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The Marina City Twin Towers in Chicago marked the first significant use of lightweight concrete in the United States.

An Introduction to Lightweight Concrete

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An Introduction to Lightweight Concrete

Lightweight aggregates can improve concrete's properties for structural, insulating, fireproofing, and other applications.

by Martha G. VanGeem

Concrete made with lightweight aggregates—called lightweight concrete—offers a lighter dead load and better insulating properties than concrete of normal weight. While normal-weight concretes have unit weights of 140 to 150 pcf (pounds per cubic foot), lightweight concretes' unit weights can range from 120 to as low as 20 pcf. These concretes, which offer a full spectrum of compressive strengths, thermal resistances, fire resistances, and costs, can be used to construct high- and low-rise buildings, bridges, religious facilities, sports arenas, floor slabs, roof decks, and fire barriers.

Three Varieties

There are three general types of lightweight concretes—structural, moderate strength, and insulating. Concrete's compressive strength generally increases with unit weight, while thermal resistance decreases; thus the high-density concretes are generally the strongest and the low-density concretes the best insulators. Moderate-strength concretes—the type used least frequently of the three—have intermediate strengths and insulating capacities. *Table 1* shows aggregates used to make concretes with various unit weights and compressive strengths.[1]

Structural (load-bearing) lightweight concretes. Structural or load-bearing concretes are generally designed to meet the requirements of ACI 318-83, Building Code Requirements for Reinforced Concrete.[2] Lightweight aggregates, to qualify for use in structural concrete, must meet the requirements of ASTM C330—Standard Specification for Lightweight Aggregates for Structural Concrete.[3] These aggregates generally have a bulk unit weight of 70 pcf or less, whereas normal-weight aggregates weigh about 100 pcf.[4]

Aggregates most commonly used for structural lightweight concrete include rotary-kiln-expanded shales, clays, and slates; sintered shales and clays; pelletized or extruded fly ash; and expanded slags.[5] The raw materials are heated, generally to 1,800°F or hotter. Gases or steam entrapped in the softened raw materials form a cellular structure, resulting in an aggregate lighter in weight than the sand or gravel used in normal-weight concretes. The American Concrete Institute's *Manual of Concrete Practice* provides more information on the manufacturing processes used to produce these aggregates.[6]

Lightweight structural concretes made with these aggregates commonly have compressive strengths ranging from 2,500 to 6,000 psi (pounds per square inch), and unit weights from 85 to 120 pcf. A new manufactured ceramic aggregate[7] can lower those characteristics to 50 pcf for a 2,000-psi compressive strength.[8]

Moderate-strength concretes. Although ASTM C330 allows the use of pumice, scoria, and tuff in producing lightweight aggregates for structural concrete, they are most commonly used for moderate-strength concretes. These naturally occurring lightweight materials are found in volcanic deposits in the Western United States. Concretes made with these materials generally weigh from 50 to 85 pcf and have compressive strengths of 800 to 2,000 psi. Moderate-strength concretes have traditionally had a limited use as floor fills.[9]

Insulating (low-density) concretes. Insulating or low-density concretes, frequently used as fireproofing, or as insulative roofing over a structural system, generally weigh from 20 to 50 pcf and have compressive strengths lower than 800 psi. Aggregates used for low-density or insulating concretes are covered by ASTM C332—Standard Specification for Lightweight Aggregates for Insulating Concrete.[10] Although the previously mentioned aggregates can be used, most low-density concretes are made using expanded perlite, vermiculite, or polystyrene beads. Expanded perlite and vermiculite are made by heating perlite (a volcanic glass) and mica, respectively. Polystyrene beads are a processed hydrocarbon.

Thermal Conductivity and Resistance of Lightweight Concretes

Thermal conductivity is the rate of heat flow through a material at a constant temperature. The thermal resistance, or R-value, of a homogeneous material is equal to its thickness divided by its thermal conductivity. Materials with higher R-values generally are better thermal insulators.

