregate particles. By careful coring techniques the Construction Technology Laboratory was able to prepare cylinders composed entirely of lightweight aggregate.

Test Results

Figure 10.9 is typical of the expansion tests conducted in Series “A” on cores drilled from one concrete masonry unit composed of structural lightweight aggregate. The expansion curves of all tests were essentially linear to approximately 1450ºF and were virtually identical. Between 1450º and 1800ºF the specimens showed a reduction in thermal expansion that is generally attributed to dehydration of the gel in the cement past. The superposition of the shrinkage of the cementitious matrix, due to dehydration, around the expanding aggregate is an extremely complex phenomenon beyond the scope of this paper, and is covered by Harmathy and Cruz. On cooling to room temperature the specimens exhibited a net contraction of 4400 and 5100 microstrains. Visual comparison of the fired core with untested specimens indicated an intact structure confirming the integrity of a system composed of thermally stable constituents.

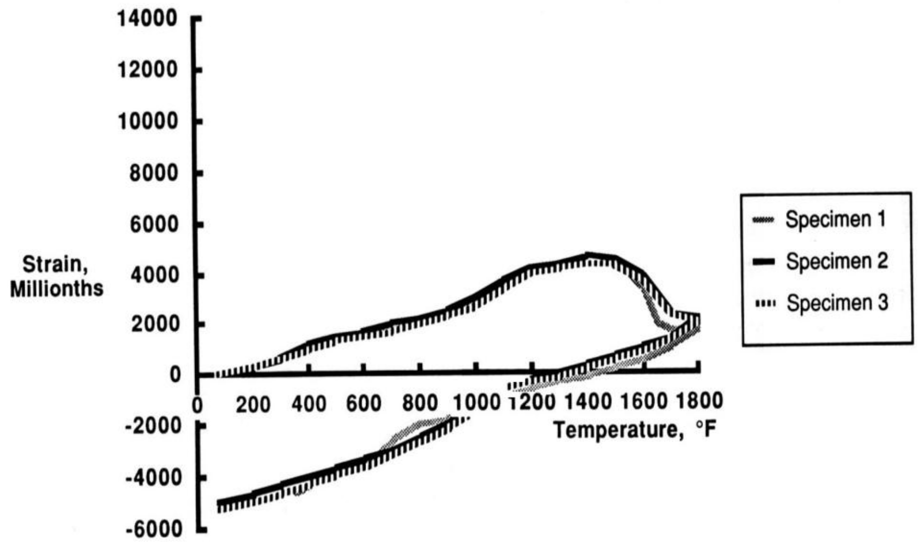


Figure 10.9. ***Thermal Expansion of Series "A" Lightweight Concrete Masonry Unit. Three Specimens taken from same Masonry Unit.***

Results of three separate tests on core sample taken from a single 4" x 8" x 16" commercial normalweight concrete masonry unit are given in Figure 10.10. The widely different results probably reflect the different aggregate composition included within a particular core sample. Note the rapid increase in coefficient of linear thermal expansion for the block concrete composed of natural aggregate due to phase changes in thermally unstable minerals.

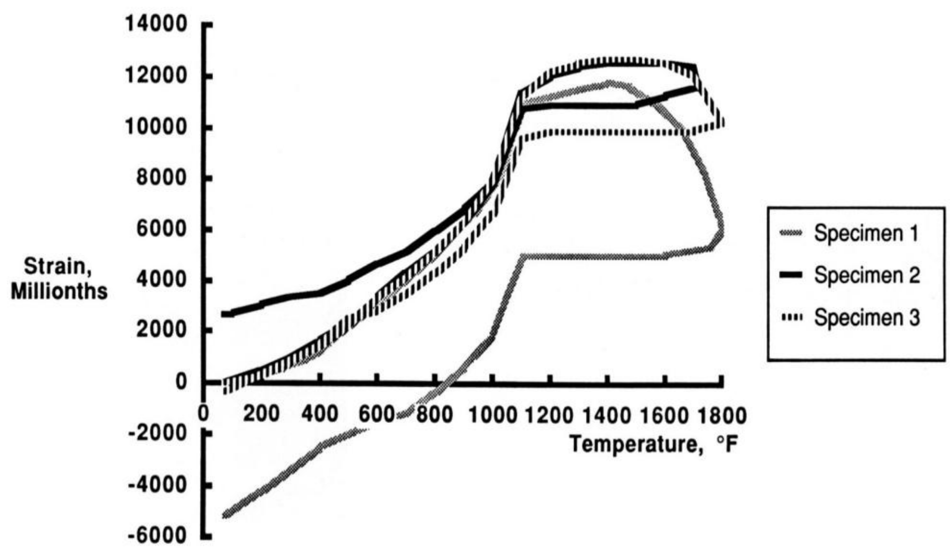


Figure 10.10. ***Thermal Expansion of Series "A" Normalweight Concrete Masonry Unit made from Florida Aggregates. Three Specimens taken from same Masonry Unit.***

Figures 10.11, 10.12, and 10.13 show the thermal expansion (heating and cooling) behavior of the Series "B" specimens. In general the results are in agreement with the work reported by Harmathy. The maximum expansions and residual deformations of this series are probably due to the mineralogical make up of the natural aggregates. For convenience the coefficient of linear thermal expansion of the various concretes has been broken down over arbitary increments in Table 1 in accordance with the Construction Technology Reports by Shirley. An indications of the effect that the type of aggregate used in the masonry unit can have on the coefficient of thermal expansion (over the 70-400ºF range) can be seen from the following.

3.3 in/in x 10^{-6}/ºF for the lightweight aggregate particles.
3.4 in/in x 10^{-6}/ºF for the 100% lightweight aggregate concrete masonry unit.
6.7 in/in x 10^{-6}/ºF for the sanded lightweight aggregate concrete masonry unit.

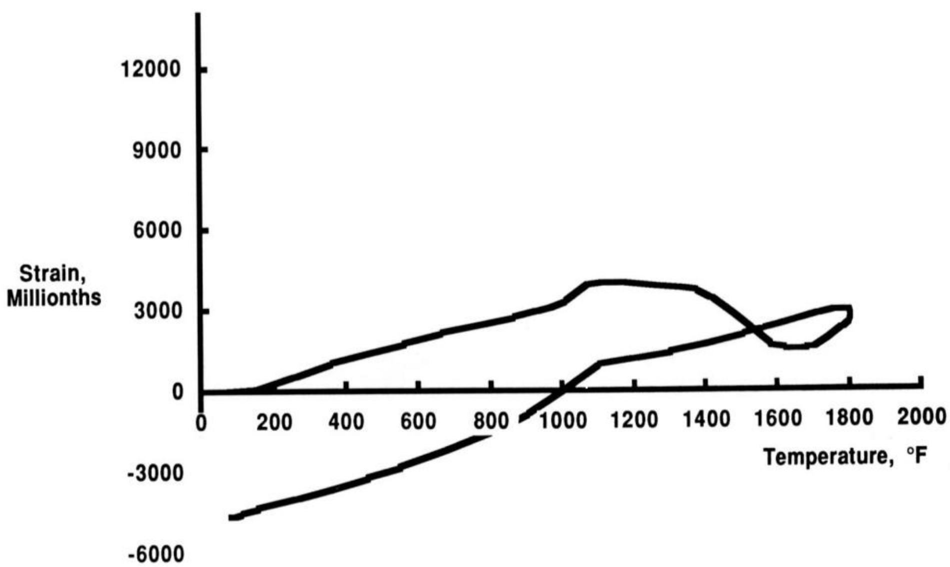


Figure 10.11. ***Thermal Expansion of Series "B" Lightweight Concrete Masonry Unit made from a Lightweight Aggregate.***

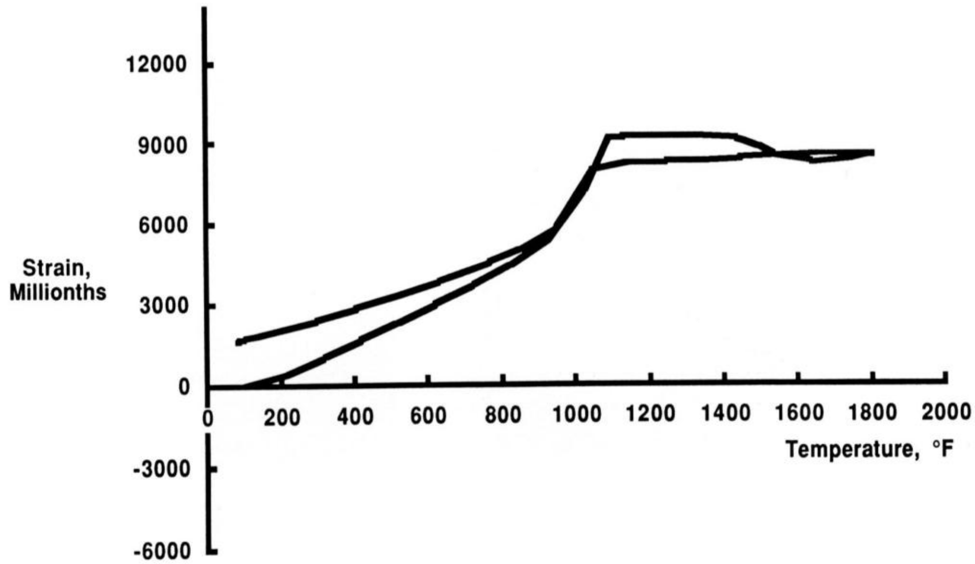


Figure 10.12. ***Thermal Expansion of Series "B" Highly Sanded Lightweight Aggregate Concrete Masonry Unit.***

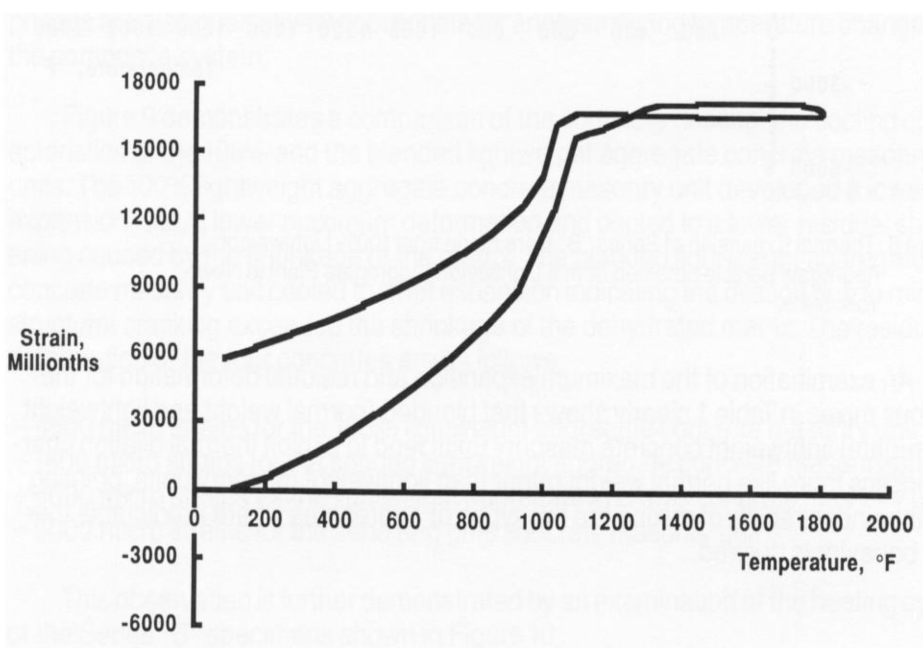


Figure 10.13. ***Thermal Expansion of Series "B" Sand and Grits Concrete Masonry Unit made with Normalweight aggregates.***

Concrete masonry may be considered a two phase composite composed of an aggregate fraction (about 70% by volume) and a "matrix" fraction that includes the hydrated cementious binder, a small volume of entrained air and a void system (5 to 15% by volume) characteristic of a manufactured, zero slump block concrete. As can be seen in Figure 10.14, the lightweight aggregate core produced an almost linear coefficient of expansion of 3.3 (in/in x 10^{-6}/ºF) throughout the temperature range of ambient to 1600ºF. The stable thermal characteristics are to be expected considering that during the manufacturing process. In effect, the lightweight aggregate was preburned in the production process.

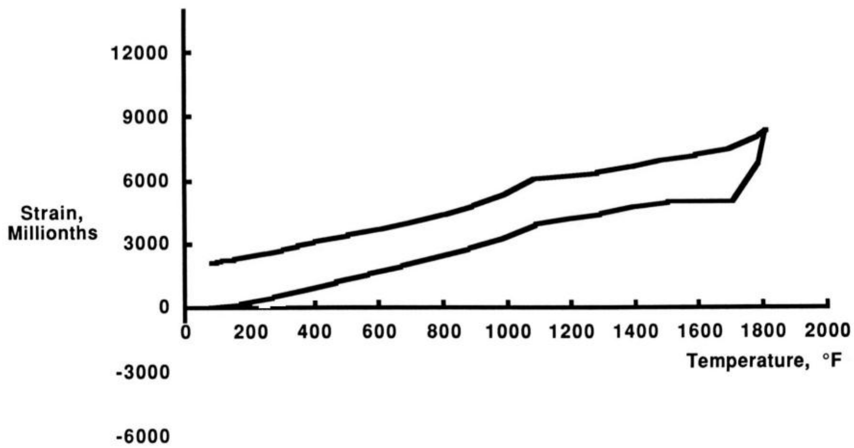


Figure 10.14. ***Thermal Expansion of Series "B" Core made from 100% ESCS Lightweight Aggregate particle.***

An examination of the maximum expansion and residual deformation for the various mixes in Table 10.4 clearly shows that lightweight concrete masonry units that include an excessive amount of thermally unstable normalweight aggregates tend to exhibit thermal dilation characteristics more like normalweight CMU's.

Table 10.4. Thermal Movement Characteristics of Cores (1/2" x 3") Drilled from Concrete Masonry Units of varying mixture compositions.

	"A" Series			"B" Series				
Description:	**100% LWA #1**	**100% LWA #2**	**Natural Agg.**	**LWA Core**	**100% LWA #3**	**Blended LWA #3 + Sand**	**Blended LWA #3 + Grits**	**Sand + Grits**
Coef. Of Linear Thermal Expansion In/in x 10^{-6}/ºF								
70-400ºF	**3.3**	**3.8**	**4.3**	**3.3**	**3.4**	**6.7**	**6.7**	**6.7**
400-800	**3.3**	**3.8**	**9.7**	**3.3**	**3.4**	**6.7**	**8.0**	**10.0**
800-1000	**3.3**	**3.8**	**14.0**	**3.3**	**3.4**	**6.7**	**15.0**	**20.0**
1000-1100	**3.3**	**3.8**	**32.1**	**3.3**	**9.3**	**30.2**	**29.9**	**46.6**
1100-1400	**3.3**	**3.8**	**Varies**	**3.3**	**-1.2**	**0.0**	**0.0**	**Varies**
Maximum Expansion In/in x 10^{-6}	**4200**	**4600**	**14500**	**8000**	**4200**	**9000**	**12000**	**17500**
Residual Deformation In/in x 10^{-6}	**-4400**	**-5100**	**+6600 to -300**	**2000**	**-4500**	**1800**	**4000**	**6000**

Reductions of internal microcracking as a result of the accommodation mechanisms developed by elastic compatibility of the matrix and lightweight aggregate phases were studied at ambient temperatures in an earlier paper (Bremner and Holm). The conclusions developed regarding the internal stress concentrations due to dissimilar elastic phases are also qualitatively appropriate for analysis during temperature changes of the composite system.

CMU's containing ESCS lightweight aggregate develop a low expansion rate, a lower maximum deformation and cool to a lower residual shortening caused by the shrinkage of the hydrated matrix. This observation is further demonstrated by an examination of the heating cycle of the Series "B" specimens shown in Figure 10.15.

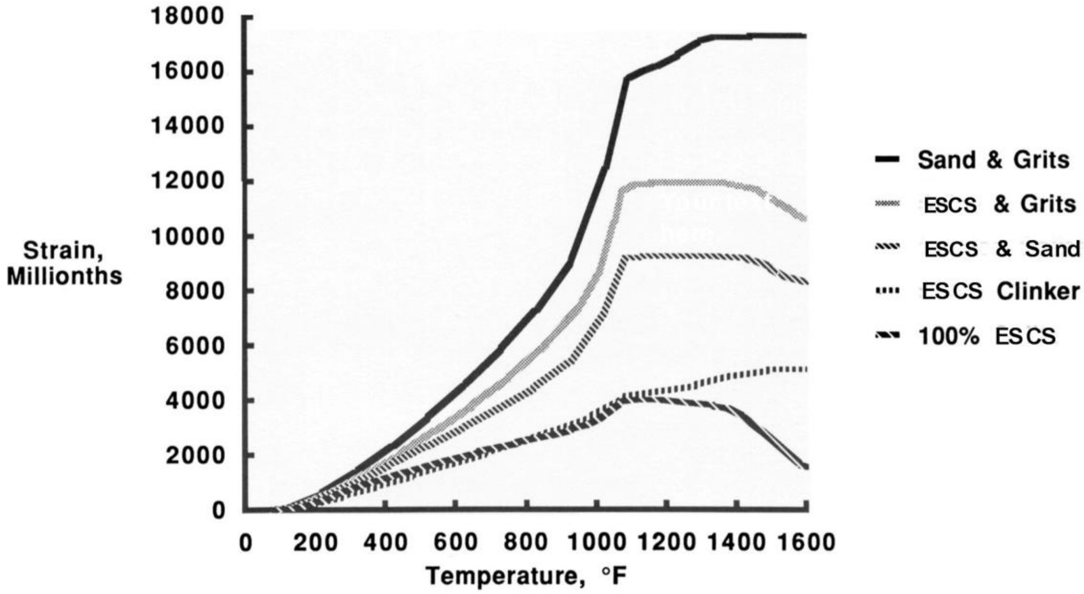


Figure 10.15. ***A comparison of Thermal Expansion of Concrete Masonry Unit made from Aggregates with different Thermal Expansion Characteristics.***

The physical mechanisms which determine thermal stability of aggregates and the mineral fractions from which they are composed are covered by Zoldners. The dominant role that the normalweight aggregates play in determining the thermal expansion of concrete made from them can be seen by noting the similarity in thermal expansion of the sand and grits masonry unit and the behavior of natural aggregates reported by Zoldners.

Application to Real Structures

Thermal stability must be provided by all of the constituents of a composite-system i.e. aggregates and the cementitious binder system, as well as providing accommodation between the differing thermal response of the two phases. This is essential to avoid concrete disintegration when exposed to violent thermal shock. This may be considered in the context of a microstructural thermal stability problem. This leads to macrothermal stability that may in turn be evaluated by considering the behavior of the wall system shown in Figure 10.16. This system was exposed to a one sided fire that induced bowing deformations caused by large temperature gradients through the wall system.

