Cellular Concrete

Nominal reductions in the dead weight of concrete are generally brought about through the use of manufactured lightweight structural aggregates. Concretes produced with such materials are broadly classified as structural lightweight concretes, and they usually fall in the range of 90 to 120 pounds per cubic foot on a plastic or wet weight basis, or 80 to 110 pounds per cubic foot on an oven dry basis. When more drastic weight reductions are necessary, such as for floor and roof insulating fills and fire retardants, the designer may use perlite1 or vermiculite2 aggregates or he may call for any one of a number of types of cellular concrete in which coarse aggregates have been replaced altogether by air or gas in the form of tiny bubbles. The weight of such concretes will largely determine whether they are to be used strictly for fill purposes or may be classified as semi-structural or structural materials.

The individual bubbles or cells in cellular concrete vary from almost microscopic size to about the size of a grain of sand. They can be bound together in several ways: with portland cement alone; with a cement-lime, cement-sand, or cement-pozzolan combination; or included as a partial replacement for conventional or lightweight aggregate. The concrete so produced, variously known as foamed, gas, aerated or cellular concrete, provides a lightweight material that excels in thermal insulation value, is fire- and water-resistant, and can be sawed, drilled and otherwise worked with ordinary hand tools.

The use of air in concrete is, of course, nothing new. Air entrainment is now standard practice to improve both durability and workability. For this purpose the amount of air entrained is normally less than 7 percent by volume; for cellular concrete the voids may occupy anything from 25 to 80 percent of the total volume. The dry density of cellular concrete can then range from as little as 20 pounds per cubic foot or less with no mineral aggregate (portland cement only as a binder) to 110 pounds per cubic foot or higher with conventional aggregate.

Cellular concretes were first developed in Scandinavia some thirty years ago. Today four out of every five buildings erected in Sweden are built of cellular concrete and in many other countries its use is widespread.

A large number of proprietary methods and agents are used to produce cellular concrete but essentially they can be considered in two groups: those using a chemical reaction, and those relying on mechanical beating. Chemical methods, more suitable for plant precasting than for field use, will not be considered here.

Mechanical beating or mix foaming of concrete to entrain air has much to recommend it. The process is much easier to control than the chemical methods and is generally much more economical. It is also possible to design a mix without worrying about water hardness, temperature changes or any other factors that affect chemical reactions. The foams used are completely neutral which means that corrosion and safety hazards present no problem. Two approaches are possible: air can be whipped into a slurry that contains a foaming or air-entraining agent; or a stable preformed foam (similar in appearance to shaving soap obtained from an aerosol can) can be added to the mix.

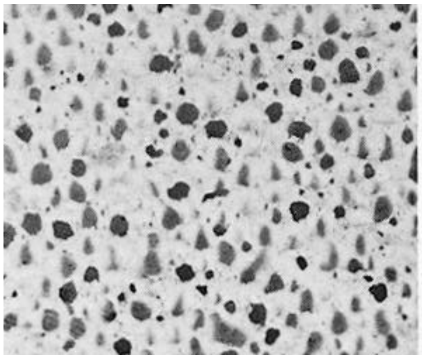
In the first system only one piece of equipment is needed—a high

The magnified portion of this insulating cellular concrete shows the remarkable size and shape uniformity of the tiny non-connecting air cells.

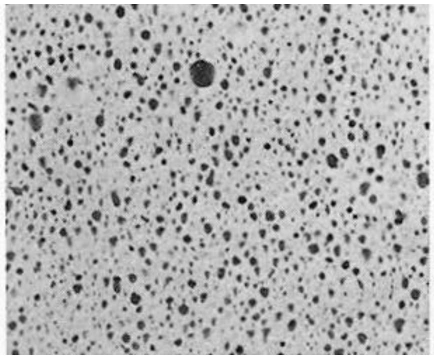
1See “Perlite Insulating Concrete,” Concrete Construction, June 1960, page 160.

2See “Vermiculite Roof Deck and Insulating Concrete,” Concrete Construction, March 1961, page 66.