Concrete's thermal conductivity and resistance can be measured using ASTM C177—Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus; ASTM C236—Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box; or ASTM C976—Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box.[11]

The thermal conductivity or resistance of lightweight concretes can vary by more than an order of magnitude. *Figure A, page 2,* shows a general range for concrete's thermal conductivity as a function of unit weight. Although actual conductivities depend on the particular aggregate used and the concrete's moisture content, conductivity generally increases exponentially with unit weight. Lightweight structural concretes weighing 85 to 120 pcf generally have thermal conductivities ranging from 3 to 11 Btu•in./hr•ft²•°F. Insulating concretes weighing from 20 to 50 pcf generally have thermal conductivities ranging from 0.7 to 1.8 Btu•in./hr•ft²•°F. More precise values that take aggregate type into account may be found in the Oak Ridge National Laboratory report, *Assessment of the Thermal and Physical Properties of Masonry Block Products.*[12]

Normal-weight concrete has a thermal conductivity of approximately 15 Btu•in./hr•ft2•°F—about ten times greater than that of 50 pcf concrete. This difference prompted Construction Technology Laboratories, Inc., to develop an energy-efficient concrete of about 50 pcf that can be used for structural applications.

Development work at Construction Technology Laboratories, Inc., has shown that a manufactured ceramic aggregate can be used to construct building elements with a 2,000-psi compressive

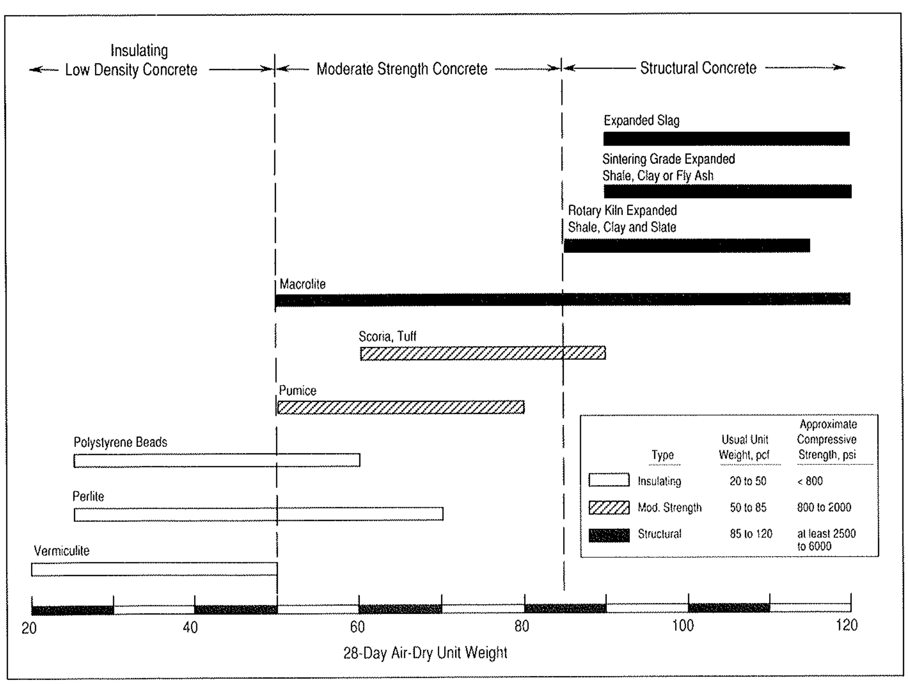


Table 1 **Classification of Lightweight Aggregate Concretes**

strength, a 50-pcf unit weight, and a thermal conductivity of 1.5. An eight-inch-thick wall constructed of this concrete had a thermal resistance of 5.2 hr•ft²•°F/Btu.[13]

Thermal Mass

Thermal resistance or R-value is frequently used as a quick indicator of a wall or roof's energy-saving capabilities. However, R-values do not take into account the energy-saving benefits of thermal mass—a building material's ability to absorb, store, and later release significant heat.

Energy research conducted using a calibrated hot box (ASTM C976) simulated the effect of outside temperature changes on wall specimens. Results showed that, compared to insulated frame walls, peak heating and cooling loads on concrete walls were reduced and the occurrence of peak loads was delayed.[13,14]

One measure of thermal mass is thermal lag, the time it takes for a peak in air temperature occurring on one side of a wall to be transmitted to the other side. *Table 2*, page 3, shows thermal lag values, along with thermal resistance, for normal-weight concrete, lightweight concrete, and insulated frame walls. The measured data show that concrete walls have greater thermal lags than insulated frame walls. Also, lightweight concretes have greater thermal lags than normal-weight concretes, because of their unique combination of mass and high thermal resistance. Thermal mass depends on a wall's thermal resistance as well as its mass.

