

Lightweight insulating concrete for floors and roof decks

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The cost of energy production and the consequences of its indiscriminate use impel us to thoughts of conservation and the construction technologies that make it possible. Just as the human head loses a disproportionate amount of heat when not properly insulated with a covering, so a building can manifest a disproportionately high level of thermal transfer through its roof to the outside atmosphere if it lacks adequate insulation. Designers, builders and owners today as never before must become aware of the energy-saving potential of lightweight concrete used as insulating fill for floors and roofs.

This article is restricted primarily to the thermal insulation qualities of lightweight concretes, although many of these concretes serve capably for other insulation purposes. The insulating lightweight concretes may be considered according to composition in three groups:

I—Concretes made with expanded perlite or vermiculite aggregate or expanded polystyrene pellets.

Oven-dry weight ranges from 15 to 60 pounds per cubic foot.

II—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.

III—Concretes made with aggregates prepared by calcining, sintering, or expanding such products as slag, clay, fly ash, shale or slate; also made with aggregates processed from natural materials such as scoria, pumice, or tuff. Concretes in this group range in weight from 45 to 90 pounds per cubic foot.

Data are given here for Groups I and II, because generally the most effective thermal insulation is found in the lower density ranges of these groups. However, attractive combinations of insulating and strength properties may be achieved with Group III concretes, and the reader is alerted to these possibilities (see box).

Design considerations

Looking at the broad spectrum of lightweight concretes now available (Figure 1), we find an almost infinite variety of mixes and a wide range of densities. It is diffi-

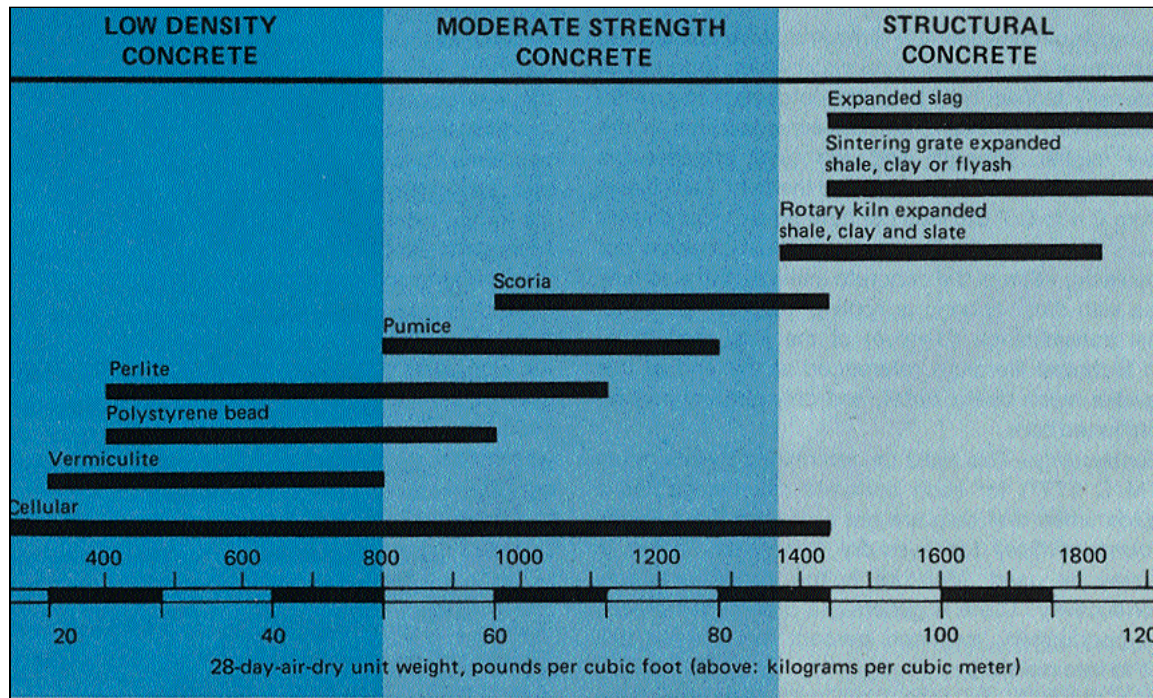


Figure 1. The full spectrum of lightweight concretes. Low density mixes discussed in this article (shaded band at left) offer best insulating properties. Chart adapted from ACI 213 report "Guide for Structural Lightweight Aggregate Concrete," *Journal of the American Concrete Institute*, August 1967, pages 433-469.

