

## **FIRE RESISTANCE OF EXPANDED SHALE, CLAY AND SLATE CONCRETE MASONRY**

### **Introduction**

*Wherever you live, work or play, ESCS Lightweight Concrete Masonry improves your world!*

The truth of this statement is perhaps no better illustrated than the protection and peace of mind afforded when your home, workplace or school is constructed of non-combustible lightweight concrete masonry made from ESCS aggregates.

What is ESCS? It is a unique, ceramic lightweight aggregate prepared by expanding select minerals in a rotary kiln at temperatures over 2000°F. The production and raw material selection processes are strictly controlled to ensure a uniform, high quality product that is structurally strong, stable, durable and non-combustible, yet also lightweight and insulative.

ESCS is in fact so durable and fire resistive, that it is the material of choice for use in high temperature refractory concrete applications.

How many times have we seen on the evening news, homes and entire apartment buildings left in total ruin as a result of construction with combustible materials?

As long as buildings are furnished and decorated with combustible materials, the threat of fire cannot be totally eliminated. However, the spread of that fire and the dangers of structural collapse can be very easily mitigated with non-combustible ESCS masonry construction.

Concrete masonry units manufactured with ESCS aggregates are readily available throughout the United States.

### **Methods for Classification of Fire Resistant Ratings of ESCS Concrete Masonry**

The fire resistive properties of ESCS concrete masonry units are generally classified by hourly fire resistance ratings. These hourly fire resistance ratings can be established by three different methods:

#### **1. Calculation**

As a result of numerous fire tests dating back to the 1930's and the resulting enormous amount of data compiled, the high temperature performance of ESCS concrete masonry has been well established. By drawing on this data, methods of calculation have been developed to determine fire resistive ratings.

#### **2. Underwriters Laboratories Inc.**

A commercial listing service which tests materials and assemblies to determine if they comply with applicable

safety standards. UL also publishes directories that list classified assemblies.

#### **3. Fire testing**

Full scale assembly testing may be conducted and the results used to confirm code compliance, or for the purpose of gathering new research data.



Regardless of the method used, fire ratings are based on data obtained from the implementation of ASTM E119 *Standard Test Methods for Fire Tests of Building Construction and Materials*. The purpose of this test method is to compare the fire resistance properties of materials and assemblies in order to classify walls, columns, floors and other building elements under a common exposure condition. Such data enables ratings to be assigned in building codes to secure structures that are safe, that are not a menace to neighboring structures or to the public, and that will offer reasonable protection to firefighting personnel and equipment.

The conditions for acceptance of test of load bearing walls and partitions are:

- (a) The wall or partition shall have sustained the applied load during the fire endurance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.
- (b) The wall or partition shall have sustained the applied load during the fire and hose stream test without passage of flame, or gases hot enough to ignite cotton waste, or of the hose stream. The assembly shall be considered to have failed the hose stream test if an opening develops that permits a projection of water from the stream

beyond the unexposed surface during the time of the hose stream test.

- (c) Transmission of heat through the wall or partition during the fire endurance test shall not have been such as to raise the temperature on its unexposed surface more than 250°F (121°C) above its initial temperature.<sup>1</sup>

The end point of a test is determined by the above conditions. Fire ratings are assigned to the last full hour. IT SHOULD BE NOTED THAT THE END POINT OF TEST FOR ESCS CONCRETE MASONRY IS TYPICALLY TRIGGERED BY HEAT TRANSMISSION, NOT STRUCTURAL COLLAPSE, AS IS THE CASE WITH MANY OTHER BUILDING MATERIALS. If you wish to obtain more detailed information regarding fire testing, refer to ASTM E 119. The scope of ASTM E 119 states that the fire tests are to register performance during the period of exposure and are not to be construed as determining suitability for use after fire exposure. FREQUENTLY, CONCRETE CONSTRUCTIONS MADE WITH ROTARY KILN EXPANDED SHALES, CLAYS AND SLATES ARE RETURNED TO SERVICE AFTER A FIRE AND ALTHOUGH NOT REFLECTED IN THE RATINGS, SUCH RESILIENCE IS A TREMENDOUS EXTRA VALUE TO THE OWNER AND OCCUPANTS.