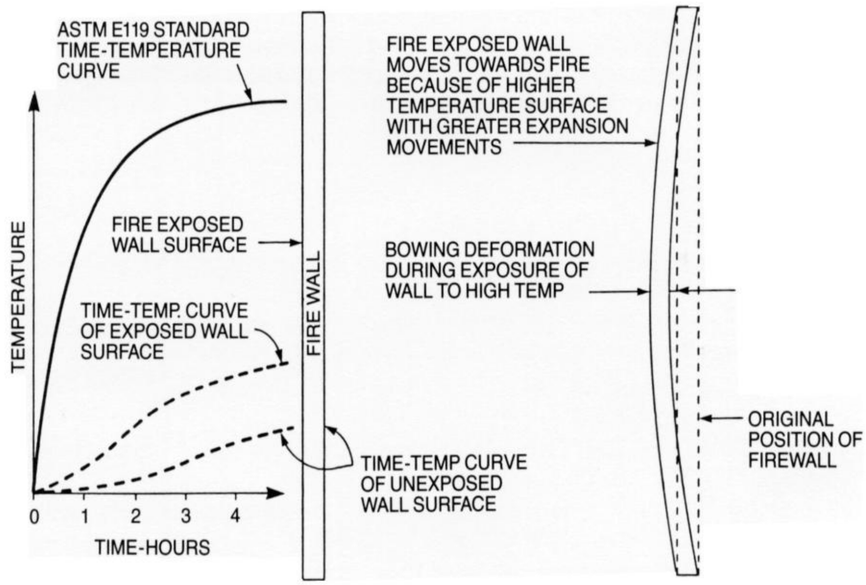


Figure 10.16. ***Schematic of Standard ASTM E 119 Fire Test and Resulting Bowing Deformation of Exposed Wall***

Summary

The coefficient of linear thermal expansion of a concrete masonry unit is not constant over the temperature ranges that fire walls are exposed to. Specimens of concrete masonry cores from three different lightweight aggregate concrete masonry units, two lightweight aggregate concrete masonry units containing an excessive proportion of normalweight aggregates and two totally normalweight concrete masonry units were examined for expansion characteristics when heated to 1800ºF and then cooled.

Because of the lower rate of thermal movement, lower modulus of elasticity and prior exposure to elevated temperatures during manufacture, block concrete composed of lightweight aggregates developed lower thermal expansions throughout the temperature ranges and cooled to low residual deformations. Several cores were taken from a single lightweight concrete masonry unit and they produced essentially identical thermal responses. Cores drilled from a natural aggregate concrete masonry unit showed wide variations in thermal behavior and developed the greatest rates of expansion and maximum heating and residual strains.

Lightweight concrete masonry units containing an excessive amount of normalweight aggregate tend to show thermal characteristics more like normalweight rather than lightweight aggregate concrete pointing out the desirability of limiting the proportions of normalweight aggregates where predictable thermal behavior is desired.

Section B-Properties of Lightweight Concrete Masonry Units

10.9 Density of Lightweight Concrete Used in Masonry Units

ASTM C 90 "*Standard Specification for Load bearing Concrete Masonry Units"*, and ASTM C 1209 "*Standard Terminology of Concrete Masonry and Related Units"*, have arbitrarily defined a *"*Lightweight Concrete Masonry Unit as a unit whose oven-dry density is less than 105 pcf (1680 kg/m^3). CMU's containing ESCS aggregates will develop oven-dry densities from 70-93 pcf (1120 -1500 kg/m^3). Therefore the ASTM definition allows the use of ordinary aggregates in a unit called "lightweight". When one considers all the aspects of sustainable construction (energy, ergomonics, life cycle, etc.) it becomes obvious this definition should be modified to meet current construction trends.

A more appropriate classification for the density ranges would appear to be:

	New kg/m^3 (pcf)	Present
Lightweight	< 1500 (<93)	1680 (<105)
Medium Weight	1500 – 2000 (94-125)	1680-2000 (105-125)
Normalweight	> 2000 (>125)	> 2000 (>125)

ASTM C 90 standard uses the word "normalweight to define concrete with densities over 125 pcf. This term is equally misleading as in many areas of the United States the normal concrete masonry unit that is used is a lightweight or medium weight unit.

For comparison purposes Table 10.5 give the approximate weight of CMU's at different densities. Table 10.6 compares SmartWall® CMU's at 93 pcf with heavyweight concrete masonry at 135 pcf.

Table 10.5 Approximate weight (lbs) of oven dry concrete masonry units as a function of concrete density

Nominal Thickness	Specified Thickness	% Solid	Gross Volume CF	Absolute Volume CF	Oven Dry Density of Block Concrete (pcf)					
					85	95	105	115	125	135
4	3.63	74	0.250	185	16	18	19	21	23	25
6	6.63	61	0.388	237	20	23	25	27	30	32
8	7.63	52	0.528	273	22	25	28	30	33	36
10	9.63	50	0.664	332	28	32	36	38	42	48
12	11.63	48	0.802	385	33	37	40	44	48	52

Table 10.6.Weight Savings with SmartWall®

Unit Size	SmartWall® Maximum Jobsite Weight lbs.(1)	Minimum Weight Savings Percent (2)	Typical Percent Solid
12x8x16	36	37	49
10x8-16	33	28	52
8x8x16	26	27	53
6x8x16	23	23	55
4x8x16	18	31	74

(1) Oven dry weight will be less than jobsite weights and will depend on ambient weather, unit shape and the concrete density used. The maximum jobsite weights are given just for field control to help for example, insure SmartWall® units are being used. For maximum oven dry weight of SmartWall units, contact your supplier.
(2) When compared to heavy concrete masonry at 135 lbs/ft³.

10.10 Mixture Proportioning Procedures for Lightweight Concrete Masonry Units

Proportioning
Mixture Proportions are generally developed through a trial and error process. It is however, possible to approach concrete masonry mixture designs through absolute volume calculations that incorporate the values associated with the binder and the aggregates. Through this technique, the interstitial void content (Fig. 10.17) may be computed and the interstitial porosity (interstitial void volume/total volume) determined. The effect of this interstitial void content on strength, stiffness, water permeability, and sound transmission is enormous.

The interstitial void system produced by the molding of zero-slump concrete masonry units is the principal difference between block and cast-in-place concretes; this difference is really one of degree, as all cast-in-place concretes contain entrapped air (± 2%) and concretes exposed to the weather generally contain deliberately entrained air (4 to 8%). Block concrete may have less than 4 and more than 10%. The influence of paste and aggregate porosity may also be evaluated.

As a further comparison between cast-in-place, fully compacted concrete to manufactured, zeros slump block concrete, consider the properties and production aspects shown in Table 10.7.

Table 10.7. A Comparison of Block and Cast-In-Place Concretes.

Property or Method of Control	Cast-in-Place Concrete	Block Concrete
Strength		
Compression	**28-day test for acceptance; carefully sampled, tested and evaluated**	**28-day test for acceptance; frequently over looked, often tested improperly**
Tension	**well documented for shear, torsion, and cracking analysis**	**generally ignored**
Modulus of Elasticity	**well documented for frame and deflection analysis**	**generally ignored**
Proportioning		
Mix Design	**Formerly volumetric, now by absolute volume analysis**	**Batch weight approach developed through experience**
Density	**Well documented and closely controlled**	**Generally specified, infrequently controlled**
Manufacturer's Control of Product		
Batching and Mixing	**Ready-mix driver controls to ASTM Specifications for Ready-Mix Concrete (C 94-74a)**	**Automated control in factory environment**
Compaction	**Contractor's responsibility**	**Totally under producer's control through feed and finish times**
Curing	**Little control; contractor's responsibility**	**Totally under producer's control at early critical ages**

Degree of Compaction

The concrete masonry producer has an opportunity to manipulate the physical properties of the unit through machine adjustments of feed, finish, and delay times as well as by optimizing the mix proportion and ingredients. The degree of compaction may be defined as (1-porosity) x 100. Commercial lightweight concrete masonry units manufactured in accordance with ASTM C 90 Specifications for Hollow Load-Bearing Concrete Masonry Units have interstitial porosities of approximately 10%, whereas highly compacted, high strength units may approach a void porosity of only 5% (95% degree of compaction). As an example, note the increased efficiency in strength potential through the increase in compactive effort (feed and finish time) demonstrated in Fig 10.18. Packing well-graded aggregates and filling the void system with efficient cementitious materials will greatly improve the compressive and tensile strength as well as the modulus of elasticity but will produce a corresponding increase in the density of the concrete. The interrelationship of strength, stiffness, and extensibility may be evaluated for any particular combination of mixture proportions and compaction by the stress-strain formula. Experiments with masonry units have validated the fact that the 5% increase in strength for each 1% reduction in the interstitial void system is roughly paralleled over a limited range with block concrete. With different aggregates and mixture designs this reduction factor may be as much as 8 to 10% per 1% of interstitial void content. In the development of high strength masonry units (3500 psi or 24 MPa or more), minimization of this void system is crucial.

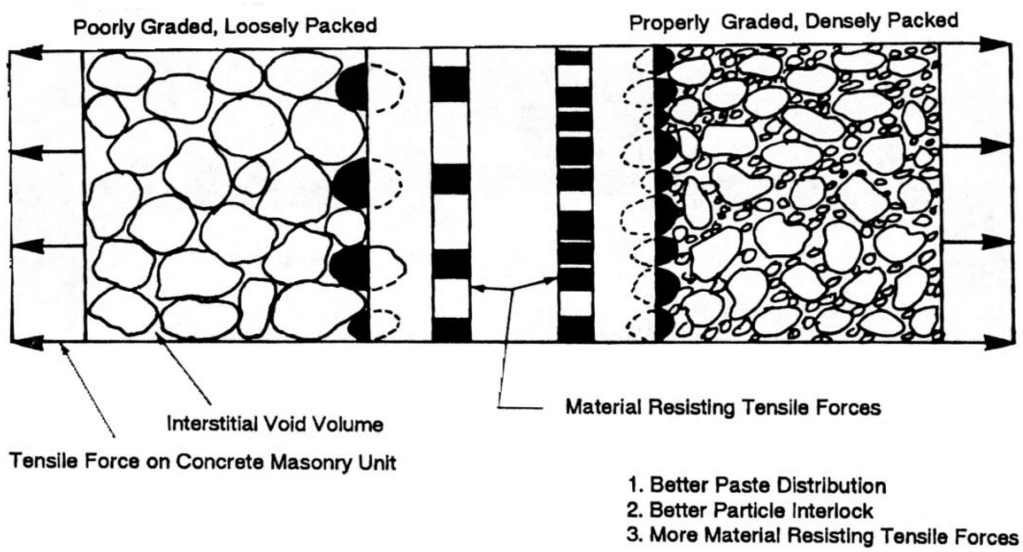


Figure 10.17. ***Pictorial view of influence of grading and compaction On tensile strength of block concrete.***

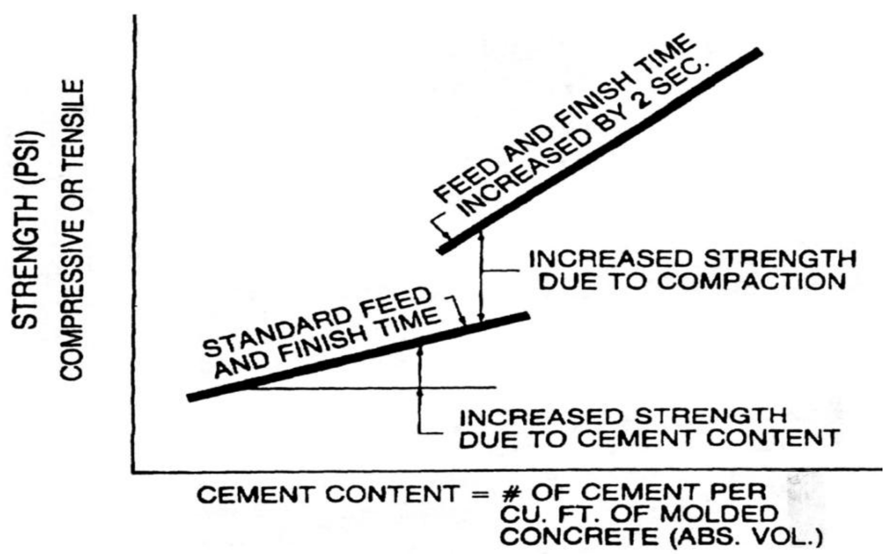


Figure 10.18. ***Effect of compaction on strength.***

10.11 Compression Strength of Lightweight Concrete Masonry Units

As with CMU's made from normalweight aggregates, lightweight concrete masonry units are designed to meet the physical requirements of ASTM C 90 "*Standard Specification for Load-Bearing Concrete Masonry Units"*. ASTM C 90 Section 5 "Physical Requirements at the time of delivery to the purchaser, units shall conform to the physical requirements prescribed in Table 1 and Table 2" (From ASTM C 90).

Note: Higher compressive strength then those listed in Table 2 may be specified when required by designer. Consult with local suppliers to determine availability of units with higher strength.

ASTM C 90 Table 1. Minimum Thickness of Face Shells and Webs

Nominal Width (W) of Units, in. (mm)	Face Shell Thickness (t_{fs}), min, in. (mm)[A]	Web Thickness (t_w) Webs[B] min, in. (mm)	Web Thickness (t_w) Equivalent Web Thickness, min, in./linear, [C] (mm/linear m)
3 (76.2) and 4 (102)	3/4 (19)	3/4 (19)	1 5/8 (136)
6 (152)	1 (25)[D]	1 (25)	2 1/4 (188)
8 (203)	1 1/4 (32) [D]	1 (25)	2 1/4 (188)
10 (254)	1 3/8 (35) [D] 1 1/4 (32) [D, E]	1 1/8 (29)	2 1/2 (209)
12 (305) and greater	1 1/2 (38) 1 1/4 (32) [D,E]	1 1/8 (29)	2 1/2 (209)

ASTM C 90 Table 2. Strength and Absorption Requirements

Compressive Strength, [A] min, psi (MPa)		**Water Absorption, max, lb/ft³ (kg/m³) (Average of 3 Units)**		
Average Net Area		**Weight Classification-Oven-Dry Weight of Concrete, lb/ft³ (kg/m³)**		
Average of 3 Units	**Individual Unit**	**Lightweight, less than 105 (1680)**	**Medium Weight, 105 to less than 125 (1680-2000)**	**Normalweight, 125 (2000) or more**
1900 (13.1)	**1700 (11.7)**	**18 (288)**	**15 (240)**	**13 (208)**

10.12 Tensile Strength of Lightweight Concrete Masonry Units

The tensile strength of concrete is approximately ten percent of the compressive strength. This relationship is not unusual among building materials: stone, cast iron, mortar, and clay masonry have a similar high ratio of compressive to tensile strength. It is curious that the compressive strength of concrete masonry is considered the sole criterion of quality while tensile strength has been generally ignored. The preponderance of masonry limitations are based on tensile strength and the development, through restraint, of a maximum tensile strain! (Holm)

Whether or not the origin of the forces are due to (1) restrained volume change (moisture loss, carbonation, temperature drop), (2) handling or manufacturing implications (culls, chipped corners), or (3) frame movements (structural frame deflections, foundation settlement), the limitation is almost always imposed by the available tensile strain capacity. In most instances the maximum compressive capacity in laboratory testing of units or prisms and especially high strength block is also limited by shear (diagonal tension) strength. Yet we busily break in compression millions of block supplied by hundreds of block plants in hundreds of laboratories. But consider when was the last time a true compression failure in a masonry application was reported in actual use?

The structural design of cast-in-place concrete is covered in ACI 318 "*Building Code Requirements for Structural Concrete"*. Included within this code are minimum tensile strength requirements, due to the influence on shear, cracking, torsion and flexural strengths. Tensile strength is measured on 6 x 12 fully compacted cylinders that are tested in accordance with the procedures of ASTM C 567 "*Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens"*.

ASTM Test C 496 can be adapted to the tensile testing of 100% solid lightweight concrete masonry units (Fig.10.19 and 10.20). The theoretical applicability of testing a rectilinear unit as opposed to a cylindrical specimen has been verified by Nillson and Davies and Bose. Other investigators have pursed research along these lines as well as recognizing the limitations of this method. While the strength levels of concrete used in masonry may start somewhat lower than structural concrete (1900 psi as opposed to 3000 psi or 13 MPa versus 21 MPa), the results of indirect splitting tests on 100% solid lightweight concrete masonry units of all ages and cures from twelve block plants are shown in Table 10.9. The relationship between tensile and compressive strengths, despite wide variations in age, is remarkably uniform and bears a close relationship to the data on structural lightweight concrete. In general, the ratio of tensile to compressive strength (f_t'/f_c') is lowered when compressive strengths are increased.

