How to use air-entrained concrete

... and why you should use it

By William C. Panarese*

Many concrete contractors have only a vague knowledge of why and how air is entrained in concrete. Today, after more than 23 years of extensive field and laboratory studies, the benefits of intentionally entrained air in both fresh and hardened concrete have been demonstrated beyond all doubt. Entrained air is so beneficial to concrete in so many ways that it's now recommended for all types of concrete for nearly all forms of construction and in all climates. Many consider intentionally entrained air, concrete's fifth ingredient.

Air-entrained concrete is an established must for structures exposed to severe frost action and de-icers. It is also now being employed extensively for all exposed concrete work by large concrete-using organizations such as the U.S. Bureau of Reclamation and the Corps of Engineers.

In addition to its resistance to freeze-thaw damage, air-entrained concrete offers other advantages to the user of concrete who follows the recommendations outlined in this article. Experience shows that air-entrained concrete discharges from the mixer more readily, spreads and finishes more easily, is more cohesive, more workable, more uniform, and more durable throughout.

What is air-entrained concrete?

Air-entrained concrete is ordinary concrete that contains controlled amounts of air in the form of microscopic bubbles. These intentionally entrained air bubbles are extremely small. They range is size from a few thousandths of an inch in diameter to a few hundredths. There are literally billions of these air bubbles in a single cubic foot of air-entrained concrete, and their presence dramatically changes the nature of both the fresh and hardened concrete.

Freshly mixed air-entrained concrete looks fatty when it comes from the mixer. It is cohesive and slightly sticky. Because of its air content it weighs a little less than non-air-entrained concrete. Once it has hardened, however, it is indistinguishable from conventional concrete.

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How does it work?

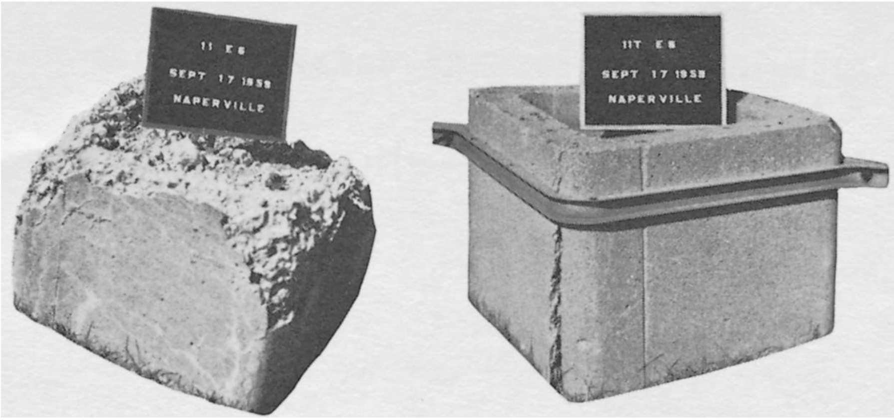
Let's look at how these tiny air bubbles can make concrete more workable and more durable with far less segregation and bleeding.

Workability refers to the ease with which concrete can be moved and consolidated. Entrained air acts as a lubricant, making concrete more plastic and workable. The air bubbles can be likened to flexible ball bearings that assist particles of sand and stone to slide past one another. Entrained air not only improves workability, it also permits use of less water and sand in the mix.

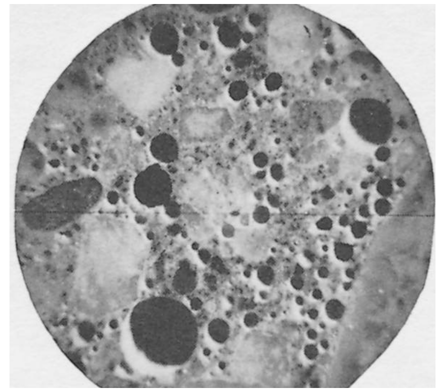
In mixes that are harsh and difficult to work, the effect of entrained air is readily apparent. For example, the workability of mixes containing angular and poorly graded aggregates is improved greatly with entrained air. It is not a cure-all of course: if concrete is made with unsound or soft aggregates, popouts may occur whether the mix is air-entrained or not. But such surface defects should not be confused with surface scaling, which is significantly reduced by entrained air.