Because concrete building components delay the effect of outside temperatures on heating and cooling requirements, savings can accrue when lower off-peak energy pricing is in effect. Reduced peak loads can also result in savings since many electric utilities have peak load charges.

For many buildings occupied only during office hours, exposed concrete and masonry can absorb unwanted heat during times of peak demand, and ventilating equipment with low operating costs can cool the structure during the night. Smaller, less costly HVAC equipment can be specified.

Actual energy savings from thermal mass will depend on other aspects of the building's design, orientation, and operation, and on yearly weather conditions.[15]

Fire Resistance

The ability of insulating concretes to support design loads before and after a fire, and their relatively low heat transfer through a construction assembly, make them competitive fire-resistant materials.[16] One measure of fire endurance is the ability of a material to maintain a low temperature at one surface when exposed to a high temperature at the opposite surface. This characteristic is dramatically improved by adding an insulating concrete layer to a normal-weight concrete element.[17] Results of fire endurance tests conducted on wall, floor, and roof assemblies constructed with insulating concrete over concrete, galvanized steel decks, and wood structures may be found in the *ACI Manual of Concrete Practice*, and are also available from Underwriters Laboratories, Factory Mutual, and other recognized laboratories.

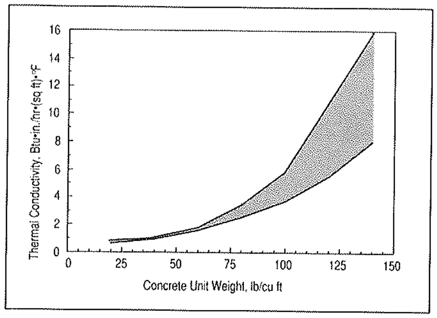


Figure A **Concrete Unit Weight and Thermal Conductivity**

Economical Uses

Production costs make manufactured aggregates such as expanded shales and clays more expensive than sand or gravel. A cost-effective lightweight aggregate must deliver either superior performance at equal cost or equal performance at lower cost.

Using lightweight structural concrete can reduce job costs by lessening a structure's dead load, reducing the required size and reinforcement of major supports such as columns and foundations. Lightweight concretes are used for long-span roofs and bridges to reduce support-point loading. Lightweight precast members can also cut transportation, handling, and erection costs. It may be possible to use smaller cranes or fewer workers for lifting on a lightweight concrete job.

Lightweight structural concrete in tall buildings reduces the building's weight, thus reducing the required sizes of supporting structural members. The 64-story Marina City Twin Towers in Chicago (1962), which marked the first significant use of lightweight concrete in the United States, incorporated nontraditional architectural shapes constructed of reinforced concrete. Lightweight concrete floor slabs allowed for smaller, more economical vertical structural members. Concrete in the floor slabs had a unit weight of 105 pcf and a 28-day compressive strength of 3,500 psi.[18]

The entire structural frame of the 52-story One Shell Plaza Tower in Houston is constructed of 115-pcf lightweight concrete. The building's concrete mat foundation, required due to Houston's soil conditions, could have accommodated either a 35-story normal-weight concrete building or a 52-story lightweight concrete building.

Large shell structures built with lightweight structural concrete include the University of Illinois-Urbana Assembly Hall. This multi-use facility is a 400-foot-diameter, folded plate dome topping a corrugated saucer with a capacity for 16,200 spectators. One-hundred-five-pcf concrete reduced the dome's weight, allowing for its large span. The concrete used had a 28-day compressive strength of 4,000 psi.[19]

All above-grade structural elements in the 55,000-capacity Busch Memorial Stadium in St. Louis are constructed of lightweight concrete, as are the roof panels and stiffening ribs of the Terminal Building at Washington D.C.'s Dulles International Airport, and the shell roof at the TWA Terminal at New York's Kennedy Airport. Lightweight structural concrete has also been used for public housing facilities, low-rise buildings, and unique religious facilities.[20]

Lightweight structural concrete lintels (see photo below) are being used to support HVAC equipment on the roofs of commercial buildings. The lintels, made with Macrolite™ ceramic aggregate, reduce roof loading over that of similar normal-weight concrete lintels. The concrete weighs 78 pcf and has a compressive strength of 3,500 psi.