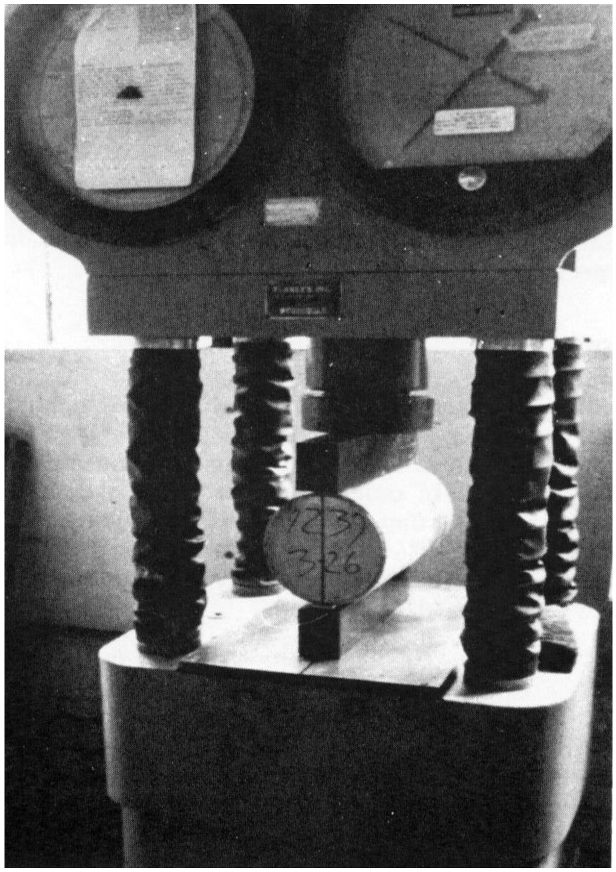


Figure 10.19 ***Test method to determine indirect tensile Splitting strength of 100% solid concrete masonry unit.***

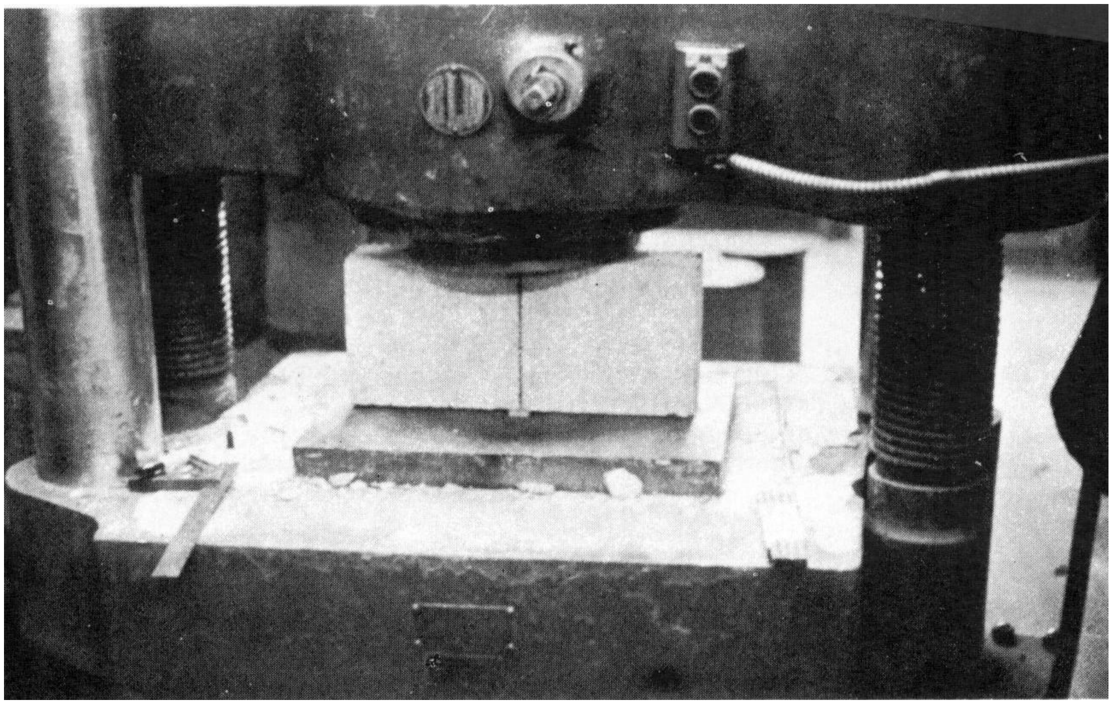


Figure 10.20 ***Test method to determine indirect tensile Splitting strength of lightweight concrete cylinder.***

Table 10.9. Indirect tensile strength tests of 100% solid lightweight concrete masonry units of various ages randomly sampled from twelve concrete block plants.

Block Plant	Oven-Dry Concrete Density Lb/ft³	Tensile Strength f_t' psi	Compressive Strength f_c', psi, Net area	f_t / $\sqrt{f_c}$	f_t/ f_c'
1	89.0	302	2620	5.90	0.115
2	83.3	370	3350	6.39	0.110
3	84.0	285	2780	5.41	0.103
4	89.4	232	2000	2.19	0.116
5	86.7	279	2680	5.39	0.104
6	93.3	340	2530	6.76	0.134
7	91.6	288	2180	6.17	0.132
8	91.6	286	2590	5.62	0.110
9	93.1	321	2950	5.91	0.109
10	97.0	305	3280	5.33	0.093
11	97.4	390	2990	7.13	0.130
12	93.5	305	2320	6.33	0.131
Avg	90.8	309	2689	5.96	0.116

10.13 Tensile Strain Capacity

A comparison of physical properties may be observed by rearranging the stress-strain formula to $e = f/E$, where e is the unit strain and f is the unit stess.

Thus, to achieve greater stain capacity (extensibility or the ability to deform prior to fracture) it is possible to improve the ratio between ultimate tensile strength and the corresponding modulus of elasticity.

Using the recommendation of Hedstom, the extensibility of concrete may be defined as the stain at 90% of the maximum strength achieved, see Fig. 10.21. To illustrate this, a comparison of an all-lightweight concrete masonry unit with a typical heavyweight unit by means of the modified formulas for cast-in-place concrete (ACI Code 318) follows.

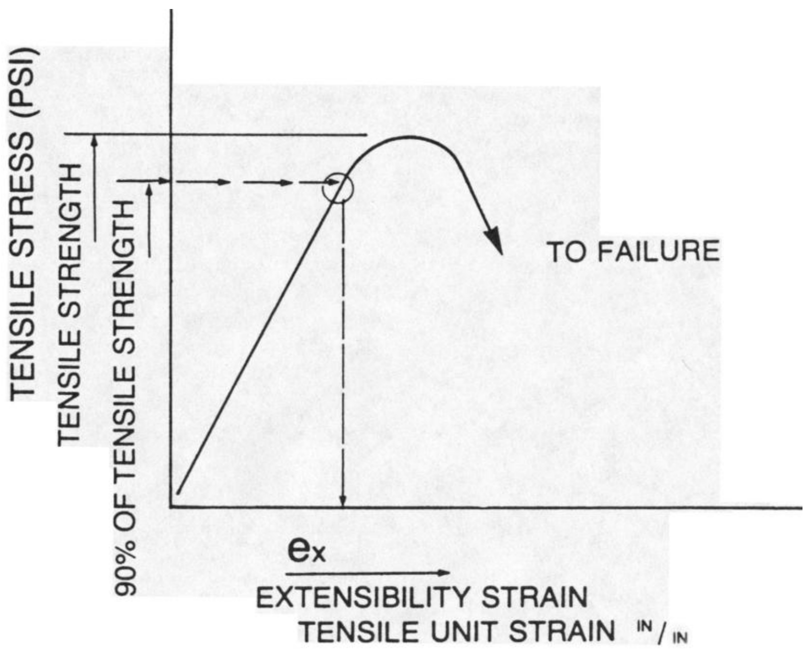


Figure 10.21. ***Definition of extensibility strain.***

All-Lightweight Concrete Masonry Unit 95 lb/ft³ (ASTM Specification C 90).

$$\text{Code tensile strength} = (0.75)(6.7)\sqrt{f'_c} = 0.75 x 6.7 x \sqrt{1900} = 219 psi$$

$$\text{Code modulus of elasticity} = 22W^{1.5}\sqrt{f'_c} = 22x95^{1.5}\sqrt{1900} = 888{,}000 psi$$

$$\text{Indicated strain} = \text{unit stress/modulus of elasticity} = {}^{219}\!/_{888{,}000} = .000247 \text{in/in}$$

Heavyweight Concrete Masonry Unit 135 lb/ft³ (ASTM Specification C 90)

$$\text{Code tensile strength} = 6.7\sqrt{f'_c} = 6.7\sqrt{1900} = 292 psi$$

$$\text{Code modulus of elasticity} = 22W^{1.5}\sqrt{f'_c} = 22x135x\sqrt{1900} = 1{,}505{,}000 psi$$

$$\text{Indicated strain} = \text{unit stress/modulus of elasticity} = {}^{292}\!/_{1{,}505{,}000} = .000194 \text{in/in}$$

Increased Indicated Strain Capacity

(Structural lightweight concrete masonry unit)/(heavyweight concrete masonry unit)=(0.000247)/(0.000194)=1.27. That is, with units of the same compressive strength, lightweight concrete masonry units can tolerate 27% greater deformation.

10.14 Sampling and Testing of Lightweight Concrete Masonry Units

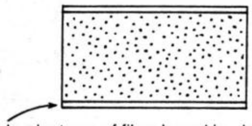
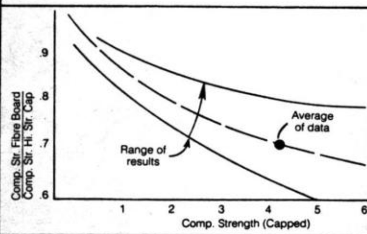
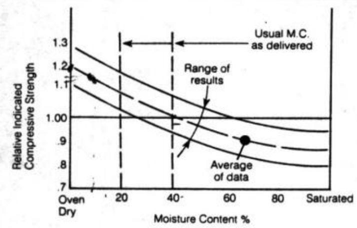
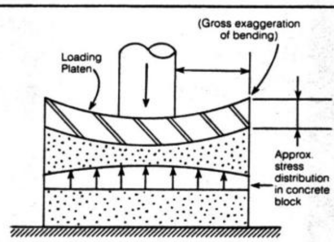
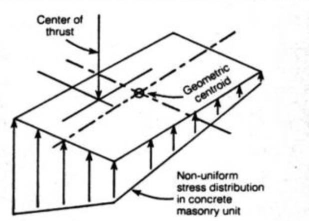
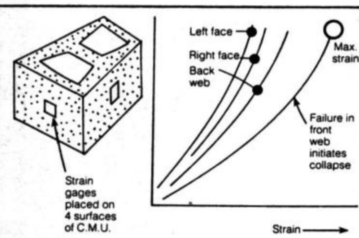
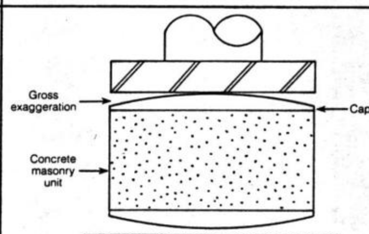
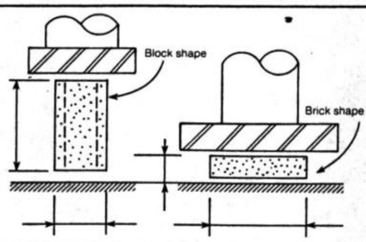
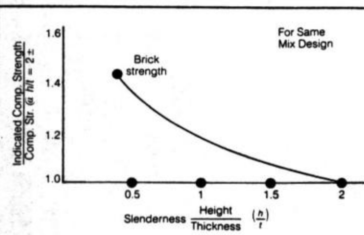
ASTM C 140 (Sampling and Testing of Concrete Masonry Units) is cited in almost every block specification, but it appears that all provisions are rarely enforced. Five samples should be tested in compression for every 10,000 units (or fraction thereof) used in a project. Furthermore, units should be tested periodically for the related property and concrete density. This data will yield other information, including net area and net volume. On a load bearing wall job, testing frequency may be modified to five units (or prisms) in compression for every 5000 sq ft (465 m²) of wall area, or once per floor.

It is important to recognize that consistent control of production variables has allowed careful manufacturers to reduce the over design factor in concrete block mixtures to a statistically acceptable minimum. Block producers are cognizant of this fact and make significant in-plant efforts to produce economical, quality units conforming to the project specifications. Characteristically, however, concrete masonry units are tested in the laboratory without an equivalent degree of care as to that given compression test specimen cylinders for structural concrete.

Table 10.10 and the following commentary describe the more important testing variables that may cause indicated test strengths to vary from (normally fall below) the actual strengths provided through the producer's diligent efforts.

> Capping techniques. For economy and convenience, fiber board is often used for in-plant quality control of commercial units. While producers generally recognize that fiberboard capping procedures reduce indicated test strength 10% to 15% below actual strength for normal commercial units, few recognize that the percentage of loss increases for high-strength units.
>
> Moisture content. Concrete block producers should provide units with appropriately low moisture contents for acceptance testing. High moisture decreases the compressive test strength. Load bearing walls are generally protected from the weather, and laboratory testing procedures should recognize the lower equilibrium moisture contents of protected masonry construction.

Table 10.10. Influence of Major Testing Variables on the Indicated Compressive Strength of Concrete Masonry Units

Variable	Cause of Variation	Effect on Indicated Strength	Reference (Remarks)
Capping Material	 In-plant use of fibre board in place of lab prepared thin cap of high-strength gypsum, sulfur, mortar etc. Soft fibre board spreads, causing lateral tension.		(A) Holm (C.O.B.) (B) Roberts. (C) Self 1. Solid block tend to have smaller loss of indicated strength when tested with fibre board. 2. Irregularly surfaced blocks produce wide scatter and greater loss.
Moisture Content of Concrete Masonry Unit at Time of Test	Axial loading causes secondary hydrostatic pressures due to moisture content resulting in additive lateral tensile forces.		(B) Roberts (C) Self (D) NCMA (Concrete Masonry Units should be delivered to lab at moisture contents comparable to intended use)
Thickness of Loading Platen		Considerable loss of indicated compressive strength on high strength CMU's if ASTM C140 is followed ($t = l/_3$ to furthest corner). California Concrete Masonry Tech. Comm. recommends $t = l$ to minimize bending of platen—thus developing uniform deformations and stresses.	(E) C.C.M.T.C.
Center of Thrust Not Co-Linear With Geometric Centroid			(A) Holm (H) Failure is precipitated by excessively loaded corner or face resulting in false, low indicated strength.
Non-Uniform Thickness of Capping		15% loss of indicated strength from tests on units sampled from same cube sent to second lab for re-testing. (Actual high rise project).	(A) Holm (F) ASTM C140 stipulates planeness within 0.003 inches in 16 inches. Max. thickness of cap ¼″ with sulfur, ⅛″ with gypsum plaster.
Shape Effect			(A) Holm (S) Indicated relationship applies to one type and strength of unit. Strength ratio varies with aggregate type, block strength, etc.

(A) Holm, T. A., unreported data from experimental block runs in various plants. (C. O. B. H. F. S.)
(B) Roberts, J. J., see ref (8) at end of paper
(C) Self, M., see ref (7) at end of paper
(D) NCMA, see ref (6) at end of paper

Rigidity of load platens. Various investigators have determined that past ASTM thickness requirements for compression test plates were not sufficient. Thick plates are required to develop uniform distribution of test load from the spherical test head of the testing machine to the outer corners of the concrete block units and prisms (See ASTM C 140).

Precision of vertical and horizontal alignment. Colinearity of the geometric axis of the specimen relative to the centroid of the loading thrust is vital in the testing of high-strength masonry. Misalignments and lack of perpendicularity can cause premature failure due to biaxial bending and horizontal shearing forces. In some instances, investigators have noticed horizontal tensile cracks opposite to the heavily loaded side of a specimen after initial failure, thus indicating misleading test strengths.

Non-uniform cap thickness (out-of-plane). Another area of poor practice is the occasional failure to provide planar capped surfaces within a flatness tolerance of 0.003 in. in 16 in. (1 mm/m). In one instance, capped surfaces were so poorly aligned that the lack of alignment could be seen from over 10 ft (3 m) away. Measurement revealed almost 1/4 in. (6 mm) misalignment. This problem generally occurs with high-strength capping plaster where the high-strength gypsum paste is made too stiff and the average thickness of the cap exceeds 1/8 in (3 mm). It is vitally important that capping be thin and uniform to assure that the unit, not the cap, is tested. Parallelism of capped surfaces is also important.

Shape factor. When comparing strength levels of various types of specimens with different height-to-width ratios, it is important to recognize that the indicated test strength may require adjustment by a correction factor relating the slenderness ratio of the test specimen and the restraining influence of the test machine platens. A brick sized unit may show an indicated compressive strength as much as 40% higher than a much larger concrete block shape made from the same concrete mix with equivalent machine time. The increased test strength is due to the influence on the failure mechanism of frictional restraint by the loading platens as well as the reduction of bending moment magnification caused by the slenderness ratio.

Testing age. Concrete masonry units increase in strength with time somewhat less than structural cast-in-place concrete. The rate of strength increase is significantly modified by curing parameters (curing time, pressure, and temperature) and type of unit. Solid units show a greater increase in strength than hollow units. This is because moisture used in molding is released slowly due to the high compaction of high-strength mixes.

Engineered masonry codes generally provide two alternative methods for determining the allowable masonry compressive strength f'_m. One method is based on selection from a table of an empirical value for the strength of the walls (f'_m) based on the compressive strength of the individual units (f'_c). The other method allows use of a value for f'_m determined by testing small samples of walls called prisms. ASTM C 1314 "Standard Test Method for Compressive Strength of Masonry Prisms", describes the procedure for testing small walls of masonry incorporating typical units, mortar, and workmanship to determine data for a given project. When project specifications call for f'_m to be verified by prisms testing, the usual requirement of one series of tests per floor or 5000 sq ft (465 m^2) of wall area governs. The obvious purpose is to closely represent the masonry assembly actually constructed. Individual concrete masonry units should be tested concurrently with the prism tests to allow determination of responsibility should prism test results fall below the specified value of f'_m. The need for prism testing is growing due to widespread use of load bearing masonry in high-rise building construction. Prism testing is also used to justify greater f'_m / f'_c ratios through more exacting testing and controls. Economical construction of large buildings requires valid strength information in order to permit structural engineers to utilize the higher design stresses. Problems confronted in prism testing are similar to the problems experienced in testing individual units, and include the following:

Low-strength concrete masonry units.

Improper curing and handling, such as dropping or bumping during transportation.

Improper caps are more detrimental to accurate prism tests than for individual units due to increased magnification of eccentric and non-uniform loads.

Poor workmanship in placement of units on mortar course will cause decreased f'_m values. High quality workmanship is needed in both prism testing and field construction.

Inadequate strength of grout and mortar.

10.15 High Strength Lightweight Concrete Masonry Units (HSLWCMU)

The widespread usage of engineered masonry has prompted a re-examination of the concrete masonry unit. No longer a mere infill or space separation, concrete block is now an accredited structural material that requires the close engineering scrutiny and sophisticated production controls usually associated with cast-in-place concrete. Engineers and architects designing these practical, economical load bearing projects must therefore have some understanding of the fundamental physical properties of this building element. Block plants producing these higher strength units must also determine the methods of reliably manufacturing concrete masonry units to exacting specifications.

This section addresses:

- Production methods necessary to manufacture high strength lightweight concrete masonry units.
- Physical properties of high strength lightweight concrete masonry units.
- Considerations of testing units and prisms in meeting engineering specifications.

Production of High Strength Lightweight Concrete Masonry Units

The investigation into the manufacturing variables was conducted by actual production of high strength concrete masonry in many block plants over a period of many years. The procedure was to request permission from the concrete block producer to send in a team of engineers and field service representatives to produce several batches of high strength and conventional block and then conduct strength and laboratory physical testing on blocks produced from these runs. High strength lightweight concrete masonry units have been successfully produced in numerous studies throughout the U.S. This test data has been compiled and the factors affecting costs, strengths, production factors and the physical properties of the manufactured concrete are covered in this section.