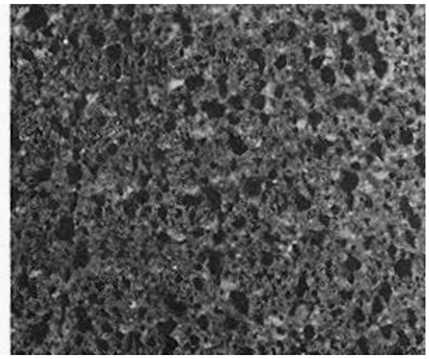
Textures of Various Cellular Concretes Shown in Full-Size Photographs



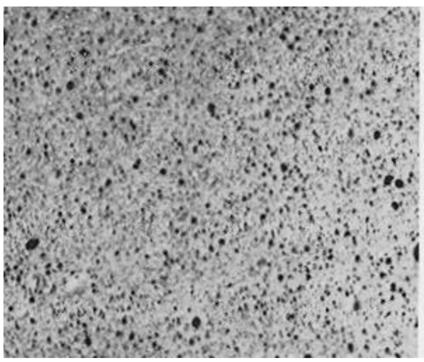
PORTLAND CEMENT / GROUND SILICA SHALE, FOAMED WITH ALUMINUM POWDER AND AUTOCLAVED.



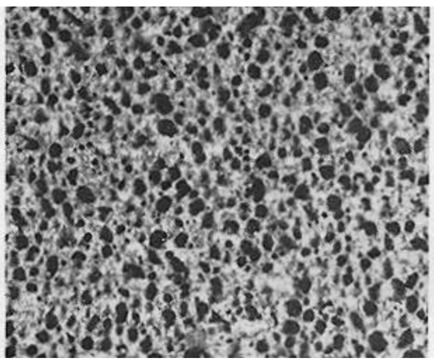
PORTLAND CEMENT / GROUND SILICA SHALE, MIX-FOAMED BY BEATING AND AUTOCLAVED.



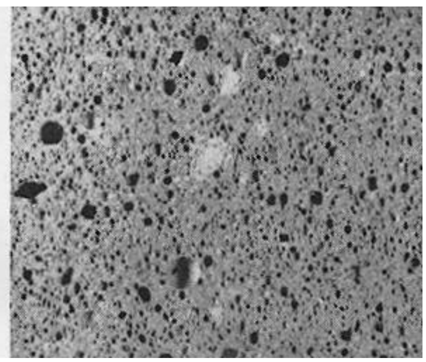
A LIME / SHALE MIXTURE, FOAMED WITH ALUMINUM POWDER AND AUTOCLAVED.



PORTLAND CEMENT AND DUST FROM AN EXPANDED SHALE KILN, MIX-FOAMED AND MOIST CURED.



PORTLAND CEMENT ALONE, FOAMED WITH ALUMINUM POWDER AND MOIST CURED.



A MIXTURE OF PORTLAND CEMENT AND DUST FROM AN EXPANDED SHALE KILN, AUTOCLAVED.

speed mixer. The mixer must have a high shearing action; this can easily be provided by operating a standard paddle type mixer at high speed. A horizontal propellor type mixer is preferred by some producers, and for one process blades of ¾-inch heavy wire mesh, rotating at 55 to 60 rpm, are recommended. For very low density cellular concrete containing little or no aggregate, the practice is to mix water and foaming agent first to produce the foam, and then to add portland cement (and sand, if needed) slowly while blending the mass together. For denser concretes, with higher proportions of aggregate, the procedure is reversed. The agent can be a proprietary compound or any of the usual admixtures for air entrainment—sodium lauryl sulfate, alkyl aryl sulfonate, or the various soaps, detergents and resins—except that they are needed in much larger quantities than for normal air entrained concrete. A wide range of densities can be produced by varying the amount of additive, the mixing time, or both.

