Low density concretes

For insulation and fill

At the lower end of the lightweight concrete spectrum pictured on page 247, concretes weigh as little as 12 to 15 pounds per cubic foot,[1]* and have compressive strengths ranging down to 5 psi[2] or less. These lightest of the lightweight concretes may be divided into two groups according to their composition:

- Cellular concretes—made by incorporating air voids in a cement paste or cement-sand mortar, through use of either preformed or formed-in-place foam. These concretes weigh from 15 to 90 pounds per cubic foot.[3]
- Aggregate concretes—made with expanded perlite or vermiculite aggregate or expanded polystyrene pellets. Oven-dry weight ranges from 15 to 60 pounds per cubic foot.[4]

When normal weight sand is included in these mixes, increased weight and strength usually can be achieved, but the information in this article focuses on concretes weighing 50 pounds per cubic foot[5] and less, a range where thermal insulation is most effective. Cellular concretes in this density range are also used for highway and foundation fills where their weight-strength combination offers advantages over natural soils.

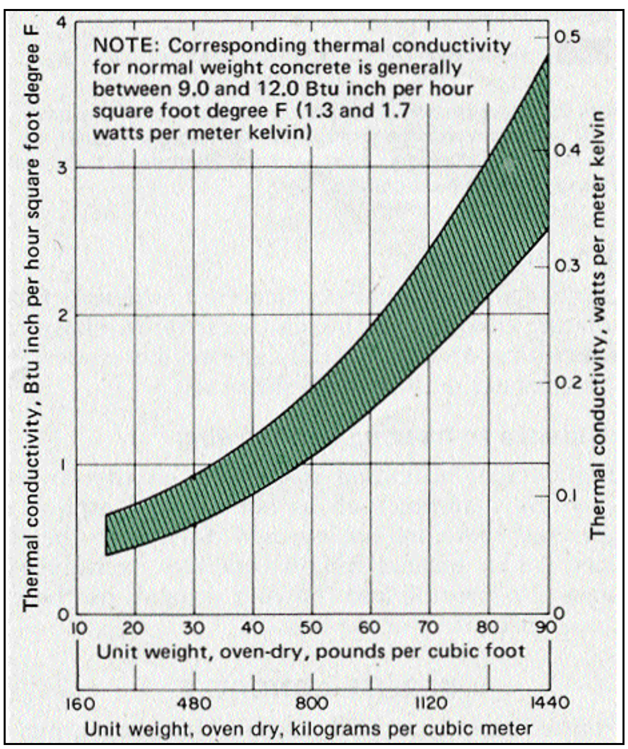

Figure 1. Approximate relationship between oven-dry unit weight and thermal conductivity of low density insulating concretes. Adapted from Reference 1, courtesy Portland Cement Association.

* Superscript numbers refer to metric equivalents listed with this article.

PROPERTIES CONSIDERED FOR DESIGN

Within the spectrum of lightweight concretes now available, the lightest ones provide the best insulation—k-values from 0.4 to 0.7 Btu inch per hour square foot degree F[6]—but little strength. The designer must consider not only the insulating value of the concrete material but also its other properties and how it will be combined with adjoining materials, whether in a roof assembly or a foundation fill.

Thermal conductivity

This must be determined by laboratory test (ASTM C 177**) for each concrete mix design. As a general guide in the absence of test data, the k-values (thermal conductivities) for oven-dry concretes shown in Figure 1 may be used. Moisture in the concrete affects thermal conductivity. There is generally a 5 percent increase in thermal conductivity for each percent increase in unit weight due to free moisture.

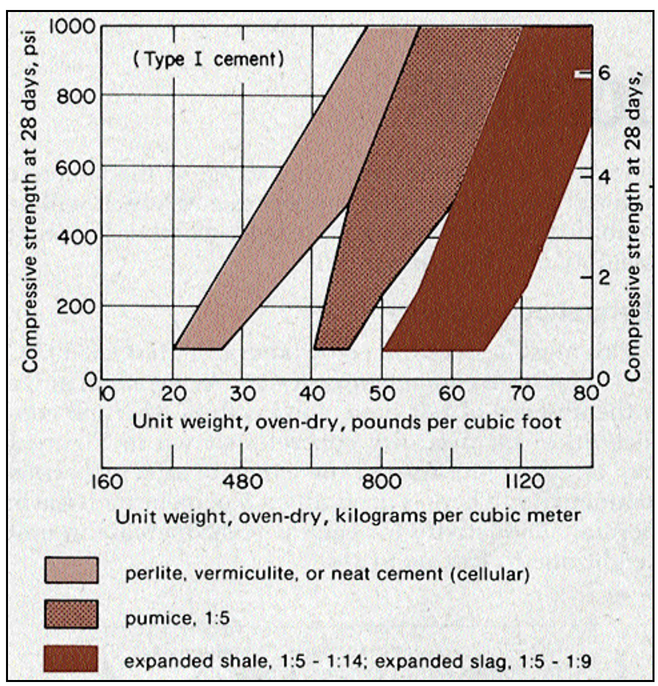

Figure 2. Approximate relationship between oven-dry unit weight and compressive strength of lightweight insulating concretes, tested air-dry. Adapted from Reference 1, courtesy Portland Cement Association.

** Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Guarded Hot Plate.

Compressive strength

As shown in Figure 2, compressive strength increases with increasing unit weight. Design requirements depend on the installation. A compressive strength of 100 psi[7] or less may be acceptable for insulating underground steam lines; however, roof and floor fill requires enough early strength to withstand the traffic of workmen. Strengths of 100 to 200 psi[8] are usually adequate, although up to 500 psi[9] is sometimes specified.

Drying shrinkage

Shrinkage is not usually critical for low density fill or insulating concretes, although excessive shrinkage can cause curling. Moist cured cellular concretes made without aggregates do have high shrinkage.

Resistance to freezing and thawing

Lightweight insulating concrete is usually covered by roofing material such as hot mopped asphalt or pitch, and therefore not exposed directly to the elements. As for normal weight concretes, resistance to damage by freezing and thawing depends on the entrained air content of the mix.

PERLITE CONCRETE

Perlite is a type of lava mined in large open pits in the western United States, and then crushed to sand sized particles for shipment to processing plants in 32 states. A small amount of water is locked inside the tiny particles and when heated to between 1500 and 2000 degrees F[10] the particles “pop” or expand like popcorn to about ten times original volume.

Perlite insulating concrete consists of a mixture of expanded perlite, portland cement, water and an air-entraining agent. The dry concrete weigh from 20 to 50 pounds per cubic foot,[11] depending on the mix design selected. Perlite concrete can be placed monolithically on flat, uneven, curved or sloping surfaces. On flat roofs, the thickness of perlite concrete can be varied to provide specified drainage slopes.

The designer selects the strength and insulating value that he considers most appropriate to his project. The physical properties of perlite concrete are controlled by its dry density which is the principal factor in its specification. An ideal balance between reduced dead load, adequate compression and indentation strengths and good insulating value can be achieved with a density of 24 to 28 pounds per cubic foot.[12] Greater densities can be specified if higher strengths or better nail holding capacity are more important than insulating value. For insulated floor slabs on grade, a density of 20 to 24 pounds per cubic foot[13] is frequently recommended.

VERMICULITE CONCRETE

Vermiculite is a soft, laminated, mica-like mineral that has few uses in its natural state but when heated and exfoliated becomes a lightweight aggregate of great value for fill and insulating concrete. The crude vermiculite is crushed, cleaned, dried and sized, and the resulting concentrate is shipped to processing centers, where it is heated to temperatures of 1800 to 2000 degrees F.[14] Each individual granule expands to 10 to 15 times its original size. The expanded product weighs from 6 to 10 pounds per cubic foot.[15]

The components of vermiculite insulating concrete are expanded vermiculite aggregate, air-entraining admixture, portland cement, and water, all mixed and applied according to precise procedures. The ratio of cement to aggregate determines the density, strength and insulating value of the finished concrete. As used in the average roof deck, the ratio ranges from 1:4 to 1:8 by volume.

The resulting concrete mixture is usually pumped to the roof site and screeded into place over the structural base. Vermiculite concrete is installed in thicknesses of 2 inches[16] or more, depending on design needs and strength requirements. It weighs from 20 to 40 pounds per cubic foot,[17] with compressive strengths from 90 to 500 psi.[18]

EXPANDED POLYSTYRENE BEAD CONCRETE

Expanded polystyrene, processed to a nominal density of 1 pound per cubic foot,[19] serves as a stable, nonabsorptive aggregate in lightweight insulating concrete. Typically, polystyrene bead lightweight insulating concrete consists of Type I or Type II portland cement, polystyrene aggregate expanded to a nominal density of 1 pound per cubic foot,19 air-entraining agent and water. To enhance specific properties for a given application, additional mix components such as sand, limestone or pozzolans may be used.

Insulating roof fill of polystyrene bead concrete usually has a dry density of 26 to 30 pounds per cubic foot.[20] Densities are available from 25 to 60 pounds per cubic foot.[21] Fire resistance, verified by small scale ASTM E 119† fire tests conducted by the Portland Cement Association on 46-pound-per-cubic-foot-density[22] concrete, resulted in the following ratings: 2½ -inch[23] slab, 2 hours; 5-inch[24] slab, 6 hours; 7-inch[25] slab, 11 hours.

Polystyrene beads tend to resist absorption of water and are not readily wetted by water. Accordingly, cement paste or mortar does not adhere very well to them. Furthermore, their extremely low density makes them tend to segregate by floating out of the mix. To overcome this, the manufacturers have developed a number of bond-improving admixtures. Epoxy resin or an aqueous dispersion of polyvinyl propionate have been recommended.