The test runs are essential to produce the first batch in precisely the manner the block plant manufactures the conventional ASTM C 90 lightweight masonry unit. With this unit as a standard the cement content was increased and as a separate variable the feed and finish times were increased as well. Quoting mix designs and feed and finish times in an industry where so many factors influence the final product is not reasonable and this section will avoid specifics. In general the following facts have been determined:

Considering all the many runs, the evidence points to a strength level of 3500 psi net as a readily available standard for high strength masonry units. The NCMA committee that produced the report on special considerations for manufacturing high strength concrete masonry units substantiated this criteria and also added an ultra high strength level. Experience has shown that testing and production factors develop limitations on the ultra high strength level which unnecessarily complicate the issue for most ordinary projects.

The specified strength can be exceeded in some plants by merely varying the mixture design but in most cases requires simultaneously increasing the feed and finish time to obtain greater compaction. The interrelationship of feed and finish is not generally understood and close rapport with plant personnel in accounting for this behavior is mandatory. Adequate compaction should be the fundamental objective of the block manufacturer. See Figure 10.17 for an example of the strength increase due to increased compaction. Actual production of economical high strength units will determine minimum feed and finish time and will also require running the units as wet as possible short of smearing the texture. In this instance the cheapest ingredient is water.

The cost of producing the unit must reflect the greater material costs as well as the slower production rate and the extra marketing servicing and testing costs.

High cement requirements will require exacting gradation control in order to minimize sticky mixes that are difficult to feed.

As in high strength ready-mix concrete, selection of high performance cementitious material is essential for the production of high strength block concrete.

Normal curing practices are adequate but should be investigated at each plant in order to optimize the hydration of these rich and well compacted mixes. An increase in preset time for all types of curing on the order of two hours over conventional timing practices is desirable.

Physical Properties of High Strength Lightweight Concrete Masonry Units

High cement contents and increased compactive efforts have produced lightweight concrete masonry units with physical properties substantially different from the conventional C 90 units traditionally produced and tested. In some instances these changes require a re-thinking of the usual practices in specification writing, joint reinforcing and architectural detailing. A synopsis of the physical properties is listed below:

STRENGTH LEVEL The dual requirements of high strength (plus 3500 psi net) combined with the size of the concrete masonry unit mandate the use of a structural aggregate with the highest strength to weight ratio. Non-structural lightweight aggregates are not practical. All block producers should make preparation for the advent of supplying high strength engineered masonry projects well in advance of their actual need in order to adequately research the various possibilities of producing a high quality unit.

STRENGTH VERSUS TIME For high strength units, the increase in strength with time is greater than that of traditional units. This is due to the continued hydration developed by the reluctance of highly compacted units to release unchemically combined water. The rich cement contents continue to develop strengths beyond the usual plateau associated with regular C 90 units.

DENSITY The extra compactive effort and rich mixtures will produce an increase in density averaging 7.4%. The compactability of the mixtures depend on aggregate grading characteristics, particle shape, block machine cycle and compactive efficiency. The weight of a standard 8x8x16 2-core hollow unit will typically increase from 1.0 to 3.5 pounds. Specifications and labor restrictions governed by concrete density must reflect these changes.

ABSORPTION The decrease in absorption (See Figure 10.22 for this relationship) generally parallels the increase in density with an average decrease of 24%.

SHRINKAGE Linear drying shrinkage of high strength units relative to traditional C 90 units generally increased from 0.005 to 0.010% for various types of curing, the increase of shrinkage being due to the increased paste content of the high strength mixtures. In manufacturing high strength units with only slightly increased shrinkage, the producer should clearly emphasize the compaction contribution, thus choosing a slower production cycle with rather moderate increase of binder. The majority of engineered masonry buildings are of the "crosswall" type, in which the short dimension of the building is generally composed of two 20 to 30 foot long walls interrupted by a center corridor and thus this increase in shrinkage has proven to be of no significance. "Longitudinal wall" type projects, where the bearing walls run the long length of the building, may necessitate close scrutiny in regard to location of control joints.

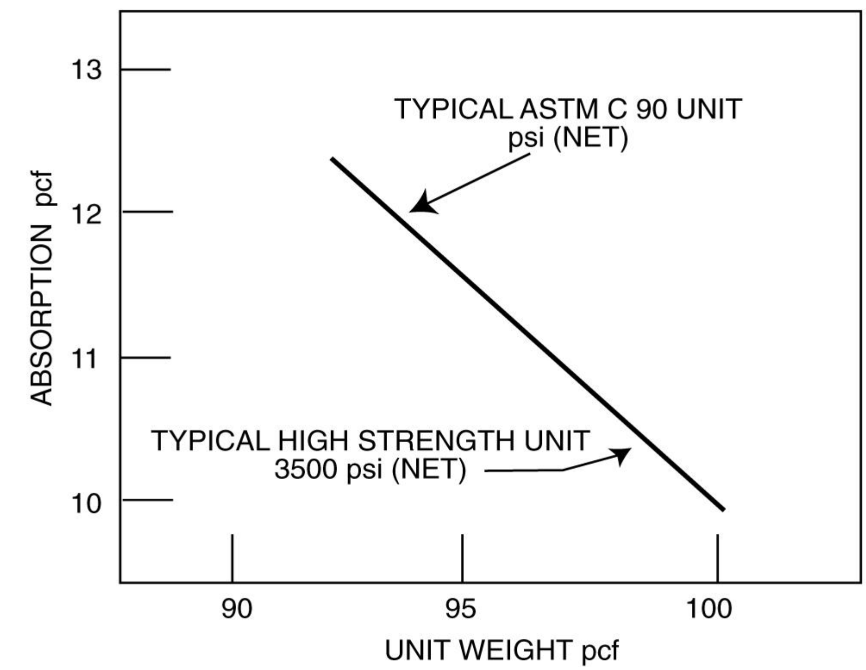


Figure 10.22 ***Absorption versus Unit Weight of Concrete***

Laboratory Strength Testing of High Strength Units

Testing of high strength units, particularly the large solid units, presented challenges that were eliminated after some concerted effort. The problem stems from the fact that the compression testing equipment of most commercial testing laboratories has a maximum capacity of 300 kips (300,000 pounds – a kip being 1000 pounds). Thus for example in meeting a specified 3500 psi net strength, and average strength of say 3800 to 4000 psi will be produced and an 8" – 75% solid could develop 7.62 x 15.62 x 4000 x .75 = 357^k. In order to adequately document a project as well as to prepare for future field testing, the following program was conducted:

a) Whole unites (12" – 75% solid) were tested in the Fritz Engineering Laboratory of Lehigh University with an 800 kip machine.
b) Three units were sawed in half by making several passes with a testing lab saw – 3 half units were tested.
c) Prisms of 2 unit high 12" – 75% solids were tested. See Figure 10.23.
d) At an independent testing laboratory the 12" units were core drilled by a concrete coring machine and the cores carefully centered and tested in compression.

The results of the test may be generalized as shown in Figure 10.24.

From the completed testing program the following deductions and observations may be made:

a) For projects involving large size high strength units, saw cutting into half units will provide conservative results that may be tested in ordinary (300^k) testing machines.

b) From a concrete technology standpoint the strength of cores relate to the units (approximately 87%) in a manner comparable to our experience in field tests on cast-in-place concrete.

c) The mode of failure in units, cores and prisms is of a shear type and seems to be independent of mold configuration but affected by height to width ratio (within certain limits). See Figure 10.25. Anxiety about the ability of webs to transfer shear in eccentrically loaded tests was found to be unwarranted. Accurate centering of the units in the testing machine is absolutely essential to avoid bi-axial bending which causes premature failure in one heavily stressed corner or faceshell.

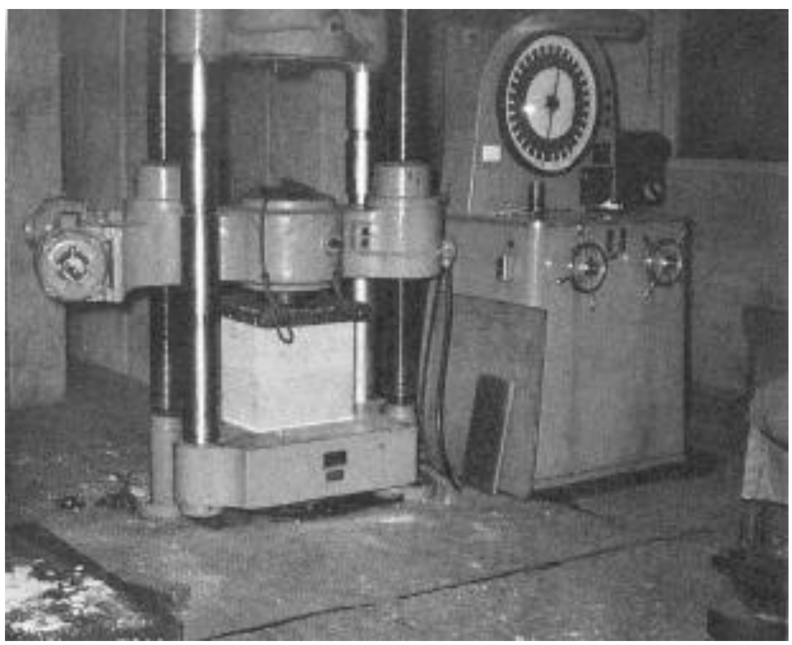


Figure 10.23. ***Test setup for 2-high prisms***

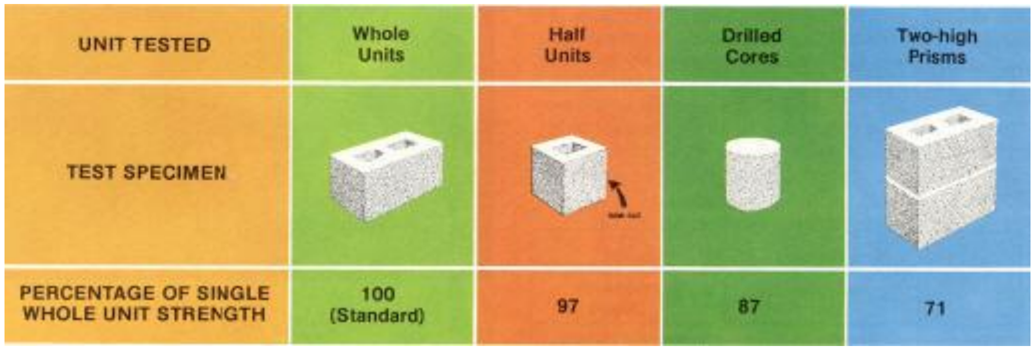


Figure 10.24. ***Relationship of compressive strengths to type of test specimen***

Figure 10.25. ***Typical test specimen failure mode***

Meeting Strength Specifications of Engineered Masonry Projects

The MSJC code allow two different methods for determination of the wall strength. In one method, the wall compressive strength (f ′ m) is directly related to the compressive strength of the CMU by an empirically developed code table. This requirement is then met in a direct, straightforward way by the block producer supplying units exceeding the necessary compressive strength.

In the other method the engineer may choose to specify the wall strength (f'_m). This approach shifts the responsibility to the contractor who then must conduct prism tests to develop information that combines the variables of unit strength, mortar characteristics and workmanship. Clearly, the introduction of the mortar and mason workmanship factors are beyond the control of the block producer and recognizing this fact he must understand the limits of his responsibility and cooperate with the contractor in achieving the desired prism performance. As an indication of these relationships, as well as that of 7 to 28-day strengths, values developed in the investigation mentioned earlier are shown in Table 10.11.

Table 10.11 High Strength Unit Test Values (psi)

	f'_c (Net Compressive Strength)		f'_m (Net prism Strength)	
Age Days	ONE-HIGH UNITS		TWO-HIGH PRISMS	
	WHOLE	HALF	WHOLE	HALF
7	4600-	4380	3250	
28		5080	3460	3650

Performance of Engineered Masonry

Architects and builders who have inspected completed projects have been impressed by the speed, simplicity and performance of high strength lightweight concrete masonry walls. Of particular importance to prospective owners is how superbly this type of structure meets the Sound Transmission Class requirements posed by the new administrative building codes. Requirements of a minimum Sound Transmission Class ratings mandate substantial separation and inevitably raising the question – "If you must provide adequate space separation for sound, privacy and fire requirements – why not use the wall for structure as well?" Engineered masonry has thoroughly answered this question and has provided the occupants with the safety and tranquility they deserve.

The economies of load bearing masonry are fundamentally determined by the architect's willingness to lay out the project's wall systems in a systematic, repetitious fashion. Layouts for motels, housing for the elderly, dormitories and apartments are easily accommodated. With a precast plank floor system placed on the walls, the system approaches the ultimate in simplicity in that one merely builds a one story structure several times – an appealing concept to the mason contractor and material suppliers. This approach lends itself to extremely rapid construction with all the mechanical and finishing trades following closely behind the wall construction and always working in a protected enclosure. In a period of high interest rates on construction money this rapid occupancy is of vital importance to owners and in some cases is becoming a significant desirable feature of engineered masonry.

Cost comparisons of engineered masonry with other structural systems on appropriate projects have consistently demonstrated far lower structural costs. Incidentally, it is of basic importance to consider the following often overlooked fact: the engineer's cost comparison on a per square foot basis must include the addition of partitions to other system frame cost. In the engineered masonry project they are already included!

Built-In Advantages of Engineered Masonry

Simple – The construction of a multi-story masonry building consists of a series of single story buildings placed one on top of the other. Since few trades are involved scheduling of manpower and materials is easily accomplished.

Economical – Combined with precast lightweight concrete floor planks which are readily available and easily place, engineered masonry units of high strength provide in a single installation structural capacity, space enclosure, fire wall, conduit space and an effective sound barrier.

Fast – With shoring and scaffolding virtually eliminated progress is very rapid after foundations are finished. When masons complete the floor, mechanical, electrical and finishing trades can go to work immediately inside an enclosed space. The speed of construction results in earlier occupancy and faster return on investment to the owner.

Fire Resistant – Positive separation of spaces provided by the proven performance of noncombustible partitions meet fire code requirements for 2, 3 and 4 hour ratings with commercially available units.

Quiet – The substantial walls provided by the structure eliminate the number one complaint of other types of construction – NOISE. High sound absorption and resistance to sound transmission developed by lightweight masonry units provide the occupant with maximum privacy.

Figure 10.26. ***The Dunes Motel, Virginia Beach, Virginia***

10.16 Durability (Resistance to Freezing and Thawing) of Concrete Masonry Made With ESCS and Ordinary Aggregate

The long service life performance of concrete masonry walls is well established. Instances of lack of durability are almost unknown. The primary reason for this long service life is that CMU walls are usually vertical and are frequently protected by a paint or coating, or by other masonry units, e.g. bricks.

The fact that the voids in CMU's are essentially connected provides permeable path for the moisture in front of the frost line, thus relieving, or eliminating the restraint that causes internal stresses due to the 11% expansion in the formation of ice. Additionally, the free draining verticality also limits the possibility of the block concrete reaching a critical degree of saturation.

Still it must be understood that in order to produce highly compacted zero slump block concrete there must be sufficient mortar to fill the voids between aggregate particles. This produces a void content that may vary from about 5% for highly compacted high strength units to as much as 10% for CMU' graded for texture and manufactured at high rate of speed.

Consider for example a 50 cf batch of CMU's, made with a cement content of 400 pounds. If this batch yielding 130-8" units then:

$$\mathbf{130 - 8'' units (abs\ vol.\ of\ .27\ cf) = 35.1\,\mathit{cf}\ of\ solid\ block\ concrete\ or}$$

$$\mathbf{\frac{35.1}{27} = 1.3\ cubic\ yards\ of\ solid\ concrete.}$$

$$\mathbf{Then\ the\ cement\ content = \frac{400\#/batch}{1.3\,cy/batch} = 308\,pcy}$$

If the unit was placed in a horizontal mode and exposed to freezing/thawing at a critical degree of saturation, a long-term service life could not be anticipated. No concrete technologist would give assurance of durability for a sidewalk constructed with a concrete containing 5-10% voids (honeycombing as expressed in a cast-in-place concrete semantic) and with a binder content of 308 pcy.

Durability is enhanced by an adequate amount of cementitious material, a low void content that is achieved by a properly graded aggregate that is surrounded by a fully compacted matrix.

In 1998 the Expanded Shale, Clay and Slate Institute conducted a comprehensive investigation into the resistance to freezing and thawing of concrete masonry units manufactured with ESCS and ordinary (heavy) aggregate. This project included commercially available lightweight and normalweight block concretes used in the manufacture of segmental retaining wall (SRW) units. The mixtures were run at 13 different block manufacturing plants with all units made being 4 x 8 x 16 in. (102x204x406 mm) solid masonry units. Coupons (5 per mix) were cut from the end of the 4 x 8 x 16 in. (102x204x406 mm) solid units, and sent to the University of New Brunswick (UNB) to be tested according to the American Society for Testing and Materials (ASTM) C 1262-94, *Standard Test Method for Evaluating the Freezing Thaw Durability of Manufactured Concrete Masonry Units and*

Related Concrete Units. Tests for strength, absorption, and density (unit weight) were completed at local laboratories on companion specimens. The results of these tests were analyzed to determine if lowering the weight of a SRW unit by adding ESCS lightweight aggregate would affect the freezing-thawing durability of the unit. As a secondary interest, the data were analyzed to determine if any correlation existed between the extent of deterioration and the absorption, cementitious content, strength, and admixture usage.

Based on the results of these tests the density of the concrete masonry units appears to have no significant effect on the results of the ASTM C 1262-94. Consequently, concrete masonry units containing expanded shale, clay and slate can be expected to perform as well as normalweight aggregates where freezing and thawing is involved.

The reason for doing this work was two fold. First, to help set industry standards for durable concrete SRW units. Secondly, SRW units made with normalweight aggregate are very heavy, with some weighing more than 100 lbs. (45.5 kg) each. If the units weighed less, there would be many economical advantages. Labor productivity on commercial projects would greatly increase because less weight would be handles. The do-it-yourself market would benefit because the SRW systems would be more user friendly and easier to handle. Other advantages would be fewer worker-compensation injuries, and more lightweight units can be transported with less trucks.

Segmental retaining wall units are frequently placed in harsh environments where a large number of freezing and thawing cycles can occur each year. Also, they are used in exposed environment applications where they can absorb water. Any voids in the hydrated cement paste or aggregate that are greater than 91 percent full will develop a hydraulic pressure when the water changes to ice, unless the water can be escape from the void during freezing. Masonry units, being of a porous texture, tend to lose water during the dry season of the year and so the chances of having voids fully saturated during the cold wet season are reduced. Although masonry units normally are not air entrained, they frequently have a chemical admixture added to the mix that would entrain some air in a regular concrete mixture. When expanded shale, clay and slate aggregates are used to produce lightweight concrete masonry units the vesicules within these expanded aggregates can act as relief mechanisms. The pores within the aggregates can provide relief from the hydraulic pressure developed during the freezing of the concrete. With normalweight aggregates that contain coarse internal channels that easily fill with water, the opposite can occur. Mixture proportions testing procedure etc. are covered in detail in ESCSI information sheet #3384.