The second approach, with preformed foam, uses a liquid based on hydrolyzed protein, free from starches and sugar. The protein is usually obtained as waste material from packing houses (hooves, horn, hair, blood) or from fish scales. The liquid is delivered to the site in drums and is subject to the action of compressed air to foam up to 20 times its original volume at a 90-pound air pressure. Foam so produced is essentially identical to that used for fighting gasoline fires. Most manufacturers of the base liquid supply a simple foam generator, accurately calibrated to supply foam at a given rate. This foam is fed into a standard mixer where it has the ability to more than double the volume of the concrete, depending upon the amount of agitation to which it is subjected. Each bubble of air in the foam is surrounded by a tough protein membrane which insures 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. The use of high-early-strength cement further insures rapid setting and stability of foamed concrete, although good results are also obtained with standard portland cement plus 2 percent calcium chloride, by weight of portland cement, as an accelerator.

Choice of aggregates for cellular concrete depends largely on the method of curing to be followed. The type of curing, in turn, has the major influence on the strength that can be obtained for the mix. For moist curing at normal temperatures (3 to 7 days) or in steam at atmospheric pressure, ordinary concrete sand or plaster sand may be used, with portland cement as the cementitious component.

When selecting a particular cellular concrete mix the choice will be governed basically by one of three interrelated requirements: weight (density), thermal insulating value, or strength. In the actual design of the mix, the following factors will influence the properties obtained: type and quantity of additive (foaming agent); portland cement content; cement/sand/aggregate ratio; mixing procedure and action; size of batch. It is then necessary to make trial mixes, taking all these factors into account, until the basic requirement for the application is filled. Most of the suppliers of proprietary foaming agents have charts and mix details showing precisely what their products can offer for a wide range of mix conditions and proportions.

As with conventional concrete, the strength of cellular concrete depends on its density. For any given cement/sand ratio, an increase in the amount of air in cellular concrete has the same effect on the leanness of the mix as adding more aggregate. Since the air cells cannot offer any resistance to compression, the strength of the mix decreases as the amount of air increases. Thus a 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.

Actual figures for compressive strength vary considerably depending on the foaming agent used. Developments have been rapid within recent years and some of the proprietary agents now available, containing special chemical additives and reagents, offer strengths much in excess of those obtained with the natural agents. For site-cast (moist-cured) applications a standard cellular concrete with a dry density around 20 pounds per cubic foot, made with 5 bags of portland cement, will have a 28-day compressive strength of only around 95 psi. With the same cement content and natural sand in the proportion 1 : 4 to give a density of 75 pounds per cubic foot, strength increases to 740 psi. For a 6-bag mix this figure is increased further to 1,300 psi, and mixes designed to give densities up to 110 pounds per cubic foot can offer strengths up to 2,500 psi. A general picture for this trend, based on data from various sources, both official studies and manufacturers' literature, is given in the accompanying graph. The flexural strength of cellular concrete is, in general, between ⅕ and ⅓ of the compressive strength.

Thermal conductivity of cellular concrete is proportional to density—the lighter the material the better the insulation it provides. K factors (BTU/hour/square foot/F./inches thickness at 75 degrees F.) range from 0.51 for 20 pounds per cubic foot concrete to 2.3 for a 90 pounds per cubic foot mix. In practice this means that a 10-inch wall of 40 pounds per cubic foot cellular concrete will have the same insulating value as a brick wall three times as thick, or as a dense concrete wall eight times as thick.