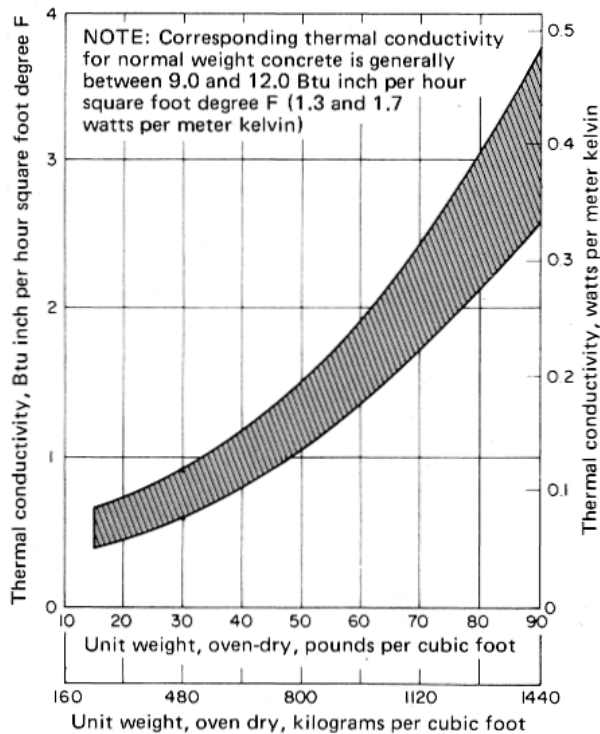


Figure 2. Approximate relationship between oven-dry unit weight and thermal conductivity of lightweight insulating concretes. From *Special Types of Concrete*, Portland Cement Association, Skokie, Illinois, Publication IS183T, 6 pages, 1977.

cult to draw a sharp line between structural and non-structural capabilities, or to say at just what density a given type of concrete ceases to provide effective insulation. Generally, the heavier concretes in the group have higher strength and are less effective as insulation. The lightest concretes provide the best insulation—k-values from 0.4 to 0.7 Btu inch per hour square foot degree F—but very little strength. The designer must consider not only the insulating value of the concrete material, but also how it combines with other flooring or roofing materials and what the thermal transmittance (U-value) of the total system is. Trade and technical literature referenced at the end of this article provides much useful detail, and only general properties are mentioned here.

Thermal conductivity—This must be determined by laboratory test (ASTM C 177†) for each concrete mix design. As a general guide when test data are not available, the k-values (thermal conductivities) for oven-dry concretes shown in Figure 2 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.

Compressive strength—As shown in Figure 3, compressive strength increases with increasing unit weight. Design requirements depend primarily on the installation. A compressive strength of 100 psi or even less may be quite 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 are usually adequate, although up to 500 psi 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.

Expansion joints: to use or not to use?—Follow the aggregate producers' recommendations. Some recommend insertion of a 1-inch expansion joint at the juncture of all roof projections and the concrete. Transverse expansion joints are used at a maximum spacing of 100

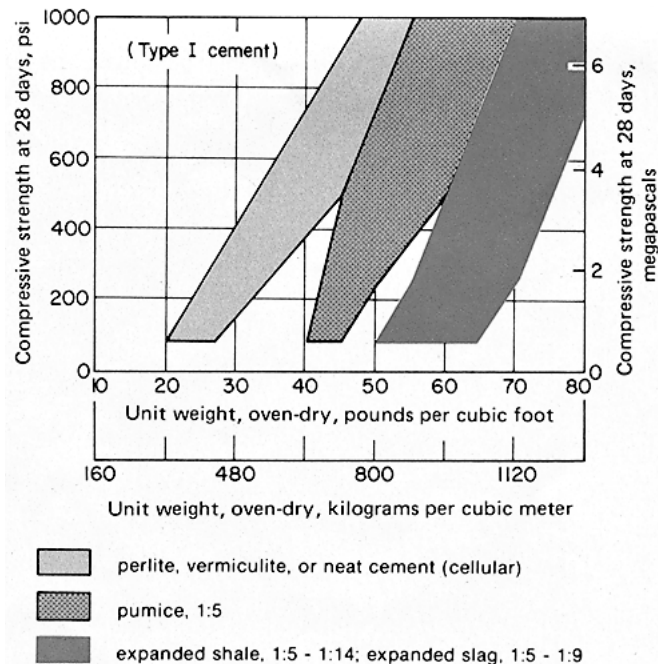


Figure 3. Approximate relationship between oven-dry unit weight and compressive strength of lightweight insulating concretes tested in air-dry conditions.

Note: mix proportions for perlite and vermiculite concretes range from 1:3 to 1:10 by volume. From *Special Types of Concrete*, Portland Cement Association, Skokie, Illinois, Publication IS183T, 6 pages, 1977.

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

feet in any direction to allow for a thermal expansion of 1 inch per 100 lineal feet. A joint material that will compress to one-half its thickness under a stress of 25 psi is generally used. With other aggregates, expansion joints may not be necessary because the initial shrinkage of the concrete is greater than any combination of thermal, moisture or freezing expansion that will occur in a roof deck.