Segregation and excessive bleeding, common characteristics of unsatisfactory concrete mixes, can be reduced or eliminated by use of entrained air. Segregation refers to the separation of gravel or crushed stone from the mortar (cement, sand, and water) in fresh concrete. It results in a non-uniform concrete. Bleeding is the term used to describe the appearance of water on the surface of freshly placed concrete. Excessive bleeding increases the water-cement ratio of the mix at the surface of the concrete and thus weakens the wearing surface. Bleeding also carries silt, clay and other nondurable materials to the surface. Many of the common defects in hardened concrete can be traced to excessive segregation and bleeding. Not only does air-entrained concrete minimize segregation but the billions of disconnected air bubbles also provide a barrier to the movement of water to the surface, thereby reducing the formation of capillaries or channels. This in turn reduces the possible later passage of water through the hardened concrete, resulting in a more watertight concrete—which means longer life and less maintenance.

The primary benefit of entrained air in hardened concrete however is the resistance if offers to freeze-thaw



After 20 years of severe winter exposure in Naperville, Illinois, these two concrete boxes show the benefit of entrained air. The box on the left was non-air-entrained while the box at the right did contain an air-entraining agent. In all other respects the two boxes are identical; both were similarly constructed with a lean mix concrete of high slump.


The surface of hardened air-entrained concrete magnified many times. These tiny air pockets range in size from a few thousandths to a few hundredths of an inch in diameter.

damage and scaling caused by de-icing salts or chemicals. Most concrete contains some moisture which expands during freezing temperatures. Without room for this expansion, large forces develop that can rupture the surface causing what is commonly called surface scaling. The small, entrained air bubbles serve as reservoirs or expansion chambers to relieve these pressures. Research has shown that the spacing and size of air bubbles are important in assuring their proper action. To be effective, bubbles must be spaced not more than .01 inches apart throughout the cement paste. Using today's methods of entraining air, it is not difficult to obtain this bubble spacing.

It is recommended that entrained air be used in all concrete subjected to cycles of freezing and thawing—especially where de-icing chemicals will come in contact with the concrete. Remember that surface scaling also can result from indirect application of de-icers on concrete surfaces from sources such as drippings from the underside of vehicles. Whether or not removal of ice and snow with de-icing chemicals is planned, indirect application cannot be avoided and air-entrained concrete should be used for all sidewalks, driveways, parking areas, garage slabs, etc., in freeze-thaw regions. Due to the availability of de-icing chemicals in supermarkets, hardware, and drug stores, it can be assumed that most concrete in severe climates will be subject to their use. Properly designed concrete walks, drives, parking lots, etc., made with top-quality, well-consolidated, air-entrained concrete using durable aggregates have little need for further protection where all but a few commercially produced chemicals are used to remove snow and ice. The exceptions are ice-removal agents that contain ammonium nitrate and ammonium sulfate salts. These chemicals are extremely corrosive, and they will attack any concrete, including air-entrained concrete. They should not be used as de-icing agents under any circumstances.

Importance to contractors

Air entrainment provides many advantages to contractors without an increase in cost. These advantages are of prime importance to builders involved in municipal construction especially in cities requiring performance bonds to insure that concrete will not scale or deteriorate for a given number of years. In such municipal work a contractor may proceed with greater confidence when using entrained air.

Specifications for air-entrained concrete usually hold the contractor responsible for keeping the air content within specification limits. This is another reason why contractors owe it to themselves to investigate and become familiar with air-entrained concrete.

Entrained air means more than just durable concrete to the contractor; it means more plastic concrete that can be hauled and placed easier, that flows into forms and around complex reinforcement easily and with less vibration. It means concrete that will discharge and flow down longer chutes with flatter slopes; concrete that can be finished sooner and with resulting surface textures remarkably free of pits, honeycomb or other blemishes. It means concrete that can be placed with lower slumps due to the substantial increase in workability of air-entrained concrete.