### Relative Humidity

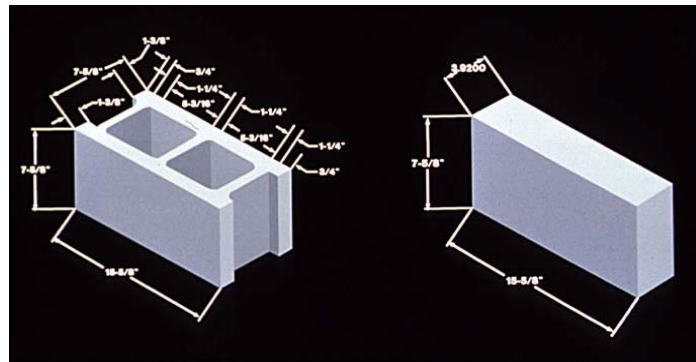
During the late 1950's and early 1960's, ASTM Committee E 5 on Fire Standards began considering the seasoning of specimens to equilibrium with a specified relative humidity. This was brought about as a result of fire testing of structural and prestressed concrete by PCA and of fire testing of concrete masonry beginning in 1954 by ESCSI. Unpublished work by ESCSI indicates that relative humidity equilibrium of the concrete in a masonry unit wall has a measurable effect on fire endurance. ASTM E 119, Fire Tests of Building Construction and Materials, stipulates that the relative humidity in the dampest section of massive constructions such as masonry be in the range of 50-75% @ 73 ± 5°F.

### Effect of Aggregate Type and Moisture

Aggregate types affect fire ratings in two ways: on the basis of heat transfer and on the basis of moisture absorption. Countless investigations indicate that as the density of concrete decreases, the insulation value increases; consequently, ESCS concrete masonry units afford better heat insulation than normal weight units. This property, which is due to the voids in the lightweight aggregate, retards the transfer of heat through the wall during a fire test, thereby extending its fire endurance period. Aggregates absorb moisture in varying degrees depending upon the type of aggregate. Normal weight aggregates absorb the least, rarely more than 2% by weight, and lightweight aggregates typically absorb from 7% to more than 25%. The presence of moisture in the aggregate of a block during a fire test extends the fire duration by the time it takes for the moisture to be turned to steam, and evaporated from the unit.

### Calculation of Fire Resistance Ratings

As previously stated the high temperature performance of concrete masonry as it relates to various aggregate types used in their production is well established. Methods of calculation have been developed and are presented in the *Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies*, ACI 216.1-14/TMS 0216.1-14. This Standard is now incorporated by reference into the national model codes. Calculations are based on the thermal performance characteristics of the aggregates used and the equivalent thickness of the concrete masonry assembly.



### Equivalent Thickness

The equivalent thickness is determined in accordance with ASTM C-140, the methods of which are based on Archimedes principles of buoyancy and water displacement. It represents, in essence, the theoretical thickness of the masonry unit if it were reformed as a solid mass.

It is represented by the formula:

$$ET = V_n / L \times H$$

Where:

$V_n$  = net volume in cubic inches

$L$  = length of the cmu in inches

$H$  = height of the cmu in inches

Equivalent thickness may also be determined by multiplying the percent solids of the cmu by its actual thickness. Once the equivalent thickness is known, it is then compared to the required minimum equivalent thickness for the given aggregate type as listed in table 3.1 of ACI 216.1-07. For ESCS aggregates, the minimum required ET for various hourly ratings are as follows:

1 Hr. = 2.6"

2 Hr. = 3.6"

3 Hr. = 4.4"

4 Hr. = 5.1"

A typical 8" ESCS concrete masonry unit with 50% solids will have an approximate ET of 3.81" which, as can be seen exceeds the requirement for a 2-hour fire rating. A typical 12" ESCS concrete masonry unit with 48% solids will have an approximate ET of 5.58," exceeding the requirements for a 4-hour fire rating.

The minimum required equivalent thickness corresponding to the fire resistance rating for units made with a combination of aggregates shall be determined by linear interpolation, based on the percent by volume of each aggregate used in the production of the cmu.

#### Effect of Filling the Cores

Fire tests sponsored by ESCSI and others show that filling the cores of masonry units with lightweight aggregate increases the fire resistance by more than two hours. Again, this is logical because of the greater insulation value (ESCSI Information Sheet #3201) and of more aggregate volume to hold moisture to be released during the fire test.

#### Effect of Finish Materials

Plaster adds additional thickness to the unit, thereby increasing the equivalent thickness. Sanded gypsum plaster

one half-inch thick increases the fire endurance of concrete masonry by one-half to approximately 1 hour, depending upon the fire endurance of the unplastered unit. Sanded Portland cement plaster offers about 75% of the protection of sanded gypsum plaster. NCMA TEK 7-1C provides a comprehensive description of the effects of various finishes.

#### Conclusion

Lightweight concrete masonry manufactured with ESCS aggregates offers the ultimate in life safety for both occupants and firefighting personnel. It's non-combustible nature combined with it's inherent structural integrity following exposure to fire make it the obvious choice for building construction. Following are various tables of reference reprinted for the convenience of the reader.