Construction practices

Whether low density concrete is used as a floor fill or part of a roof deck, the form which supports it generally becomes a permanent part of the in-place construction. Typical forming or support systems include:

- Corrugated, galvanized sheet metal, appropriately vented and designed to carry the roof load.
- Insulating acoustical form board supported on flanges of steel subpurlins, with woven wire mesh reinforcement draped over the subpurlins to lie in the lower part of the concrete.
- Lath and mesh systems, where the concrete is placed on either paper backed wire mesh or a ribbed, expanded metal lath.
- Structural precast concrete or wood floors or roofs, where concrete serves as either leveling or insulating fill.

All of these systems require adequate venting in accordance with the recommendations of manufacturers and the National Roofing Contractors Association.

Mixing, placing and finishing—Proper consistency and uniform distribution of materials are necessary to achieve the required unit weight and can only be accomplished by mechanical means. Excessive mixing and handling can break down aggregate particles and should be avoided. Insulating concretes should be placed immediately after mixing by qualified technicians. Conventional placement methods can be used, but pumping is ideal and customarily used due to the normal consistency of lightweight insulating concrete.

Low density concrete should not be placed during rain or snow, nor should it be placed on a deck or form where standing water, snow or ice are present.

Workability—Insulating concretes have excellent workability because of their high air content. Appearance of the mix may be the most reliable indication of consistency. Slumps of 5 to 7 inches are usually quite satisfactory, and the mixtures are highly plastic and homogeneous.

Bleeding and segregation problems will not ordinarily be present. These mixtures can usually be placed simply by pouring and screeding, without further consolidation. This is particularly true with the cellular concretes which can be handled as liquids.

Curing and weather conditions—The surface of freshly smoothed low density concrete should be prevented from drying for not less than 3 days. If temperatures are

above 40°F during the first 24 hours after placing, standard curing practices may be used. When temperatures during the first 24 hours are predicted to be from 30 to 40°F, high-early-strength cement and heated mixing water are recommended. Low density concrete should not be placed during freezing weather unless special cold weather procedures are followed.

Perlite concrete

Perlite, derived from the French word *perle*, resembles tiny clusters of pearls when viewed under the microscope. 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° F the particles “pop” or expand, just like popcorn. The crude rock expands to about ten times its original volume.

Expanded perlite weighs only 7 1/2 to 10 pounds per cubic foot, approximately one-twelfth as much as sand. During the popping process, it changes to almost pure white from gray or black. The tiny perlite particles are composed of many minute glass-sealed dead air cells. The thermal conductivity of expanded perlite itself is 0.34 Btu inch per hour square foot degree F when graded for use as a concrete aggregate, which explains its excellent insulating value.

Perlite insulating concrete consists of a mixture of expanded perlite, portland cement, water and an air-entraining agent. The dry concrete weighs from 20 to 50 pounds per cubic foot, 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 must select 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. 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 is recommended.

Perlite roofs may have polystyrene insulation board sandwiched between layers of perlite concrete and supported on a metal deck. This system is capable of achieving U-values as low as 0.04 Btu per hour square foot degree F with a 2-hour fire rating.

Perlite concrete should meet the specified physical properties at the point of placement. It should be deposited and screeded in a continuous operation until the placing of a panel or section is completed. The 1-inch

expansion joints mentioned earlier should be installed through the full depth of the concrete around the perimeter of the roof deck and at the juncture of all roof projections (skylights, penthouses, ventilators, parapet walls) and perlite concrete.

The built-up roofing should be applied as soon as the perlite insulating concrete can carry construction traffic and is dry enough to develop adhesion with hot asphalt or pitch. Normally the perlite concrete should be permitted to cure at least three days.

For greater strength and corresponding higher density, blends of perlite and medium weight aggregates may be used. However, due to varying characteristics of naturally occurring aggregates in different parts of the country, the local perlite aggregate manufacturer should be consulted before specifying blends.

Vermiculite concrete

Vermiculite is a soft, laminated, mica-like material in its raw form. It is found in twelve states and mined commercially in seven. Vermiculite is a 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 in furnaces at temperatures of 1800 to 2000°F. Water molecules trapped in the flakes of vermiculite ore turn to steam and force the micaceous plates of the material to expand or exfoliate in an accordion-like fashion. Each individual granule is expanded to 10 to 15 times its original size. Air spaces thus formed convert the vermiculite into an aggregate that provides excellent insulating properties. Usually light brown or golden in color, the expanded product weighs from 6 to 10 pounds per cubic foot.

The components of vermiculite insulating concrete are expanded vermiculite aggregate, air-entraining admixture, portland cement, and water, all mixed and ap-

plied 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 and greater, depending on design needs and strength requirements. It weighs from 20 to 40 pounds per cubic foot, with compressive strengths from 90 to 500 psi.