10A

ASTM C 331-05
“Standard Specification for Lightweight Aggregates for Concrete Masonry Units”

Visit www.ASTM.org for document

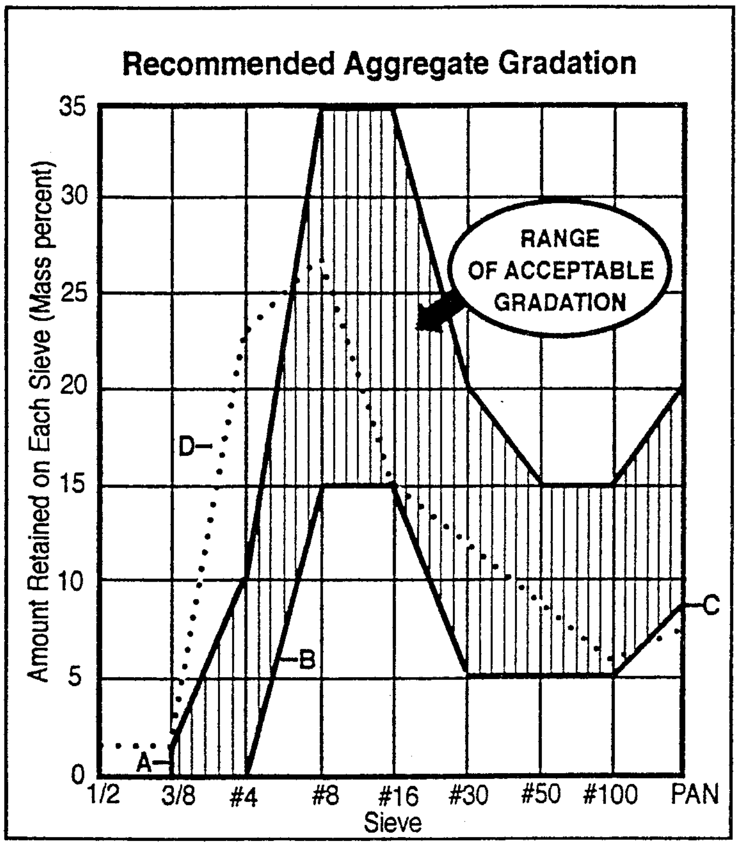
10B

ESCSI Information Sheet 3555
"Recommended Combined Aggregate Gradation for High Quality Lightweight Concrete Masonry Units"

Information Sheet 3555

Recommended Combined Aggregate Gradation For High Quality Lightweight Concrete Masonry Units*

Proper aggregate gradation is an essential ingredient in producing high quality concrete masonry units. The aggregate gradation range shown optimizes the particle size distribution which in turn optimizes the quality of the lightweight CMU in the following ways: (1) Compactability and high strengths are obtained without excessive amounts of cementitious materials. (2) Shrinkage is reduced by maximizing aggregate contact. (3) Water absorption and penetration are reduced because of higher strengths, tighter textures and fewer interstitial voids. These three qualities also enhance the effectiveness of water repellant coatings. (4) Freezing and thawing durabiltiy is improved because of better compactabiltiy and fewer interstitial voids.



Reference: *Recommended Gradation for Structural Lightweight Aggregate Used In High Quality Masonry Units*, by Thomas A. Holm, PE, FACI 1997.

Comments

A. Keep 3/8" particles to a minimum.

B. Uniform, tight texture surface provided by the material on #4 and #8 screens

C. A minimum of 8% passing the #100 screen is desirable for green strength, moldability and compactibility with today's faster block machines. Less than 8% is acceptable when using rich mixes or supplementary cementitious or pozzolanic materials.

D. Today's high quality CMU's with high strengths, low permeability, and uniform tight textures require a finer gradation than indicated by the dotted gradation curve. This dotted curve was compiled many years ago by averaging what was being used to make a lightweight "popcorn" textured block. The dotted curve allowed excessive particle size distribution on the 3/8" and #4 sieves, and inadequate on passing the #100 sieve.

Sieve Size	Amount Retained On Each Sieve (Mass %) (see graph above)	Cumulative Retained-Amount Larger Than Each Sieve (Mass %)	Cumulative Passing-Amount Finer Than Each Sieve (Mass %)
3/8"	0-2	0-2	98-100
#4	0-10	0-10	90-100
#8	15-35	20-40	60-80
#16	15-35	45-65	35-55
#30	5-20	60-75	25-40
#50	5-15	70-85	15-30
#100	5-15	80-92	8-20
Pan	8-20	100	0

*Aggregates Conforming To ASTM C 331 or C 33 (whichever is applicable)

Rotary Kiln Produced Structural Lightweight Aggregate

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10C
Grading Work Sheets

Combined Aggregate Gradation Report For Lightweight Concrete Masonry Units*

MATERIAL SOURCE ________________ SAMPLED FROM ________________

________________ SAMPLED BY ________________

REMARKS ________________

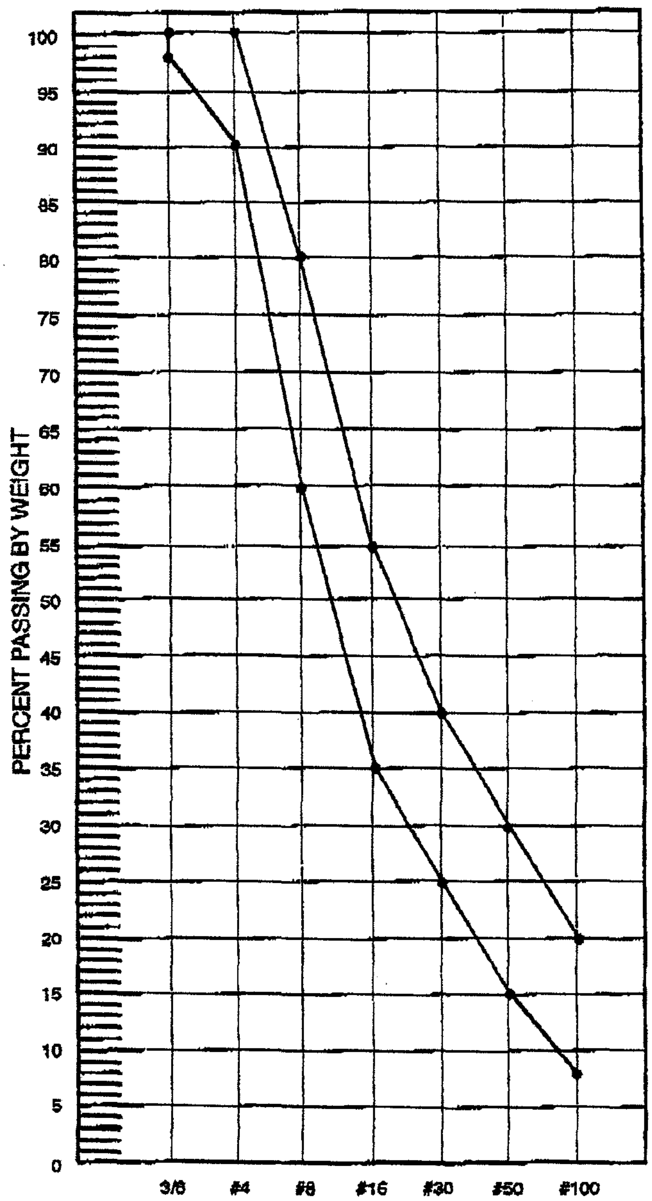
________________ DATE ________________

WT. AS RECEIVED ________ DRY WT: ________ % FREE H_2O: ________

LOOSE MOIST WT. ________ LOOSE DRY WT: ________ FINENESS MODULUS: ________

U.S. SIEVE	WEIGHT	% RET.	CUM. % RET.	% PASSING	SPECIFICATION % PASSING
3/8"					98-100
4"					90-100
8"					60-80
16"					35-55
30"					25-40
50"					15-30
100"					8-20
PAN					0

AGGREGATE GRADATION GRAPH (CUMULATIVE PASSING)



*AggregatesConforming To ASTM C 331 or C 33 (whichever is applicable)

June1999

Combined Aggregate Gradation Report For Lightweight Concrete Masonry Units*

COMPANY NAME ______________________________

PHONE # ______________________________

MATERIAL SOURCE ______________________________ SAMPLED FROM ______________________________

______________________________ SAMPLED BY ______________________________

REMARKS ______________________________

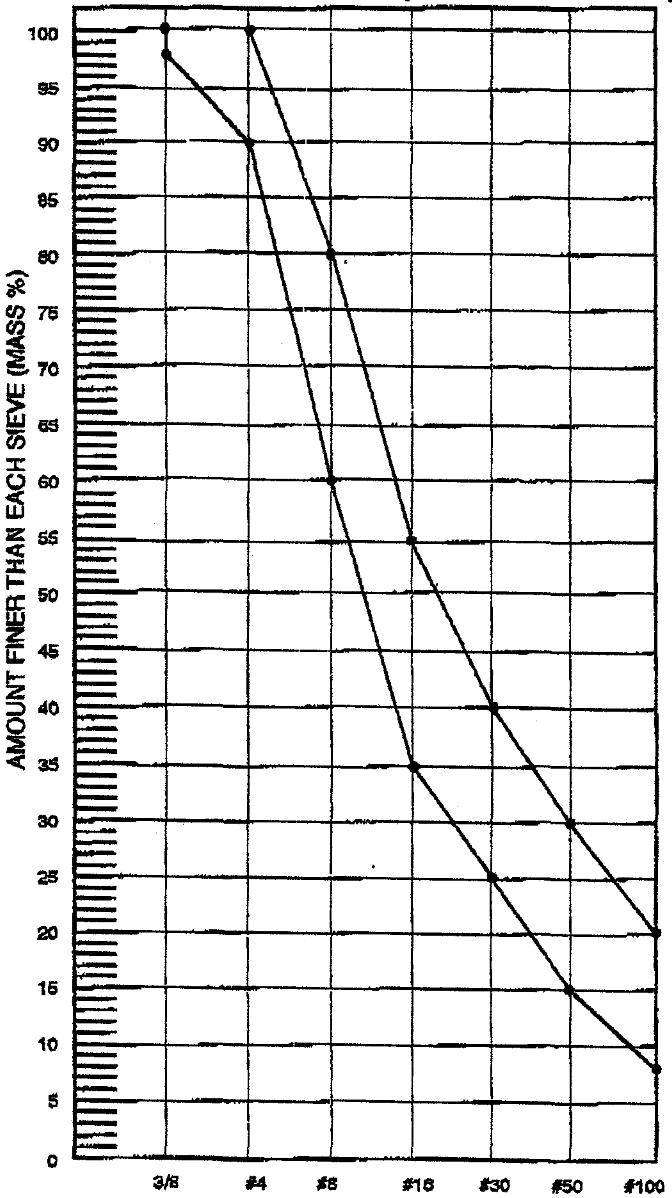
______________________________ DATE ______________________________

WT. AS RECEIVED ______ DRY WT. ______ % FREE H_2O: ______

LOOSE MOIST WT. ______ LOOSE DRY WT. ______ FINENESS MODULUS: ______

U.S. SIEVE	WEIGHT	% RET. EACH SIEVE	RECOMMENDED % RET. EA. SIEVE	CUM. % RET.	CUM. % PASSING	RECOMMENDED CUM. % PASSING
3/8"			0-2			98-100
4"			0-10			90-100
8"			15-35			60-80
16"			15-35			35-55
30"			5-20			25-40
50"			5-15			15-30
100"			5-15			8-20
PAN			8-20			0

AGGREGATE GRADATION GRAPH (CUMULATIVE PASSING)



*Aggregates Conforming To ASTM C 331 or C 33 (whichever is applicable)

June1999

Combined Aggregate Gradation Report For Lightweight Concrete Masonry Units*

COMPANY NAME ____________________

PHONE # ____________________

MATERIAL SOURCE ____________________ SAMPLED FROM ____________________

____________________ SAMPLED BY ____________________

REMARKS ____________________

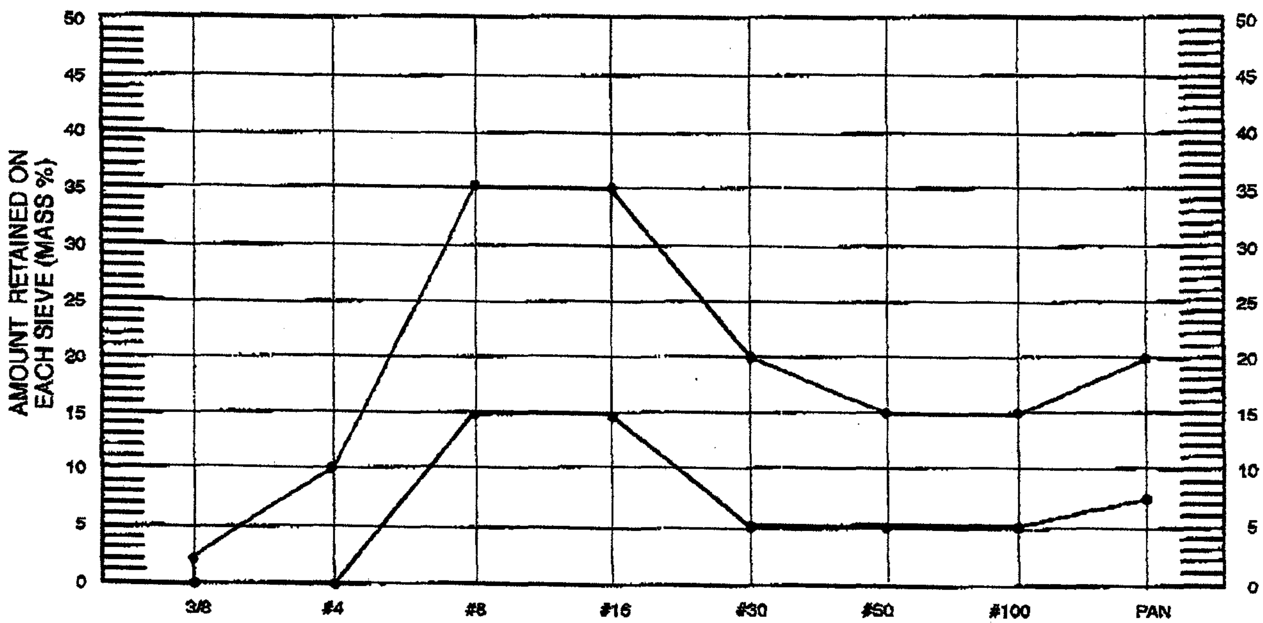
____________________ DATE ____________________

WT. AS RECEIVED ____________________ DRY WT: ____________________ % FREE H_2O: ____________________

LOOSE MOIST WT. ____________________ LOOSE DRY WT: ____________________ FINENESS MODULUS: ____________________

U.S. SIEVE	WEIGHT	% RET. EACH SIEVE	RECOMMENDED % RET. EA. SIEVE	CUM. % RET.	CUM. % PASSING	RECOMMENDED CUM. % PASSING
3/8"			0-2			95-100
4"			0-10			90-100
8"			15-35			60-80
16"			15-35			35-55
30"			5-20			25-40
50"			5-15			15-30
100"			5-15			8-20
PAN			8-20			0

AGGREGATE GRADATION GRAPH (AMOUNT RETAINED ON EACH SIEVE)



*Aggregates Conforming To ASTM C 331 or C 33 (whichever is applicable)

June1999

Combined Aggregate Gradation Report For Lightweight Concrete Masonry Units*

COMPANY NAME ______________________

PHONE # ______________________

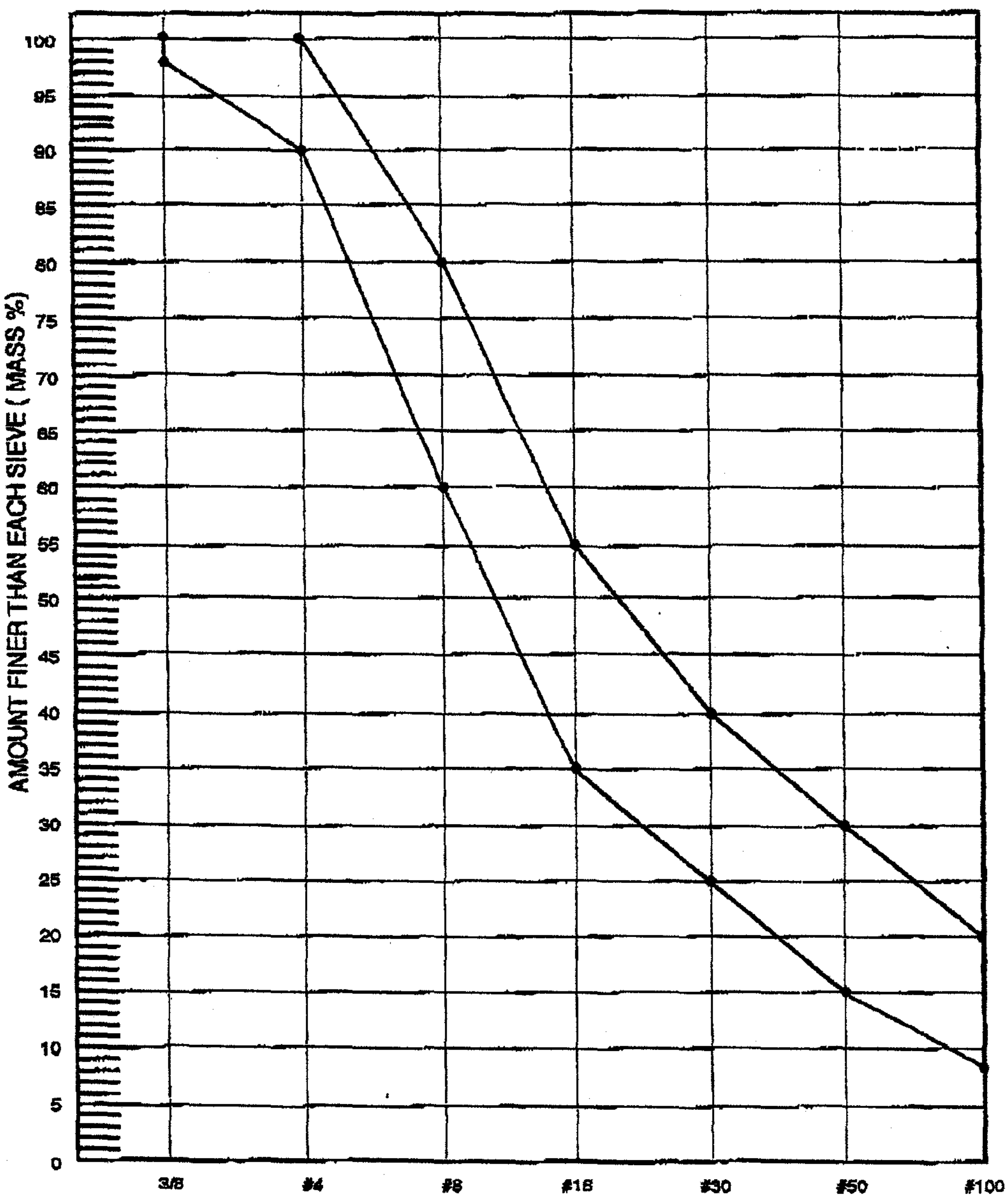
MATERIAL SOURCE ______________________ SAMPLED FROM ______________________

______________________ SAMPLED BY ______________________

REMARKS ______________________

______________________ DATE ______________________

AGGREGATE GRADATION GRAPH (CUMULATIVE PASSING)



*Aggregates Conforming To ASTM C 331 or C 33 (whichever is applicable)

June1999

Combined Aggregate Gradation Report For Lightweight Concrete Masonry Units*

COMPANY NAME ______________________

PHONE # ______________________

MATERIAL SOURCE ______________________ SAMPLED FROM ______________________

______________________ SAMPLED BY ______________________

REMARKS ______________________

______________________ DATE ______________________

WT. AS RECEIVED ______________ DRY WT: ______________ % FREE H_2O: ______________

LOOSE MOIST WT. ______________ LOOSE DRY WT: ______________ FINENESS MODULUS: ______________

U.S. SIEVE	WEIGHT	% RET. EACH SIEVE	RECOMMENDED % RET. EA. SIEVE	CUM. % RET.	CUM. % PASSING	RECOMMENDED CUM. % PASSING
3/8"			0-2			98-100
4"			0-10			90-100
8"			15-35			60-80
16"			15-35			35-55
30"			5-20			25-40
50"			5-15			15-30
100"			5-15			8-20
PAN			8-20			0

*Aggregates Conforming To ASTM C 331 or C 33 (whichever is applicable)

June1999

10D

ESCSI Information Sheet 3384
"Freezing and Thawing Resistance of Segmental Retaining Walls"

FREEZING AND THAWING RESISTANCE OF SEGMENTAL RETAINING WALLS

This research report on the Freeze-Thaw performance of commercially available lightweight and normalweight segmental retaining wall (SRW) units was presented at the Seventh North American Masonry Conference - June 2-5, 1996, University of Notre Dame, South Bend, Indiana.