ACI 216.1-14 Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies Table 3.1  
Fire resistance rating of concrete masonry assemblies

Aggregate Type	Minimum required equivalent thickness for Fire resistance rating, in. <sup>AB</sup>				
	1 hr	1.5 hr	2 hr	3 hr	4 hr
Calcareous or siliceous gravel (other than limestone)	2.8	3.6	4.2	5.3	6.2
Limestone, cinders, or air-cooled slag	2.7	3.4	4.0	5.0	5.9
Expanded clay, expanded shale or expanded slate	2.6	3.3	3.6	4.4	5.1
Expanded slag or pumice	2.1	2.7	3.2	4.0	4.7

- A. Fire resistance ratings between the hourly fire resistance rating periods listed shall be determined by linear interpolation based on the equivalent thickness value of the concrete masonry assembly.
- B. Minimum required equivalent thickness corresponding to the fire resistance rating for units made with a combination of aggregates shall be determined by linear interpolation based on the percent by volume of each aggregate used in the manufacture.

#### NCMA TEK 7-1C

#### Fire Resistance Rating Concrete Masonry Assemblies

#### Steel Columns Protected by Concrete Masonry

The fire resistance rating of steel columns protected by concrete masonry as illustrated in Figure 4 is determined by the following equation:

$$R = 0.401(A_{st}/p_s)^{0.7} + \{0.285(T_{ea}^{1.6}/k^{0.2}) \times [1.0 + (42.7\{(A_{st}/Dt_{ea})/(0.25p + T_{ea})\}^{0.8})]\}$$

#### Where:

R= fire resistance rating of the column assembly, hr

A<sub>st</sub> = Cross-sectional area of the steel column, in<sup>2</sup>

D = Density of concrete masonry protection, lb/ft<sup>3</sup>

p<sub>s</sub> = Heated perimeter of steel column, in

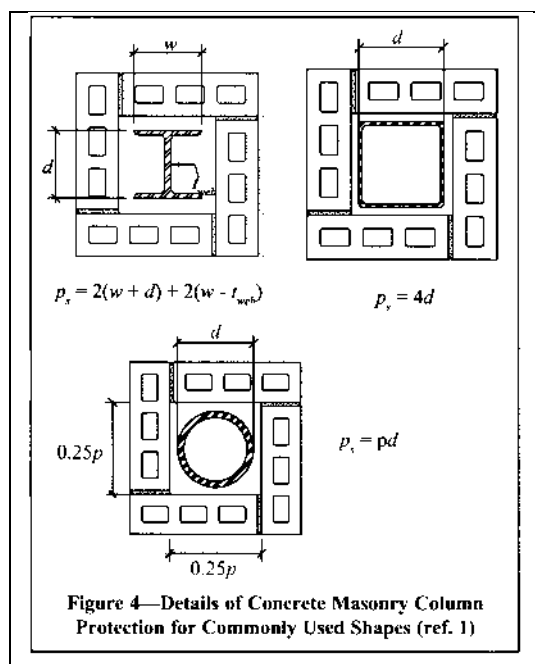
k = Thermal conductivity of concrete masonry, Table 6, Btu/hr\*ft\*°F

p = Inner perimeter of concrete masonry protection, in

T<sub>ea</sub> = Equivalent thickness of concrete masonry protection, in

Table 6-Properties of Concrete Masonry Units

Density, D pcf	Thermal Conductivity <sup>1</sup> , k Btu/hr*ft*°F
80	.027
85	.228
90	.252
95	.278
100	.308
105	.340
110	.376
115	.416
120	.459
125	.508
130	.561
135	.620
140	.685
145	.758
150	.837
1. Thermal conductivity at 70°F	



## CONCRETE MASONRY UNITS - UL 618

Table 4A.1

Thickness, material and strength requirements

Type of aggregate <sup>a</sup>	Manufacturing Process	Equivalent Thickness, in.			Cement to Aggregate Ratio Maximum	Minimum Compressive Strength, psi*	
		Hourly Rating				Average	Individual
		2 hr	3hr	4hr			
Expanded clay, shale, slate	Rotary kiln process	3.6	4.4	5.1	1:10.0	1000	800
Expanded clay, shale, slate	Sintered process	4.2	4.75	5.4	1:9.0	1000	800
Expanded slag	Blast furnace	4.1	4.8	5.3	1:8.0	1000	800
Fly-ash	Sintered process	4.0	4.7	5.2	1:8.5	1000	800
Fly-ash with sand	Sintered process (fly ash)	4.2	4.9	5.4	1:8.5	1000	800
Pumice	--	--	4.1	4.4	1:7.0	1000	800
Natural, by-products with or without sand	--	4.2	5.5	--	1:7.0	700	600
Natural, by-products with or without sand	--	--	--	6.5	1:6.0	1800	1600

a. Units made of a blend of aggregates shall meet the equivalent thickness and compressive strength requirements of each component of the blend, and also contain a cement to aggregate ratio of the component which requires the greater proportion of cement.

b. Equivalent thickness is defined as the average thickness of solid material in the wall and is represented by the formula:  $T = V/L \times H$

In which:

T is the equivalent thickness in inches

V is the net volume (gross volume less volume of voids) in cubic inches,

L is the length of block in inches, and

H is the height of block in inches.