Shrinkage and swelling strains are high compared to dense concretes, and allowance must be made for this in the design. Polystyrene bead concrete has good workability, is quite pumpable, and requires minimum vibration in placement.

CELLULAR CONCRETE

Cellular insulating lightweight concrete owes its distinctive properties to a multitude of macroscopic, discrete air cells uniformly distributed throughout the mix. These cells may account for up to 80 percent of the total volume. Weight of the concrete may range from 12 to 90 pounds per cubic foot.[26] Density and strength can be controlled to meet specific design requirements by varying the amount of air.

Numerous proprietary methods and agents are used to produce cellular concrete but essentially they can be considered in two groups: those using a preformed foam and those using formed-in-place foam. Formed-in-place foam is generated by special high speed mixing of water, foaming agent, cement and aggregates (if any) to allow foam to form in the mixer. Initially large air bubbles are reduced to a reasonably uniform size as mixing proceeds.

By the other method, a uniform preformed aqueous foam is blended with a portland cement and water slurry using only enough water to ensure proper hydration of the cement and facilitate the placing operation. The portland cement used may by Type I, II, III or portland blast-furnace slag cement, Type IS. The foam itself is made by blending a foam concentrate, water and compressed air in predetermined proportions in a foam generator calibrated for discharge rate.

As with other lightweight insulating concrete, the strength and thermal conductivity depend on density. The material can be made so light that its strength is only sufficient for it to retain its shape during handling. Thermal conductivities range from 0.51 Btu inch per hour square foot degree F[27] for a density of 20 pounds per cubic foot[28] to 2.3 Btu inch per hour square foot degree F[29] for a density of 90 pounds per cubic foot.[30]

Cellular concrete is totally incombustible (8 inches[31] of concrete represents a fire rating of about 8 hours); yet it can be worked much like wood. It has been widely used for floor and roof fills. Recently highway departments have begun to use it as a stabilized fill over poor soil at bridge approaches and beneath embankments and roadways .

References:

(1) Special Types of Concrete, IS183T, Portland Cement Association, Skokie, Illinois, 1977, 8 pages.

(2) Valore, R. C., Jr., "Insulating Concretes," Journal of the American Concrete Institute, November 1956, pages 509-532.

(3) ACI Committee 523, Guide for Cast-in-Place Low Density Concrete, American Concrete Institute, Detroit, Michigan, 1987, 8 pages.

(4) The Roof Deck, National Roofing Contractors Association, 1515 North Harlem Avenue, Oak Park, Illinois 60302.

(5) "Vermiculite Roof Deck and Insulating Concrete," Concrete Construction, March 1961, pages 66-67.

(6) "Perlite Roof Deck and Insulating Concrete," Concrete Construction, April 1961, pages 95-97.

(7) "Perlite Insulating Concrete," 3.4d/Per, Perlite Institute Inc., 45 West 45th Street, New York, New York 10036.

(8) Cook, D. J., "Polystyrene Aggregates," Constructional Review (Sidney, Australia), August 1972, pages 52-53.

(9) Cellular Concrete for Insulated Roof Decks, Cellular Concrete Association Inc., 715 Boylston Street, Boston, Massachusetts 02116.

(10) "Cellular Concrete," Concrete Construction, January 1963, pages 5-8.

(11) Valore, Rudolph C. Jr., "Cellular Concretes, Parts 1 and 2," Journal of the American Concrete Institute, May and June 1954, pages 773-796 and 817-836.

† Standard Method of Fire Tests of Building Construction and Materials.

Metric equivalents (approximate values)

(1) 190-240 kilograms per cubic meter
(2) 0.034 megapascals
(3) 240 to 1440 kilograms per cubic meter
(4) 240 to 960 kilograms per cubic meter
(5) 800 kilograms per cubic meter
(6) 0.05 to 0.1 watt per meter kelvin
(7) 0.7 megapascals
(8) 0.7 to 1.4 megapascals
(9) 3.5 megapascals
(10) 815 to 1090 degrees C
(11) 320 to 800 kilograms per cubic meter
(12) 385 to 450 kilograms per cubic meter
(13) 320 to 385 kilograms per cubic meter
(14) 980 to 1090 degrees C
(15) 96 to 160 kilograms per cubic meter
(16) 50 millimeters
(17) 320 to 640 kilograms per cubic meter
(18) 0.62 to 3.5 megapascals
(19) 16 kilograms per cubic meter
(20) 415 to 480 kilograms per cubic meter
(21) 400 to 960 kilograms per cubic meter
(22) 740 kilogram-per-cubic-meter-density
(23) 65-millimeter
(24) 130-millimeter
(25) 180-millimeter
(26) 190 to 1440 kilograms per cubic meter
(27) 0.07 watt per meter kelvin
(28) 320 kilograms per cubic meter
(29) 0.33 watt per meter kelvin
(30) 1440 kilograms per cubic meter
(31) 200 millimeters

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