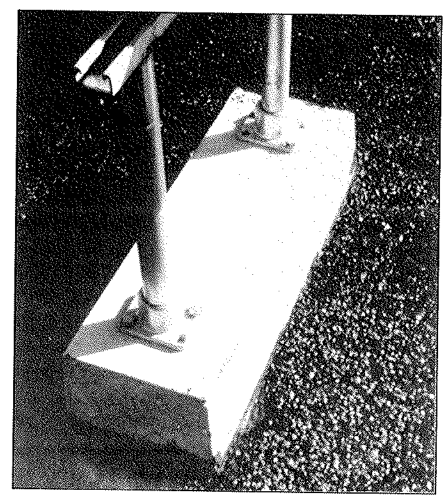
Costs associated with heating and cooling losses are reduced when walls and roofs are made of lightweight rather than normal-weight concrete. To achieve equivalent performance, lightweight concrete can be used to reduce or eliminate the cost of applying additional insulation.

Although most insulating concretes are weaker than structural concretes, they are stronger than many insulation products. Insulating concretes are useful where energy or fire endurance requirements demand insulating capabilities, and strength requirements need to be met. Precast low-density concretes are frequently used for short-span roof decks, floors, interior partitions, and minimal-load exterior walls.[21]

Mix Designs and Other Properties

Lightweight concrete mix designs and their resulting properties vary with the aggregate used and the desired end use. Additional information is available from the lightweight aggregate trade associations listed on the next page, product manufacturers, ACI, and the Portland Cement Association.[22]

Engineering consultants are also available to develop mix designs that meet special needs.



Lightweight structural concrete lintels can reduce rooftop loading.

Wall Designation	Wall Description	Thickness in.	Concrete Unit Weight, pcf	Wall Unit Weight, psf	28-day Compressive Strength, psi	R-Value** Thermal Resistance, hr*(sq ft)* °F/Btu	Thermal Lag, hr
NW	Normal-weight structural concrete with sand and gravel aggregate	8.3	144	100	5720	1.6	4
S	Structural lightweight concrete with expanded shale aggregate	8.3	102	70	5350	2.6	5.5
M	Structural lightweight concrete with Macrolite™ aggregate	8	56	37.3	2000	5.2	6.5
P	Insulating concrete with expanded perlite aggregate	8.5	46	33	880	6.8	8.5
F	2x4-in. wood frame with R-11 fiberglass batt insulation between studs, gypsum wallboard on inside surface, and plywood cedar siding on outside surface	4.8	***	5.3	***	12	1.5

* Data from References 13 and 14.
** From calibrated hot box (ASTM: C976) test results at a wall mean temperature of 75 °F. Values include surface film resistances.
*** Not applicable for wood frame wall.

Table 2 **Thermal Lag of Concrete and Other Walls**

Lightweight aggregates are economical when their increased costs are offset by reducing construction costs such as foundation, handling, fire insulation, and thermal insulation costs.

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3. American Society for Testing and Materials, *1988 Annual Book of ASTM Standards*, Philadelphia: ASTM, 1988.
4. ACI, *ACI 213R-79*.
5. ACI, *ACI 213R-79*.
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7. Macrolite™, a manufactured ceramic aggregate, is a trademark of the 3M Company. For more information on Macrolite, contact 3M Industrial Mineral Products Division, Building 209, 3M Center, St. Paul, Minnesota 55144; (800) 225-1402.
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21. American Concrete Institute, *Lightweight Concrete*, SP-29, Detroit: ACI, 1971.
22. More information on mix designs can be found in the American Concrete Institute's *ACI Manual of Concrete Practice.* Consult ACI 523.1R-86, "Guide for Cast-in-Place Low-Density Concrete," and ACI 523.2R-68, "Guide for Low-Density Precast Concrete Floor, Roof, and Wall Units." Also consult two publications of the Portland Cement Association, *Design and Control of Concrete Mixtures* (EB001.13T, 1988), and "Structural Lightweight Concrete" (IS032.05T, 1972).

Lightweight Aggregate Trade Associations

Associations established to promote the various lightweight aggregates can provide information on regional availability and suppliers. Many associations and producers provide technical information, such as aggregate properties, concrete properties, and mix designs.

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6218 Montrose Road
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Perlite Institute
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Chicago, Illinois 60605
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Society of the Plastics Industry
1275 K. Street, N.W., Suite 400
Washington, D.C. 20005
(202) 371-5200

Vermiculite Association
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