The report concludes that the density of the SRW unit has no significant effect on its durability. Consequently, properly designed SRW units containing expanded shale, clay and slate aggregate can be expected to perform comparably to normalweight aggregate units.

SRW units are frequently placed in harsh environments where moist conditions and a large number of freezing and thawing cycles can occur each year. Therefore, the concrete mixture must be designed to be durable in a freezing and thawing environment, regardless of the type of aggregate used in the SRW units. This study reinforced and expanded our knowledge of what is needed to provide freeze-thaw durability. The ESCS producer should be consulted about recommended mix designs.

TEST OF FREEZE-THAW RESISTANCE OF COMMERCIALLY AVAILABLE LIGHTWEIGHT AND NORMALWEIGHT CONCRETE MASONRY MIXES USED IN SEGMENTAL RETAINING WALL UNITS

Theodore W. Bremner[1] and John P. Ries[2]

ABSTRACT

The purpose of this test program was to analyze the freeze-thaw performance of commercially available lightweight and normalweight segmental retaining wall (SRW) units made at thirteen (13) different block manufacturing plants located in the United States. The block manufacturing plants made both lightweight and normalweight units on the same day using the same machine, cement, and curing regime. The thirteen normalweight control mixes (130 to 145 lbs/cf) (2080 to 2320 kg/m^3) were typically what the block company uses on a regular basis for SRW units, and were made with normalweight sand and gravel aggregate. The twenty mixes incorporating lightweight aggregate (90 to 118 lbs/cf) (1440 to 1890 kg/m^3) were developed using higher design criteria than regular concrete masonry units to accommodate the harsh environment often endured by SRWs. Net compressive strength of 4000 to 6000 psi (27.6 to 41.4 MPa), and absorption of less than 10 lbs/cf (160 kg/m^3) were targeted. Some of these lightweight mixes are also being used commercially on a regular basis. The lightweight aggregate used was predominately expanded shale, clay, and slate (ESCS) manufactured by the rotary kiln method.

Over 175 test coupons, from 33 lightweight and normalweight mixes, were tested according to ASTM C1262-94, Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units (1).

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The results of these tests indicated that no correlation existed between freeze-thaw durability and concrete density. The lighter units made by adding ESCS aggregate performed as well as the control normalweight units. As a secondary interest, the data were analyzed to determine if any correlation existed between the extent of deterioration and the absorption, cementitious content, strength, and admixture usage.

KEYWORDS

Concrete masonry, freeze-thaw durability, absorption, lightweight, normalweight, segmental retaining walls, expanded, aggregates.

INTRODUCTION

This project investigates the freeze-thaw durability of commercially available lightweight and normalweight block concretes used in the manufacture of segmental retaining wall (SRW) units. The mixtures were run at 13 different block manufacturing plants with all units made being 4 x 8 x 16 in. (102x204x406 mm) solid masonry units. Coupons (5 per mix) were cut from the end of the 4 x 8 x 16 in. (102x204x406 mm) solid units, and sent to the University of New Brunswick (UNB) to be tested according to the American Society for Testing and Materials (ASTM) C1262-94, Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units (1). Tests for strength, absorption, and density (unit weight) were completed at local laboratories on companion specimens. The results of these tests were analyzed to determine if lowering the weight of a SRW unit by adding ESCS lightweight aggregate would effect the freeze-thaw durability of the unit. As a secondary interest, the data were analyzed to determine if any correlation existed between the extent of deterioration and the absorption, cementitious content, strength, and admixture usage.

The reason for doing this work is two fold. First, to help set industry standards for durable concrete SRW units. Secondly, SRW units made with normalweight aggregate are very heavy, with some weighing more than 100 lbs.(45.5 kg) each. If the units weighed less, there would be many economical advantages. Labor productivity on commercial projects would greatly increase because less weight is being handled. The do-it-yourself market would increase because the SRW systems would be more user friendly and easier to handle. Other advantages would be fewer worker-compensation injuries, and more units can be transported on the same truck.

DETERIORATION DUE TO FREEZING AND THAWING

Segmental retaining wall units are frequently placed in harsh environments where a large number of freezing and thawing cycles can occur each year. Also, they are used in high moisture content applications where they can absorb water. Water expands by nine (9) percent when it freezes. Any voids in the hydrated cement paste or aggregate that are greater than 91 percent full will develop a hydraulic pressure when the water changes to ice, unless the water can be forced from the void during freezing (2). Masonry units, being of a porous texture, tend to lose water during the dry season of the year and so the chances of having voids fully saturated during the cold wet season are reduced. Although masonry units normally are not air entrained, they frequently have a chemical admixture added to the mix that would entrain some air in a regular concrete mixture. When expanded shale, clay, and slate aggregates are used to produce lightweight concrete masonry units the vesicules within these expanded aggregates can act as relief mechanisms, whereby the pores within the aggregates can provide relief from the hydraulic pressure developed during the freezing of the concrete. With normalweight aggregates that contain coarse internal channels that easily fill with water, the opposite can occur; in some instances, deterioration of concrete has been traced to the use of this type of aggregate (3).

MIX PROPORTIONS

Mix designs ranging from 93 lbs/cf to 143 lbs/cf (1490 to 2290 kg/m^3) were tested in this investigation. The variation of density is largely due to the amount of expanded shale, clay, or slate lightweight aggregate in the mix. The mixture proportions for the various concretes are given in Table 1A of the Appendix.

AGGREGATES

Most normalweight aggregates have relative densities (specific gravities) in the order of 2.4 to 2.9 with lightweight aggregates having relative densities from 0.5 to 2.0. The lower density for lightweight aggregates is due to the aggregates having a vesicular structure. Although lightweight aggregates are generally less strong than normalweight aggregates due to their less dense interior structure, they are still able to make concretes of acceptable and, in some cases, extremely high strength. Lightweight aggregates perform extremely well in concrete because, when combined with a cement mortar matrix, they form a homogeneous, elastically compatible material.

The lightweight aggregates used in this investigation were expanded shale, clay, or slate made by the rotary kiln process with the exception of one control mix that included a small amount of pumice, and another control mix that included a small amount of bottom ash.

MANUFACTURE OF MASONRY UNITS

Each block manufacturing plant made both lightweight aggregate mixes and normalweight aggregate mixes on the same day using the same machine, cement, and curing regime. Most of the normalweight control mixtures (130 to 142 lbs/cf) (2080 to 2270 kg/m^3) tested were standard commercially available SRW mixtures used by that block company. The lightweight aggregate SRW mixes ranging from 94 to 118 lbs/cf (10510 to 1890 kg/m^3) were developed jointly by the lightweight aggregate producer and the block plant using a higher design criteria with a net strength greater than 4000 psi (27.6 MPa) and 10 lbs/cf (160 kg/m^3) maximum absorption. Some of the lightweight aggregate mixtures are used extensively, and some needed to be modified slightly for commercial use.

TESTING PROCEDURE

Over 175 test coupons from lightweight and normalweight concrete masonry units were tested according to ASTM C1262-94 "Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units." As required by this standard, each specimen was completely submerged in water at a temperature of 60 to 80 degrees F (15.6 to 26.6°C) for 48 hours. Upon removal from the water, the visible surface water was removed with a damp cloth, and the specimen was weighed. The specimen weight was recorded as the saturated weight. The saturated specimens were then placed face down in the containers on the specimen supports (non saw-cut surface) and the water in the container was adjusted to 10 mm from the bottom of the concrete specimens. The containers were sealed to prevent evaporation.

The test begins with a freezing cycle for a period of 4.5 hours and a thaw cycle of 3.5 hours. One freeze thaw cycle is defined as a complete freeze cycle followed by a complete thaw cycle.

Three freezing and thawing cycles are completed each day, seven times a week for a total of twenty-one cycles per week. After 21 cycles the individual specimens are removed from the container and rinsed with water. All the rinse water is carefully collected in the container along with all loose particles from the specimen. The water is poured from the specimen container through previously weighed filter paper (Wf) to collect the residue from the test specimen. This is continued until all residue is collected. The specimen is then returned to the container and sealed, and the next freezing and thawing cycle can then begin. The filter paper is dried, then weighed (Wf+r), and the residue weight is calculated: Wr=Wf+r-Wf. The amount of deterioration can be calculated by dividing the weight of residue by the saturated weight of the specimen. The procedure was repeated until all the accumulated residue of a specimen exceeds 10% of the initial saturated weight, or until 500 freezing and thawing cycles have been completed. The cumulative % loss at 105, 315, and 500 cycles, as well as the cycles at which dilation occurred are listed in Table 1A of the Appendix.

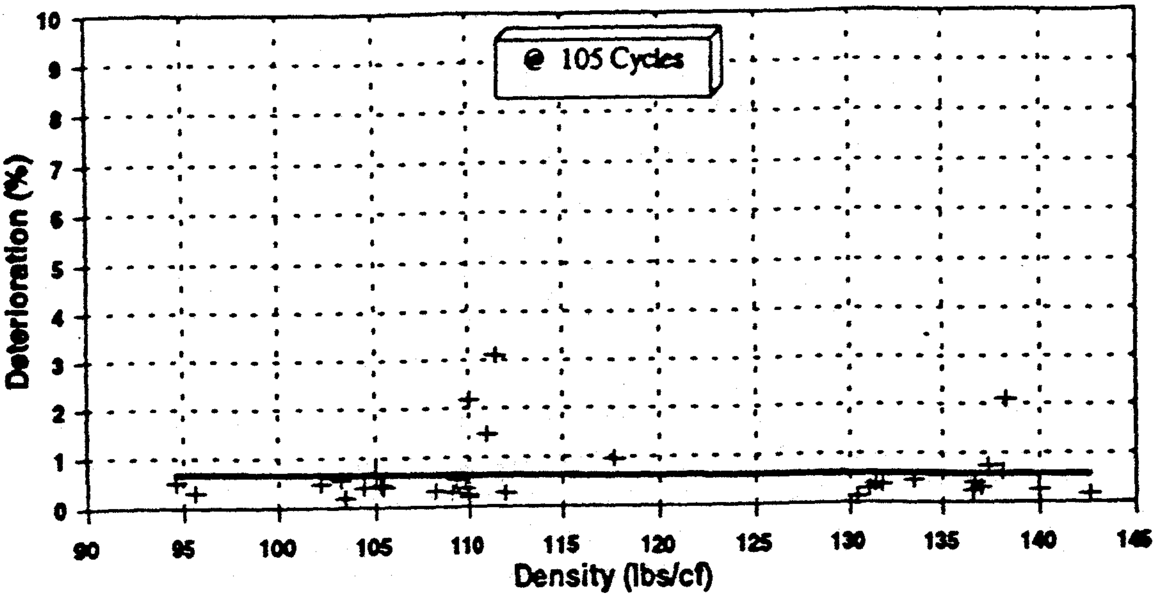
Although ASTM 1262-94 specifies that percent deterioration should be calculated after every 8 to 12 freeze-thaw cycles, it was decided to calculate deterioration after every 21 cycles so as to fit in with a weekly cycle. This procedure will be submitted to ASTM Committee C-15 as a recommended change.

TEST RESULTS

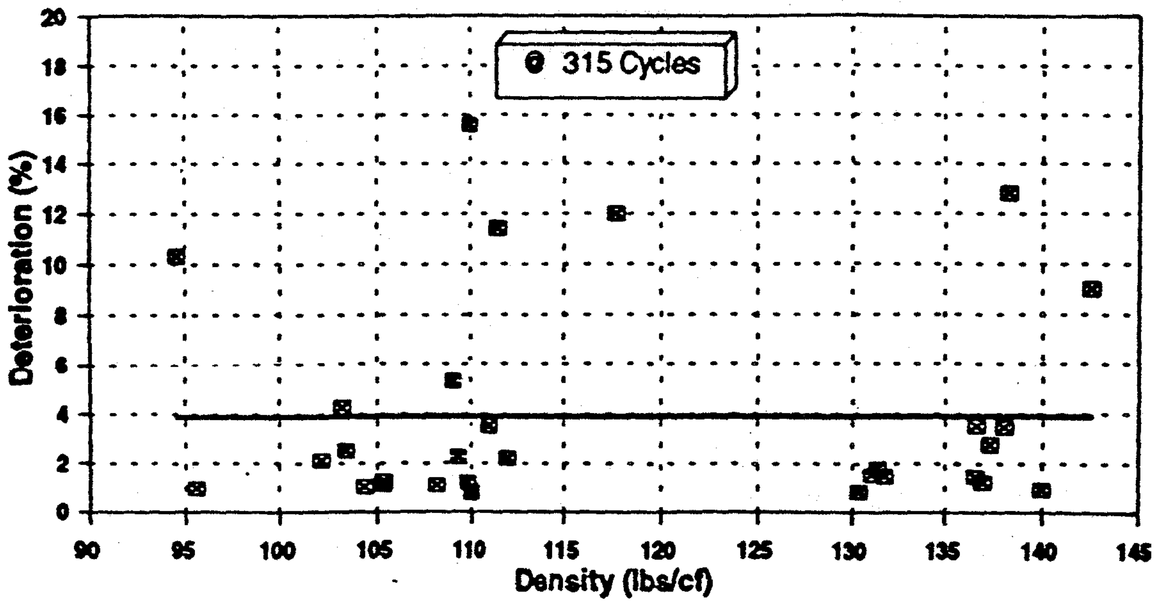
Deterioration expressed as a percentage loss in mass is plotted against density, absorption, cementitious content, and strength in Figures 1 to 4.

Deterioration vs Density

The relationship between deterioration and density at 105 and 315 cycles of freezing and thawing is shown in Figure 1. No correlation between the density of the concrete and the concrete's ability to resist freezing and thawing is evident.



(A)



(B)

Figure 1. Relationship between deterioration and density at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.

Deterioration vs Absorption

The relationship between deterioration and absorption at 105 and 315 cycles of freezing and thawing is shown in Figure 2. No correlation between the concrete's absorption and its resistance to freezing and thawing is evident at 105 cycles, but at 315 cycles a slight tendency for deterioration to increase with increasing absorption was observed.