In the final analysis, entrained air can mean large dividends to the contractor through more productive use of equipment and personnel and fewer headaches at the job site.

And, when translated into good will, a successful concrete job that is durable and attractive can mean much to a contractor's reputation.

Importance to ready mix producers

The benefits that come from intentionally entrained air probably mean as much to the ready mixed concrete industry as to any other group involved with concrete. Let's examine why.

A ready mix producer is involved in grading and proportioning concrete materials, mixing, transporting and discharging concrete at the job site. The ready mix plant can improve nearly every phase of its operation with entrained air.

Take for example the first operation—grading and proportioning or batching materials. As mentioned previously, entrained air tends to fatten a concrete mix. This is advantageous with poorly graded aggregates that would otherwise result in harsh, hard-to-work concrete. Slag and lightweight aggregates also tend to make harsh mixes. With entrained air, sands deficient in fine material become usable because the air bubbles act as fines to help fill the gaps.

The sand and water content of an air-entrained mix can be reduced significantly to compensate for increased slump. The reduction in sand often will more than compensate for the cost of air-entrainment.

There are advantages to be gained in the mixing operation too. Air-entrained concrete will discharge from mixers faster, cleaner and with less wear and tear on the mixer blades.

With entrained air concrete can be transported in specially designed nonagitating dump body trucks. Some central mix plants are transporting concrete to the job site in this manner with a minimum of segregation and bleeding.

Many ready mix plants are now delivering air-entrained concrete almost exclusively. Records show that these plants receive fewer complaints from customers, especially concerning surface defects in hardened concrete.

How much air for air-entrained concrete?

Actual field experience has shown that the following amounts of air should be specified for air-entrained concrete. These air contents provide adequate safety against scaling due to ordinary de-icers and deterioration due to freezing and thawing:

Maximum Size Coarse Aggregate	Air Content
1½, 2 or 2½ in.	5% - 1%
¾ or 1 in.	6% - 1%
⅜ or ½ in.	7½% - 1%

Air contents are usually expressed in terms of percent air by volume of the concrete. Air is entrained only in the paste (cement and water) portion of a mix. Since the amount of paste varies with the size aggregate used, it follows that the air content in the total mix will also vary with the size aggregate. Small aggregate requires more mortar and cement paste than large aggregate; hence the greater air contents. Air contents of 5 percent, 6 percent and 7½ percent are generally considered optimum.

When concrete will be subjected to extremely severe conditions, it may be desirable to design air-entrained concrete for the upper limits of a specified air content. Such conditions may exist on city streets, sidewalks, curbs and gutters, bridge decks, loading platforms, and industrial driveways where large amounts of de-icers are used or where control of the air content may be inadequate. When higher than optimum air contents are used, the possible effects on strength and on finishing should be considered. Keep in mind that air-entrained concrete can be designed for any strength although it may be necessary, in some instances, to increase the cement content slightly to maintain the desired strength level.

When entrained air is not required for protection against freezing and thawing and/or de-icers, the lower limits for air content are recommended. For example, when concrete with a 1½-inch maximum size aggregate is used in a building frame not exposed to the weather, 4 percent entrained air can be used. With this less-than-optimum air content most of the improvements in transporting, placing and surface texture are retained. Less than optimum air contents can be used in concrete for floors that will not be subjected to freeze-thaw cycles and/or de-icers.

The amount of air entrained in concrete should not be inflexible, but suited to the particular need, depending on the type of structure, climatic conditions, number of cycles of freezing and thawing expected, extent of exposure to de-icing chemicals, the presence of aggressive soils or waters and to some degree on the strength of concrete.

Controlling the air content

Competent inspection should be required on projects where entrained air is essential for good concrete performance. The necessity for making tests for air content to insure compliance with specifications cannot be overemphasized. Samples of concrete for use in these tests should be taken after the concrete is placed in the forms and consolidated. Any one of a number of field testing methods may be used.

A simple test is available for checking possible changes in air content or mix proportions. This is called the unit weight test. All that is needed to run this test is a heavy steel container of known volume (preferable ½ or 1 cubic foot) and a balance or scale sensitive to .1 pound. Any unusual variation in the weight of a concrete sample from batch to batch indicates a change in air content or mix proportions.