Vermiculite roof deck assemblies have been developed using a slotted or perforated corrugated metal deck. These positive vented decks offer up to 3 percent open area in the steel form at no penalty or loss in structural performance. The openings help to speed up ventilating and drying of the insulating concrete. Insulation values are therefore quickly reached. In the event of subsequent roofing membrane leaks, the point of leakage is easily located on the underside of the metal decking.

Vermiculite concrete roof insulation, like perlite, can also be cast around a layer of polystyrene insulation board. A slotted opening pattern in the polystyrene permits vertical vapor flow through the board, in order to promote faster, more complete drying and venting of the concrete. The slots also ensure the positive locking and keying of the polystyrene board to the vermiculite concrete to enhance the shear strength of the insulation sandwich and provide a strong, composite roof insulation system. This system provides insulation with a U-value of 0.10 Btu per hour square foot degree F or less and a 1 1/2-hour fire rating.

Vermiculite lightweight concrete is best mixed and placed by experienced, licensed contractors. Current technology now permits contractors to pour quality decks in marginal weather, down to 32°F and even lower in certain cases.

Expanded polystyrene bead concrete

Expanded polystyrene, processed to a nominal density of 1 pound per cubic foot, serves as a stable, nonabsorptive aggregate in lightweight insulating concrete. Polystyrene, unlike perlite and vermiculite aggregate raw materials which are found in nature, is a polymer of styrene which is created by an involved chemical process from a liquid unsaturated hydrocarbon. The polystyrene is foamed to produce a lightweight aggregate. The polystyrene can be pre-expanded or supplied in an unexpanded form and foamed on the site by application of steam. During this process it expands to approximately 50 times its original size. Each closed cell aggregate particle contains prepackaged air and is

HEAVIER, STRONGER CONCRETES ALSO INSULATE

Low density concrete—50 pounds per cubic foot or less—provides the best insulation, but has limited strength. The user who needs greater strength without sacrificing all insulating properties should consider both aggregate and cellular concretes in the moderate density range. For information, consult the comprehensive (and encyclopedically titled) report of ACI Committee 523, "Guide for Cellular Concretes Above 50 pcf, and for Aggregate Concretes Above 50 pcf with Compressive Strengths Less Than 2500 psi." This report was published in the February 1975 issue of the Journal of the American Concrete Institute, pages 51-66, and is reprinted in Part 3 of the ACI Manual of Concrete Practice.

* Standard Method of Fire Tests of Building Construction and Materials

spherical in shape.

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, air-entraining agent and water.

To enhance specific physical properties for a given application, additional mix components such as sand, limestone or pozzolans may be used. Depending upon the conditions of application, tensile stresses may be met by using mesh reinforcement, special bead aggregate coatings or a combination of the two.

Insulating roof fill of polystyrene bead concrete usually has a dry density of 26 to 30 pounds per cubic foot. Densities are available from 25 to 60 pounds per cubic foot. Fire resistance, verified by small scale ASTM E 119* fire tests conducted by the Portland Cement Association on 46-pound-per-cubic-foot-density concrete, resulted in the following ratings: 2 1/2-inch slab, 2 hours; 5-inch slab, 6 hours; 7-inch 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 additives. Epoxy resin or an aqueous dispersion of polyvinyl propionate are 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. Frost resistance is enhanced by entrained air, ranging from 5 to 10 percent of the matrix by volume.

As with all special types of concrete a technical consultant specializing in polystyrene lightweight concrete should be contacted for detailed recommendations covering formulations and mixing/placing techniques for your application.

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. 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 be 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. The concrete mix is blended in a mortar mixer or in a specially designed continuous blender. Each bubble of air in the foam is surrounded by a tough protein membrane which ensures stability during mixing and handling. However, since this membrane will eventually break down it is recommended that mixing and placing be completed within one hour. Use of high-early-strength cement (Type III) further ensures rapid setting and stability of cellular concrete, although good results are also obtained with regular portland cement (Type I) plus 2 percent calcium chloride, by weight of cement, as an accelerator.

As with other lightweight insulating concrete, the strength and thermal conductivity depend on density. The material can be made so light (down to 12 pounds per cubic foot) 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 for a density of 20 pounds per cubic foot to 2.3 Btu inch per hour square foot degree F for a density of 90 pounds per cubic foot.

Cellular concrete is totally incombustible (8 inches of concrete represents a fire rating of about 8 hours); yet it can be worked much like wood. Where prolonged working is likely, long-life tools are advised. These and other properties enhance the attractiveness of cellular concretes for floor and roof deck fill and insulation.

For more information

Obviously, subtle differences exist between the various lightweight insulating concretes available, which may recommend one type over another to satisfy some specific design objective. Costs and availability in the local market must also be considered.

Each type of insulating concrete, if mixed properly with high quality materials and placed and finished properly, will do an excellent job. Further research and study may reveal just the right characteristic that suits your need. A list of references for further information is given below.

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