Net volume (V) of the blocks is to be determined by a water displacement method of a number of blocks of each design. The blocks are to be "soaked" in water for 24 hours, removed from the vat, surface water removed, and then immersed in water and the displacement determined.

\*See 4A.3 below.

## CONCRETE MASONRY UNITS - UL 618

Table 4A.2

Minimum face shell web thickness

Width, in.	Face shell thickness, in.	Web thickness, in.
7-5/8	1-1/4	1
9-5/8	1-3/8	1-1/8
11-5/8	1-1/2	1-1/8

4A.2 The cement-aggregate proportions shown in Table 4A.1 are specified in terms of volumes of cement to volumes of combined dry-rodded fine and coarse aggregates (after mixture).

4A.3 The procedure in conducting tests for compressive strength is to be in accordance with ASTM C140 - 12 Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units. The compressive strength requirements specified in Table 4A.1 are based on the gross cross sectional area of the unit as laid in a wall when tested not more than 28 days after manufacture.

## References

1. ASTM Designation E 119-12 "Standard Test Methods for Fire Tests of Building Constructions and Materials."
2. "Standard for Safety," Concrete Masonry Units UL 618, Underwriters' Laboratories, Inc. 1995.
3. "Tests of the Fire Resistance and Strength of Walls of Concrete Masonry Units," Carl A. Menzel, January 1934, Portland Cement Association.
4. Retardant No. 2309, September 4, 1930, "Report on 8-in. Hollow Haydite Concrete Building Units," Underwriters' Laboratories, Inc.
5. Building Materials and Structures Report BMS 92, "Fire Classifications of Building Constructions," National Bureau of Standards, October 1942.
6. Building Materials and Structures Report BMS 117, "Fire Resistance of Walls of Lightweight Aggregate Concrete Masonry Units," National Bureau of Standards, May 1950.
7. Fire Study No. 10, October 1963, "Fire Test of a Non-Bearing Wall Built from Masonry Units (68.8 percent solid) of Rotary Kiln Expanded Shale Aggregate," National Research Council.
8. Fire Study No. II, January 1964, "Fire Test of a Non-Bearing Wall Built from Solid Masonry Units of Rotary Kiln Expanded Shale Aggregate," National Research Council.
9. Fire Study No. 12, January 1964, "Fire Test of a Load-Bearing Wall Built from Masonry Units (89.1 percent solid) of Rotary Kiln Expanded Shale Aggregate," National Research Council.
10. Fire Study No. 6, February 1962, "Fire Test of a Steel Column of 8-in. H Section, Protected with 4-in. Solid Haydite Blocks," National Research Council.
11. Retardant 3746-1-2-3-4 April 14, 1958, "8-in. Bearing Walls of Concrete Masonry Units (Blocks) Made with Rotary Kiln Process Expanded Shale Aggregates," Underwriters' Laboratories, Inc.
12. File R3746-7-8, March 2, 1970, "8-in. Concrete Masonry Units for Use in Unreinforced Load-Bearing Walls Made with Expanded Shale Aggregates (Rotary Kiln Process)," Underwriters' Laboratories, Inc.
13. File R3746, August 4, 1965, "Bearing Walls of Concrete Masonry Units (Blocks) Made with Rotary Kiln Process Coated and Uncoated, Expanded Shale, Clay and Slate Aggregates," Underwriters' Laboratories, Inc.
14. Fire Study No. 25, March 1970, "Fire Endurance of Selected Non Loadbearing Concrete Masonry Walls," National Research Council.
15. File R 3746-79NK11623, June 28, 1982, "Investigation of Equivalent Thickness Requirements for Concrete Blocks Made From Expanded Shale, Clay or Slate Aggregates," Underwriters' Laboratories, Inc.
16. NCMA TEK 7-1C 2009 "Fire Resistance Rating of Concrete Masonry Assemblies," National Concrete Masonry Association.
17. ACI 216.1-07/TMS 0216.1-07, "Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies," ACI Manual of Concrete Practice 2011.