On some jobs direct measurements of air content should be made frequently. Air tests should be made on the first few batches at the start of each day's run. If these air contents are consistent and the appearance and workability of the concrete does not change throughout the day, further air tests may not be needed, unless there are changes in slump or temperature.

If tests indicate an air content less than that required, certain adjustments can be made. If an air-entraining admixture is being added at the mixer, more admixture can be used. If air-entraining cement is being used, an adjustment in the amount and gradation of the fine aggregate can be made to increase the amount of air entrained. An increase in fine aggregate, especially the middle size particles, tends to increase the amount of entrained air.

Because good mixing is essential to the entrainment of air, the condition of the mixer should be checked if air contents are low. Also mixing time and the type of mixer can affect air contents. If a mixer is loaded beyond its rated capacity, there may be a reduction in the amount of entrained air.

Other factors affect the percent of air entrained in concrete with a given amount of air-entraining admixture or cement. Increased cement contents decrease the percent air entrained. Lean concrete mixes entrain more air than rich mixes. High water/cement ratios are apt to increase the air content and high slumps tend to entrain more air with a given amount of admixture.

Concrete temperature also affects the amount of air entrained in a mix. More air will be entrained in cool concrete than in warm concrete with the same amount of admixture hence, adjustments in the amount admixture may be necessary as the concrete temperature varies.

Prolonged and excessive vibration during placing will reduce the air content of concrete. Normal vibration, as needed to properly consolidate concrete in the forms (5 to 15 seconds for most concretes), will not affect the air content to any great extent.

Certain admixtures and coloring agents used in concrete may reduce the amount of entrained air. This is especially true with fly ash as the percent of carbon in fly ash increases. Calcium chloride can be troublesome when used in concrete that contains air-entraining admixtures. If calcium chloride comes in direct contact with some air-entraining admixtures a chemical reaction may take place causing a decrease or elimination of entrained air.

How to work with air-entrained concrete

There are no major differences between handling and placing air-entrained concrete and non-air-entrained concrete. In fact, many contractors have found air-entrained concrete easier to work with. There are, however, a few procedures that can be followed to make the job run smoothly.

Forms should be ready when the ready mix trucks arrive with air-entrained concrete. Lifts of concrete should be no deeper than 12 to 18 inches and each lift should be puddled or vibrated to remove the large entrapped air voids. These air voids are not entrained air and usually result in pitted surfaces. Entrapped air voids occur in all concrete, air-entrained or not, and a conscientious effort should be made to eliminate them during placing.

Finishing air-entrained concrete requires certain changes from normal finishing operation. Less bleeding inherent in air-entrained concrete requires that general floating and troweling be accomplished much sooner—before the surface becomes too stiff. With little or no bleeding there is no waiting for surface water to disappear. If floating is done by hand, the use of an aluminum or magnesium float is recommended. A wood float usually drags and requires more work to accomplish the same results. With power floating equipment there is no appreciable difference between finishing air-entrained concrete and non-air-entrained concrete except that floating can start sooner.

When the weather is hot and dry or windy the slab should be kept covered with damp burlap between finishing operations. A good alternative is to use a fog spray to maintain a slight film of moisture on the slab during and between finishing operations. Moist curing should start as soon as practical after finishing air-entrained concrete.

A few words of caution! Don’t wait too long before finishing air-entrained concrete, especially on hot and dry or windy days when surface moisture evaporates rapidly. However, don’t finish air-entrained concrete too soon. Sufficient time must be allowed for the concrete to stiffen so that finishing tools do not tear the surface. There is a correct time to finish any concrete. Most surface defects can be traced to finishing while bleed water or excessive moisture was still on the surface. Since air-entrained concrete bleeds very little, better results are usually obtained.