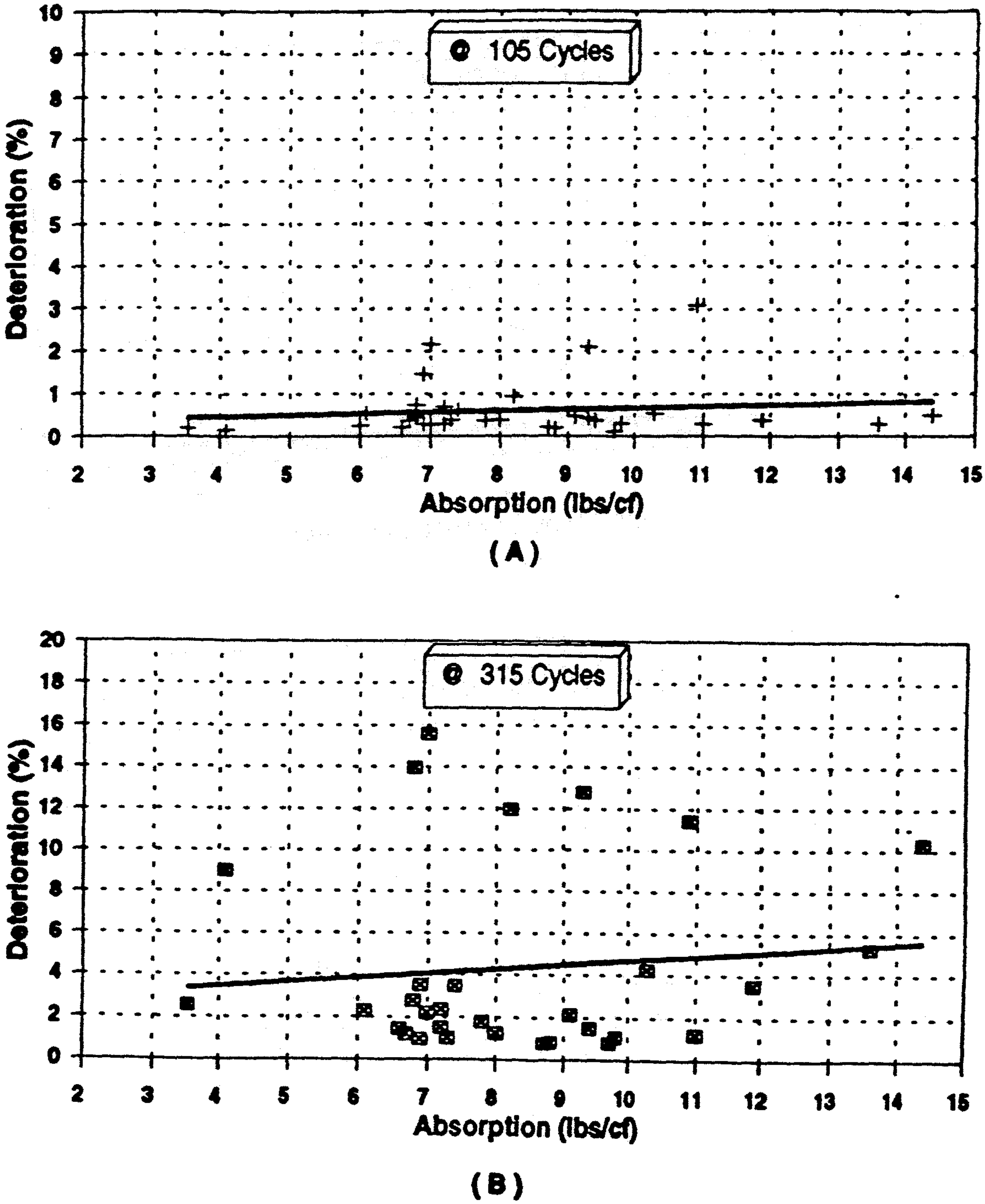
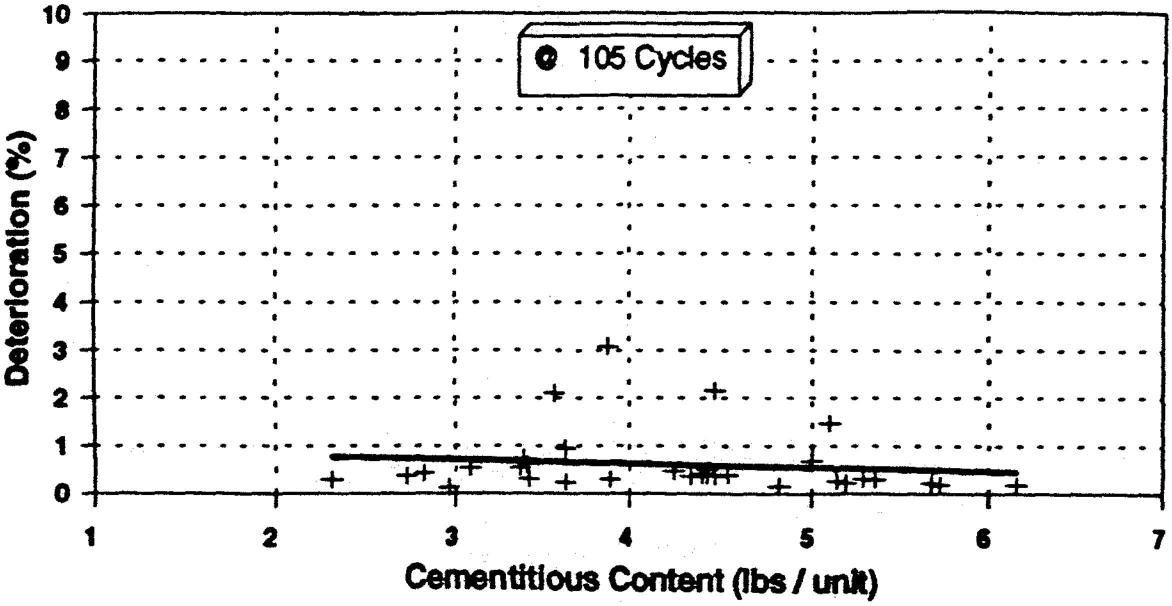


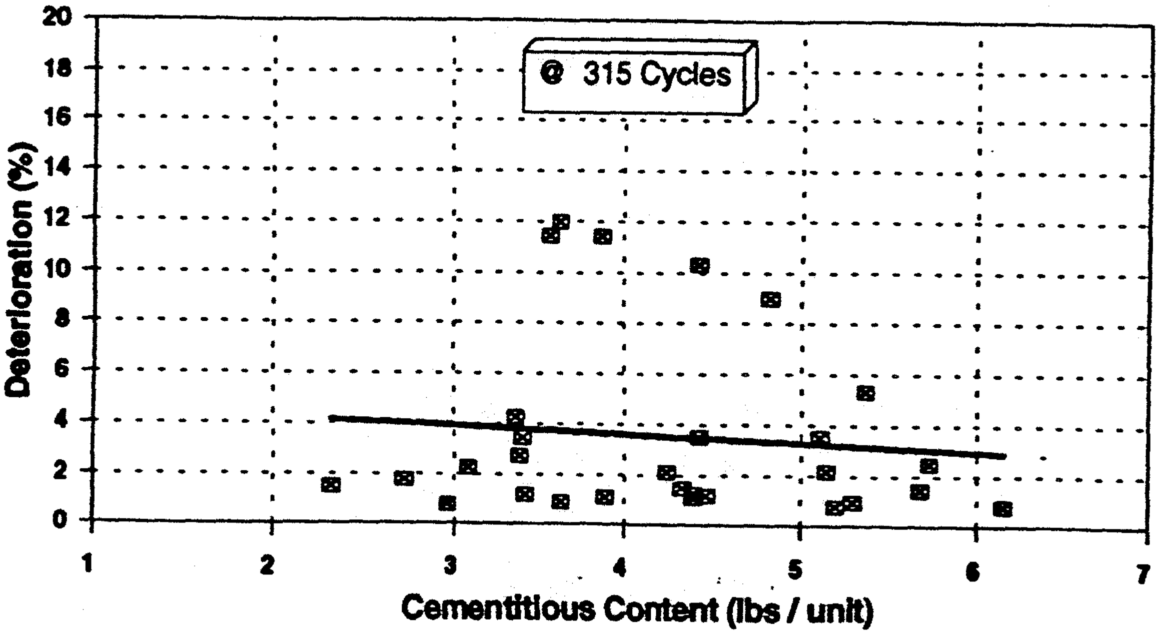
Figure 2. Relationship between deterioration and absorption at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.

Deterioration vs Cementitious Content

The relationship between deterioration and cementitious content at 105 and 315 cycles is shown in Figure 3. The results show durability slightly improving with increasing cementitious content.



(A)

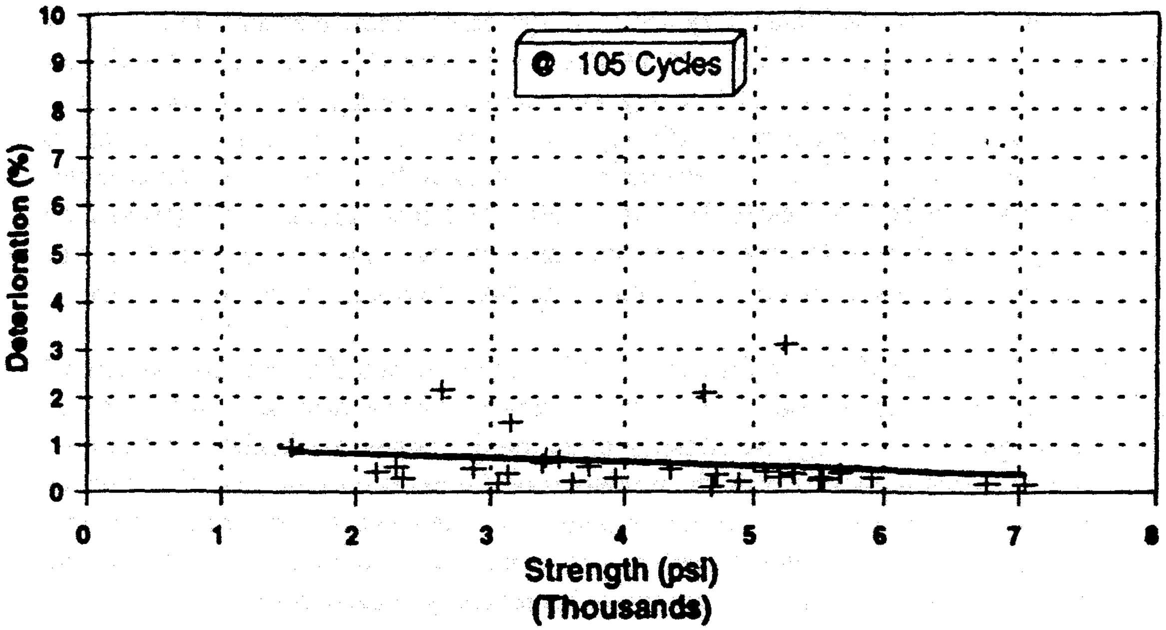


(B)

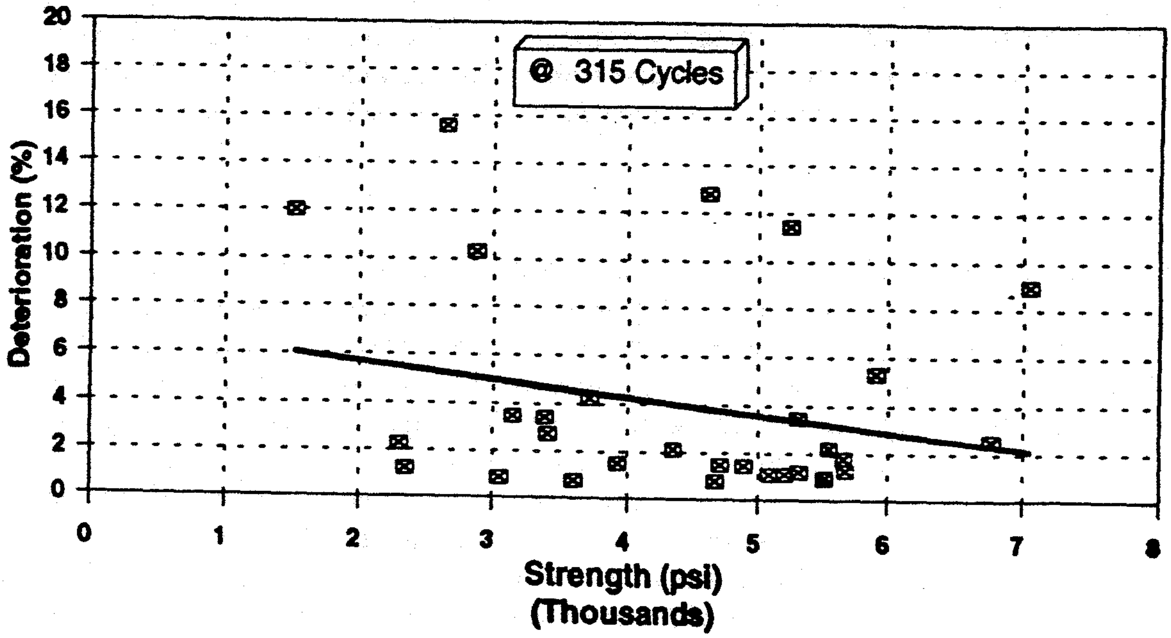
Figure 3. Relationship between deterioration and cementitious content at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.

Deterioration vs Strength

The relationship between deterioration and strength at 105 and 315 cycles of freezing and thawing is shown in Figure 4. The graphs show a trend towards increased durability with increase in strength.



(A)



(B)

Figure 4. **Relationship between deterioration and strength at (a) 105 cycles and at (b) 315 cycles of freezing and thawing.**

DISCUSSION OF RESULTS

In Figures 1 to 4 the deterioration (% loss) is plotted against density, absorption, cementitious content, and strength respectively. There is no strong correlation with any of these variables. In Figures 1 and 2 all specimens of density less than 120 lbs/cf (1920 kg/m^3) contain varying amounts of expanded shale, clay, or slate lightweight aggregates. Specimens above 130 lbs/cf (2080 kg/m^3) contain essentially all normalweight aggregates. Figures 1 and 2 indicate that expanded shale, clay and slate aggregate produce as durable a concrete with respect to the ASTM C1262 test as does normalweight concrete. Wendt and Woodworth did a similar type of freezing and thawing testing, and for units with a compressive strength of approximately 1000 psi (6.9 MPa) gross, arrived at similar results (4). Shideler and Toennies (5) also obtained similar results on freeze-thaw tests on concrete masonry units at 1000 and 1500 psi (6.9 and 10.3 MPa) using low-pressure and high-pressure steam curing. A trend towards more durable masonry units with increasing strength can be inferred from Figures 4 which was confirmed by the two previously mentioned studies.

Considering the scatter of data in Figures 1 to 4 inclusive, it would appear that additional factors need to be considered. Based on a visual observation of the detritus, it would appear that aggregate gradation is a significant factor affecting the failure mechanism. Additional information has been requested from the producers of the masonry units, and this data, as well as the information in Table 1A of the Appendix, will be subjected to further statistical analysis. Also, samples of the units tested, as well as untested companion samples, will be subjected to petrographic analysis to attempt to further analyze these results.

Plasticizers and/or integral-waterproofing admixtures were used in 78% of the mixes. In general, the mixtures without admixtures performed as well as mixtures with admixtures. Two mixtures used air entrained cement, and both performed well. Further work will be done to explain the role admixtures play in the durability of these masonry units.

METHOD OF FAILURE

The results of the cumulative weight loss (% deterioration) vs number of cycles of freezing and thawing show two distinct patterns. Figure 1A in the Appendix shows a uniform low rate of mass loss, and is typical of eleven lightweight samples and six normalweight samples. Figure 2A in the Appendix also shows a uniform loss of mass but at a high rate, and is typical of one lightweight sample and one normalweight sample. Figure 3A and 4A show a different pattern: a slow rate of mass loss for several freeze-thaw cycles initially, then rapid rate of deterioration occured. It resulted in a dilation of the specimen with a rapid increase in the rate of deterioration per cycle, leading to complete collapse of all or part of the specimen in a few cycles. The dilation prior to collapse resulted in the thickness of some specimens increasing by about 10%. The failure was a granularization process with the individual granules in some instances being relatively strong. Figures 3A and 4A in the Appendix are typical of eight lightweight samples and six normalweight samples.

As can be seen in Figure 1A to 4A inclusive, the within test variation for the five cupons each cut from a separate masonry unit (and representing one mix) is small, and confirms the effectiveness of the testing procedure used.

CONCLUSION

Based on the results of these tests the density of the concrete masonry units appears to have no significant effect on the results of the ASTM C1262-94 Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units. Consequently, concrete masonry units containing expanded shale, clay, and slate can be expected to perform as well as normalweight aggregates where freezing and thawing is involved.

ACKNOWLEDGEMENTS

We would like to thank Michele A. Blanchard and Sina Zabihiyan at the University of New Brunswick for carrying out the tests, recording the data, preparing the tables, graphs, and preliminary report.

A special thanks to the block companies that made the SRW units, and helped in the development and testing of the mixes used: Adams Products, Akron Brick and Block, Anchor Concrete, Capitol Concrete Products, Charlotte Block Inc., Cinder and Concrete Block Corp., Clayton Block Company, Consumers Block Company, Dubois County Concrete, Johnson Concrete Co., Mooresville Block Company, Superior Plasticrete Corp., and TXI Concrete Products.

Lightweight aggregate manufacturers participating in the study were: Big River Industries, Buildex Inc., Carolina Stalite Co., Lehigh Portland Cement Co., Norlite Corp., Hydraulic Press Brick Co., Solite Corporation, and Texas Industries.

REFERENCES

1. American Society for Testing Materials. 1994. ASTM C1262, "Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units" in ASTM Standards, Part 4.05. ASTM, Philadelphia, PA.

2. Pigeon M. and Pleau, R. 1995. "Durability of Concrete in Cold Climates." E & FN SPON, London, UK: 244.

3. Concrete Manual, 8th Edition revised 1981. "A Water Resources Technical Publication." US Department of the Interior, Water and Power Resources Service.

4. Wendt, Kurt F. and Woodworth, Paul M. 1939. "Tests on Concrete Masonry Units Using Tamped and Vibrated Molding Methods." American Concrete Institute, Vol. 36, November: 121-163.

5. Shideler J. and Toennies, H. 1967. "Laboratory Freeze-Thaw Resistance of Concrete Masonry." Portland Cement Association, Research and Development Division, PCA R/D, Ser. 1294-1.