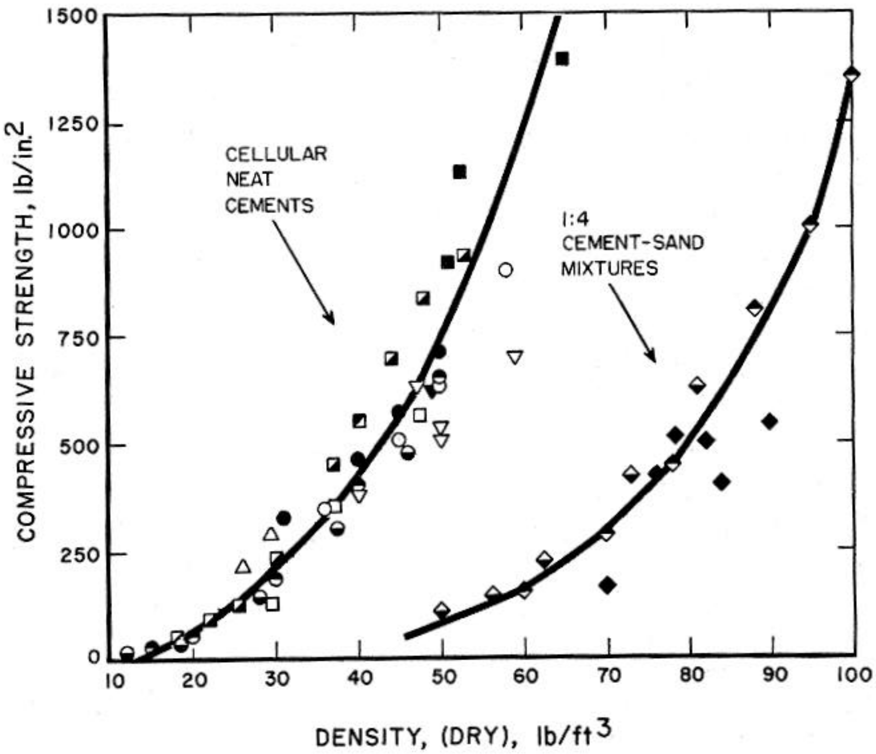
The drying shrinkage of cellular concrete is considerably higher than for ordinary concrete and can be as much as 0.5 percent with moist air curing, although the more normal range is from 0.01 to 0.10 percent. With ordinary concrete, dimensional stability is assured by the aggregates, which resist volume changes. With cellular concrete this stabilizing factor is not available, thus any measures which will prevent water absorption are an advantage. In site-cast work some shrinkage cracking is almost inevitable, although use of welded light-mesh reinforcement placed near the surface can do much to restrict this. Bonding with the reinforcement presents no problem.

The thermal expansion of cellular concrete is negligible (.000004 inch from minus 58 to plus 212 degrees F.). For pipeline insulation it is necessary to wrap the pipe in felt or paper to allow free frictional movement.

Water resistance of cellular concrete is high due to the uniform nature of the cells and the fact that they are not interconnected; capillary flow is thus avoided. In some mixes this advantage is improved by adding 2 percent of a plastic emulsion to give each air cell an individual waterproof coating. In general water absorption is about one-quarter of that of common brick. Frost resistance is similarly high. The moisture content of a wall or roof deck of 30 pounds per cubic foot cellular concrete, in equilibrium at 50 percent relative humidity, will be less than 3 percent by weight; this value rises to less than 5 percent for a relative humidity of 80 percent. These values are, of course, dependent on the fact that one side of the slab must be allowed to breathe, as with other materials. Exterior surfaces do need a weather-protective treatment; stucco or one of the masonry paints are frequently used. Where the concrete is buried a vapor barrier is advisable.

Some insurance companies offer a substantial reduction in premiums for cellular concrete buildings, since the material is completely inorganic and therefore totally incombustible. Eight inches of cellular concrete represent a fire rating of about 8 hours. This advantage can be exploited for partition walls and the fireproofing of structural steel.

Cellular concrete can be worked in the same way as wood, although where prolonged working is likely long-life tools are recommended.



The general relationship of compressive strength to density for cellular neat cements and 1 : 4 cement / sand mixtures.

Further advantages are resistance to fungus, vermin and rot.

All of the above properties point to the conclusion that the cellular concretes are special materials highly suitable for many applications. Typical of these is insulation for piping and conduit, above or below ground, as infilling for ducts. Boilers and tanks can also be insulated with cellular concrete, as well as cold storage and conventional buildings. In floors both insulation and weight saving can be exploited; use as a topping over precast elements is common. Any type of wearing surface is possible. Roof screeds are similarly a frequent application. Cellular concrete has also been sprayed successfully over steel mesh reinforcement. Obviously the design and operating advantages to be gained from the use of cellular mixes can offer substantial economic savings.

PUBLICATION#C630005