Table 1A : Mix Proportions

Mix #	Cement lbs - type (kg)	Flyash lbs - class (kg)	Cementitious material lbs / unit	LWA lbs (kg)	NWA lbs (kg)	Admixture	Strength psi (MPa)	Absorption lbs/cf (kg/m)	Density lbs/cf (kg/m)	Cum. % Loss at Cycles 105	315	500	Cycles to Dilation
1	650 I 295		3.63	800 364	3800 1727	YES	1519 10	8.2 131.4	117.6 1884	0.94	F	F	168
2	500 III 227		2.96		5000 2273	NO	4687 32	9.7 155.4	130.4 2089	0.12	0.82	1.92	
3	530 III 240		2.31		7000 3182	YES	3931 27	7.2 115.3	131.1 2100	0.29	1.15	2.46	
4	600 I 273		4.26	2495 1134	500 227	YES	4360 30	9.1 145.8	102.1 1635	0.46	2.12	3.48	
5	800 I 364		5.19	2000 909	1425 648	YES	3610 25	8.7 139.4	110.0 1762	0.21	0.78	1.58	
6	575 I 261	90-C 41	5.68		3331 1514	YES	4893 34	6.6 105.7	136.6 2188	0.28	1.45	3.24	
7	800 I 364	192-F 87	6.16	2000 909	1425 648	YES	3054 21	8.8 141.0	110.0 1762	0.19	0.84	1.56	
8	775 352		3.88	1500 682	3300 1500	YES	5240 36	10.9 174.6	111.5 1786	3.06	F	F	42
9	680 III 309		2.81		7410 3368	NO	2155 15	6.8 108.9	133.4 2137	0.44	F	F	147
10	600 I 273		4.44	2400 1091	4000 1818	YES	5301 37	11.9 190.6	136.7 2190	0.38	3.49	F	273
11	1000 III 455		3.89	2400 1091	3537 1608	YES	5197 36	9.8 157.0	108.1 1732	0.31	1.09	2.38	
12	600 I 273		4.41	2495 1134	500 227	NO	5670 39	8.0 128.1	105.4 1688	0.40	1.26	2.06	
13	750 I 341		5.1	2100 955	1225 557	YES	3150 22	6.9 110.5	111.0 1778	1.46	3.49	5.37	
14	455 I 207	50-F 23	4.55	1500 682	900 409	YES	3127 22	7.3 116.9	104.4 1672	0.36	1.03	3.84	
15	650 I 295		4.48	2100 955	1225 557	YES	5313 37	6.7 107.3	109.8 1759	0.37	1.28	9.82	
16	783 III 356		4.83		5000 2273	YES	7050 49	4.1 65.7	142.6 2284	0.16	9.03	F	147
17	600 IA 273		4.44	1700 773	900 409	NO	2875 20	14.4 230.7	94.6 1515	0.50	F	F	189

F : Failed

Revised on 1996, 07, 17

Table 1A (Cont.) : Mix Proportions

Mix #	Cement lbs - type (kg)	Flyash lbs - class (kg)	Cementitious material lbs / unit	LWA lbs (kg)	NWA lbs (kg)	Admixture	Strength psi (MPa)	Absorption lbs/cf (kg/m)	Density lbs/cf (kg/m)	Cum. % Loss at Cycles 105	315	500	Cycles to Dilation
18	525 I 239		3.39		4800 2182	YES	3420 24	6.8 108.9	137.4 2201	0.74	1.73	3.96	
19	750 I 341		5.14	2100 955	1225 557	YES	5535 38	7.0 112.1	112.0 1794	0.28	2.13	6.23	
20	500 IA 227		4.35		3300 1500	YES	4723 33	9.4 150.6	131.8 2111	0.37	1.47	3.64	
21	783 III 356		5.72	2505	253 115	YES	6754 47	3.5 56.1	103.4 1656	0.19	2.53	6.47	
22	720 III 327		3.09	2180	3880 1764	NO	2300 16	6.1 97.7	109.3 1751	0.54	2.34	F	336
23	500 I 227		3.42		4500 2045	YES	2350 16	11.0 176.2	137.0 2195	0.30	1.27	F	378
24	450 III 205		2.71		5000 2273	YES	4655 32	7.8 124.9	131.4 2105	0.37	1.80	3.64	
25	455 I 207	120-F 55	5	1400 636	1050 477	YES	3510 24	7.2 115.3	105.0 1682	0.73	2.47	3.51	
26	525 I 239		3.41		4800 2182	NO	3390 23	7.4 118.5	138.1 2212	0.62	3.46	9.30	378
27	660 300		3.57		5750 2614	YES	4630 32	9.3 149.0	138.3 2215	2.06	F	F	63
28	575 I 261	90-C 41	5.36	2420 1100	300 136	YES	5910 41	13.6 217.9	109.0 1746	0.28	5.25	F	273
29	450 III 205	130-F 59	3.37	2000 909	1850 841	NO	3725 26	10.3 165.0	103.2 1653	0.57	4.19	F	399
30	650 I 295		4.48	2100 955	1225 557	YES	2650 18	7.0 112.1	110.0 1762	2.16	F	F	168
31	783 III 356		5.29	2505 1139	253 115	YES	5510 38	6.9 110.5	95.6 1531	0.30	0.91	1.87	
33	340 I 155	135-C 61	3.63		4100 1864	YES	5500 38	6.0 96.1	140.0 2243	0.25	0.91	1.66	
34	580 I 264		4.14	1600 727	1500 682	YES	5082 35	9.3 149.0	105.3 1687	0.43	1.41	2.71	

F : Failed **Mix # 32 lost in shipping** **Revised on 1996, 07, 17**

Appendix

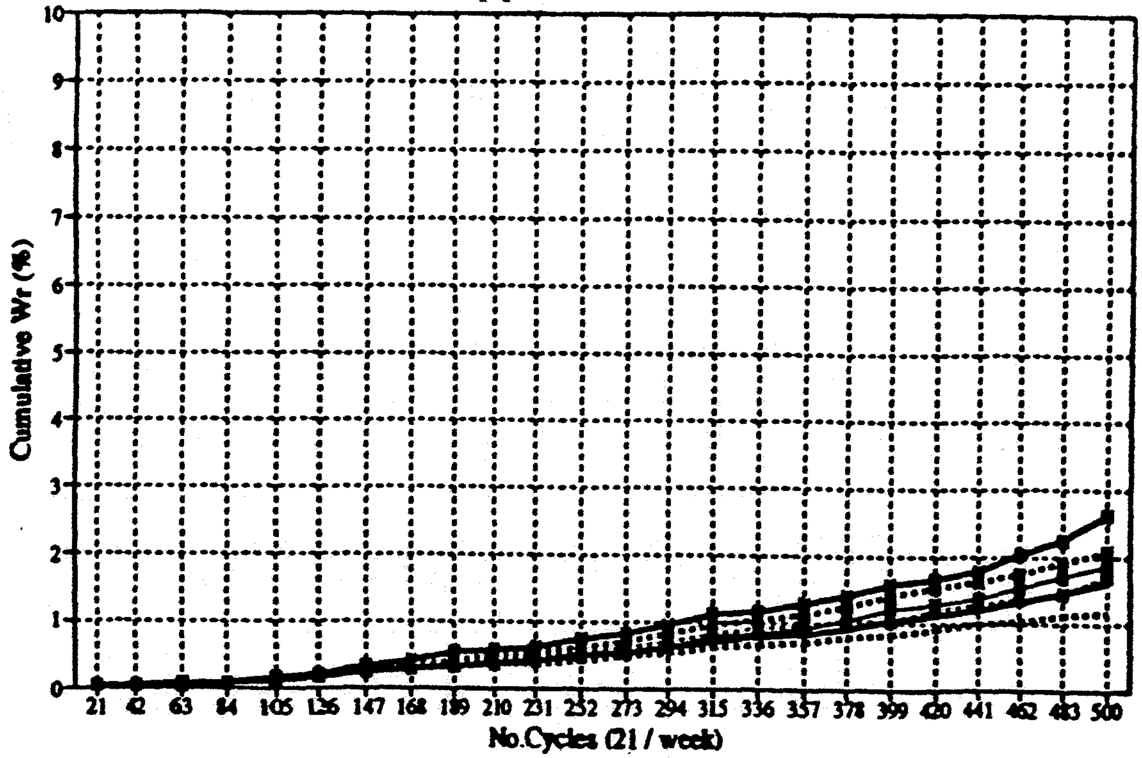


Figure 1A. Effect of freezing and thawing on coupons cut from masonry units showing good performance.

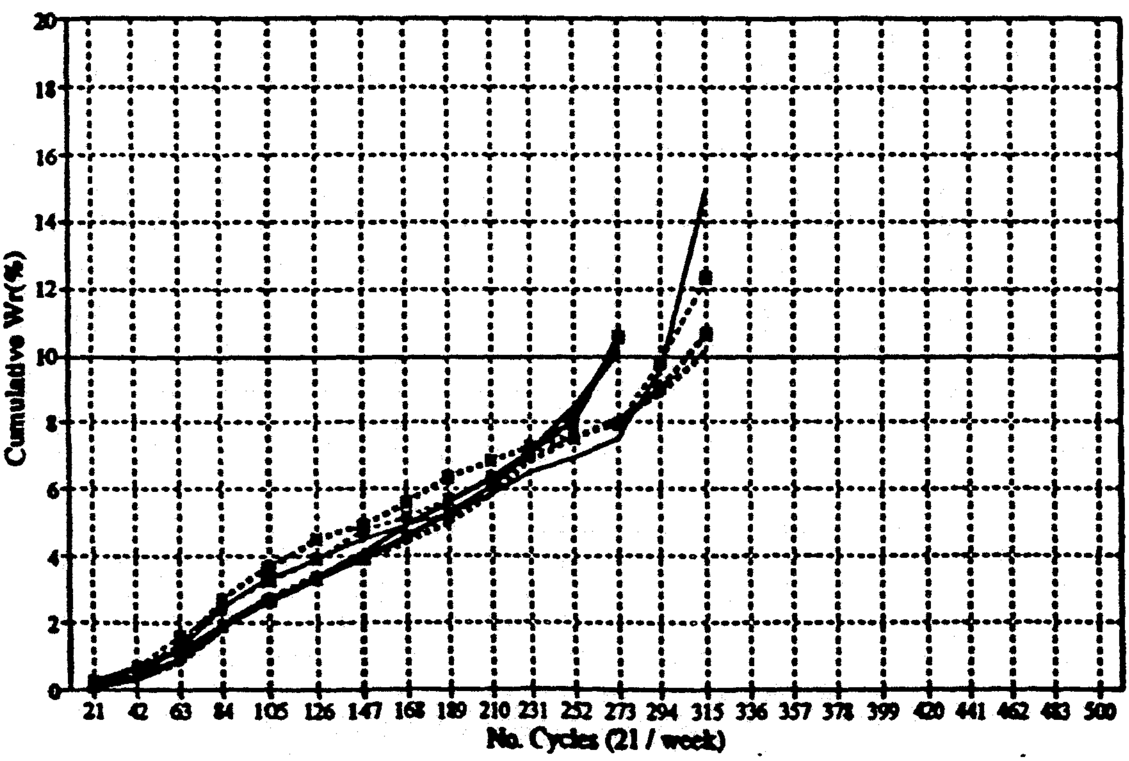


Figure 2A. Effect of freezing and thawing on coupons cut from masonry units showing a very high rate of loss.

Appendix

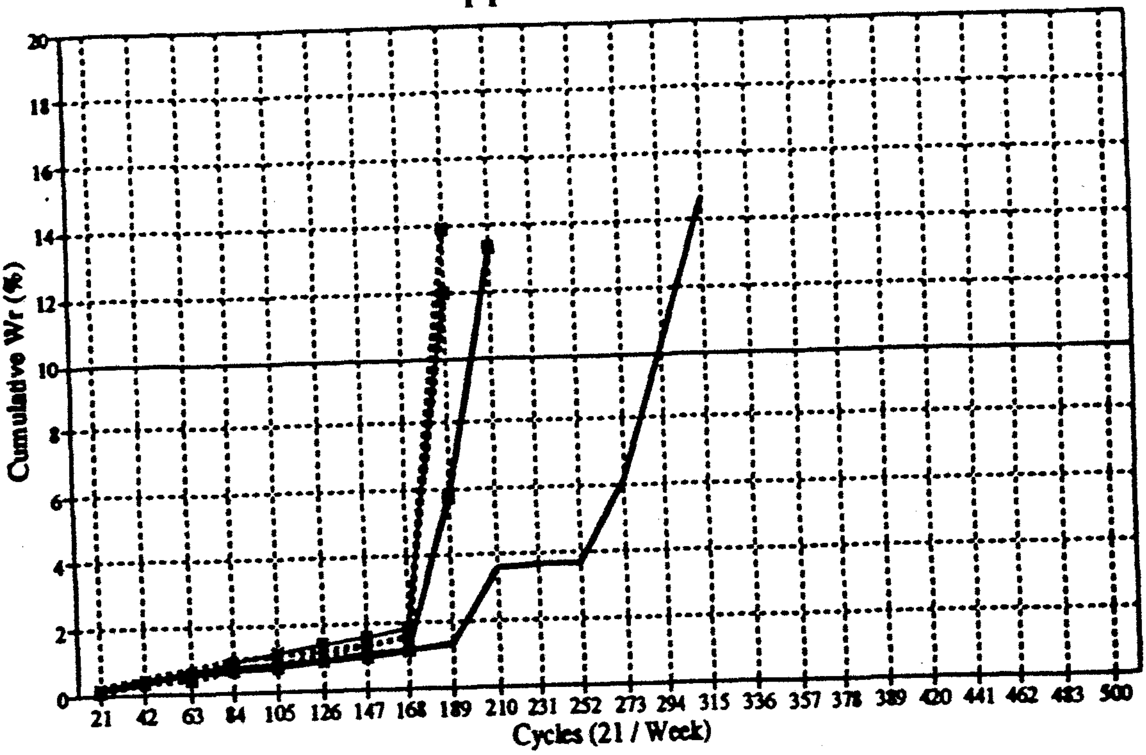


Figure 3A. Effect of freezing and thawing on coupons cut from masonry units showing dilation after a few cycles of freeze and thaw.

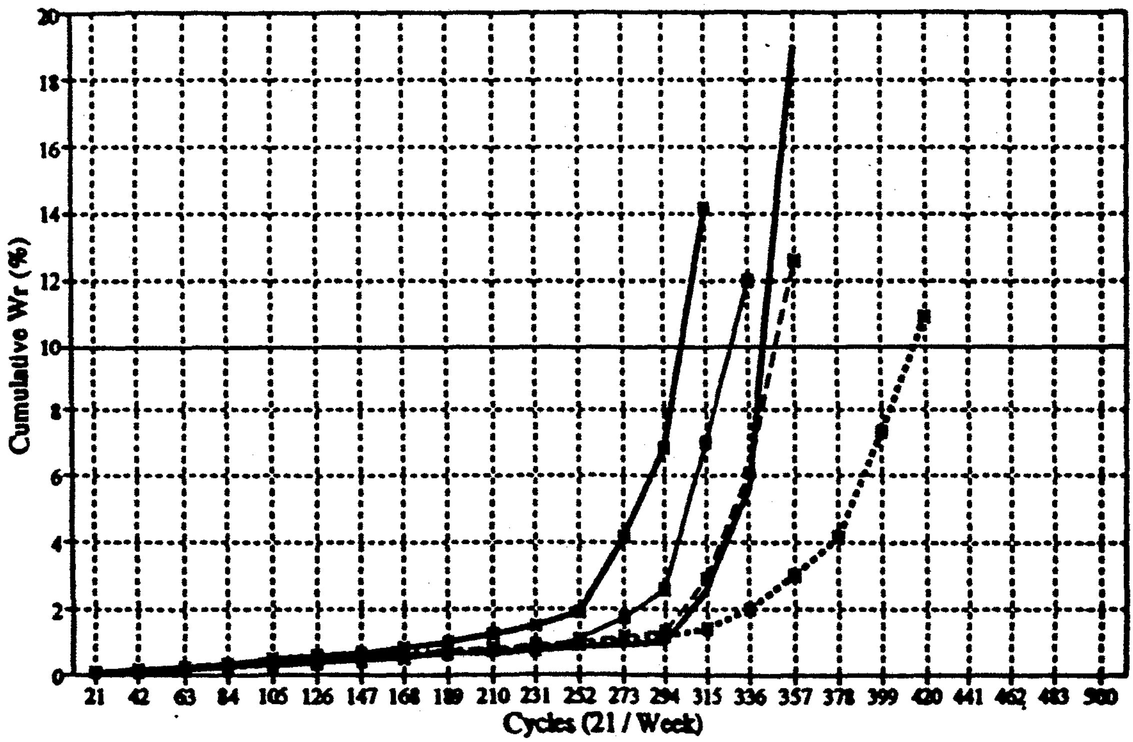


Figure 3A. Effect of freezing and thawing on coupons cut from masonry units showing dilation after a large number of freeze and thaw cycles.

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For nearly one hundred years Expanded Shale, Clay and Slate (ESCS) has been used successfully around the world in more than 50 different types of applications. The most notable among these are concrete masonry, high-rise building, concrete bridge decks, precast and prestressed concrete elements, asphalt road surfaces, soil conditioner and geotechnical fills.

What is ESCS? It is a unique, ceramic lightweight aggregate prepared by expanding select minerals in a rotary kiln at temperatures over 1000°C. The production and the raw materials selection processes are strictly controlled to insure a uniform, high quality product that is structurally strong, stable, durable and inert, yet also lightweight and insulative. ESCS gives designers greater flexibility in creating solutions to meet the challenges of dead load, terrain, seismic conditions, construction schedules and budgets in today's marketplace.

10E

ESCSI Information Sheet 3001
“Guide Specification for Load-Bearing Lightweight Concrete Masonry Units”

Guide Specification for Load-Bearing Lightweight Concrete Masonry Units

Section 4200

Lightweight concrete masonry units made from expanded shale, clay or slate lightweight aggregate provide the highest quality lightweight concrete masonry units. This guide specification is offered in a master specification format to aid the designer in projects involving lightweight concrete masonry. Comments, which are boxed and shaded, precede each specification section and should be deleted from the final specification.

SECTION 4200 - UNIT MASONRY

> In 1990 the ASTM C 90 specification was extensively revised and now includes both hollow and solid concrete masonry units. There is no longer a lower strength Grade S unit; all C 90 load bearing units are required to meet the same 1900 psi minimum average strength requirement based on the net area.
>
> Cite specification ASTM C 90-90 "Standard Specification for Load-Bearing Concrete Masonry Units" in the project "referenced specifications" section.

Load bearing lightweight concrete masonry units shall conform to ASTM C 90.

> The type of units (Type I, Moisture Controlled, or Type II, Non-Moisture Controlled) specified will depend on the local climate and the measures taken to control shrinkage. Lightweight concrete masonry units made with expanded shale, clay or slate offer the least shrinkage of any lightweight unit. Consult the local lightweight aggregate supplier for additional information.
>
> Specify the type of unit below by deleting the type of unit that will not be used.

Units shall be Type [I- Moisture Controlled] [II- Non-Moisture Controlled].

> Cite specification ASTM C 331 "Standard Specification for Lightweight Aggregate for Concrete Masonry Units" in the project "referenced specifications" section.

The lightweight aggregate used in the manufacture of lightweight concrete masonry units shall be expanded shale, clay or slate aggregate produced by the rotary kiln process and conform with ASTM C 331.

Rotary Kiln Produced Structural Lightweight Aggregate
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Delete the following paragraph if not required.

The concrete masonry unit manufacturer shall provide certification that lightweight aggregates used in the manufacture of lightweight concrete masonry units meet the requirements of ASTM C 331.

Expanded shale, clay or slate aggregate produces a typical block concrete density of 90 pcf (1440 Kg/M^3) oven dry. Consult with local masonry manufacturers or lightweight aggregate manufacturers for more specific information.

In general, units with a lower density will not only reduce the dead load in a structure, but will also have better thermal insulating properties and provide increased mason productivity during installation. These factors can result in significant overall cost savings. The fire resistance rating of a concrete masonry unit depends on its equivalent thickness and the type(s) of aggregate used in its manufacture; ratings are assigned by the model building codes and by agencies such as Underwriters Laboratories, Inc.

The architect may choose to specify thermal insulation, sound control, and fire resistance properties of lightweight concrete masonry units. Information regarding these properties is available from a number of sources: ESCSI Information Sheets, NCMA TEK Sheets, ASHRAE Handbook, PCA Concrete Masonry Handbook, Underwriters Laboratories, Inc. Standard 618, American Insurance Association's Fire Resistance Ratings, NFPA Fire Protection Handbook, National Research Council of Canada, as well as various building codes.

The density of the concrete of which the units are made shall not exceed 90 pcf (1440 kg/m^3) when measured in accordance with the provisions of ASTM designation C 140 "Sampling and Testing Concrete Masonry Units".

Expanded shale, clay and slate aggregate, as manufactured by the rotary kiln process (originally developed in 1908 and patented in 1918 as Haydite), is available throughout the world.

Local Supplier **or**

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