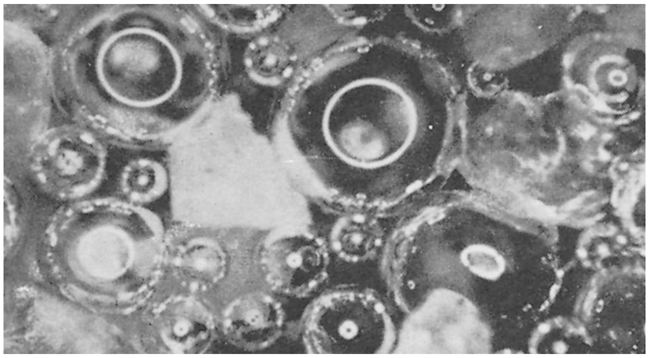
Some frequently asked questions

Questions often arise concerning the use of air-entrained concrete. The following questions are most frequently asked:

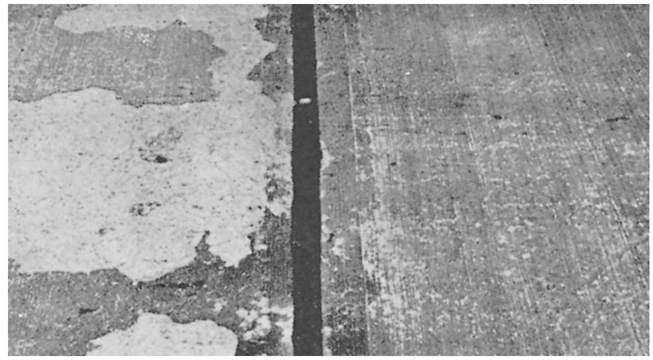
How much does air entrainment reduce strength?

The strength of air-entrained concrete depends on the water/cement ratio as it does in non-air-entrained concrete. Thus, air-entrained concrete can be designed for any required strength, whether it be 3,000 psi or 8,000 psi. Mixes not adjusted for the addition of entrained air usually result in some loss in strength. However, with lean mixes (about 4½ sacks per cubic yard or less) or mixes with small size aggregates, air entrainment is accompanied by sizable reductions in water requirements. For these mixes the strengths will not be reduced, but in fact may even be increased. At about optimum air content (5 percent in concrete with 1½-inch maximum size aggregate) the effect of entrained air on strength is negligible provided proper advantage has been taken in the mix design to reduce the sand and water content.

The question of strength reduction by entrained air in concrete can best be summarized by this statement from the American Concrete Institute’s Recommended Practice for Selecting Proportions for Concrete (ACI 613-54): “When cement content and consistency are maintained constant, this apparent penalty in strength is partially or entirely offset by reduction in mixing water requirements which result from air entrainment.”



The photomicrograph shows how bubbles of entrained air provide flexible ball bearings between mix particles.



Identical exposure has caused severe spalling in the non-air-entrained test pavement at the left, but has not affected the air-entrained concrete at the right.

How does entrained air affect the proportions of a concrete mixture?

A mix should be designed to take account of the increase in air content. The water content for an air-entrained mix will be 3 to 5 gallons per cubic yard less than for a non-air-entrained mix having the same slump. The sand content will also be less by about 90 to 125 pounds per cubic yard.

The following typical mix proportions illustrate the effect of entrained air on concrete. Both mixes have the same cement content, slump and approximately the same 28-day compressive strength.

	NON-AIR ENTRAINED	AIR-ENTRAINED
Water	300 lb. (36 gal.)	265 lb.
Cement	600 lb.	600 lb.
Coarse aggregate	1,900 lb.	1,900 lb.
Sand	1,250 lb.	1,125 lb.
Percent air	1	5
28-day strength	4,400 psi	4,300 psi
Unit weight	150 lb./cu. ft.	144 lb./cu. ft.
Slump	3 1/2 in.	3 1/2 in.
Workability	fair	excellent

Note in these two mixes that the water content is 35 pounds less (about 4 gallons) in the air-entrained mix. Also the sand content is 125 pounds less. The 28-day strengths are about equal, being within allowable testing variations. Also note that due to the increased air content in the air-entrained mix, the unit weight is slightly less. One percent air shown for the non-air-entrained mix is entrapped air. Finally, it should be noted that the workability of the air-entrained mix is considerably better with no increase in slump.

Should air-entrained concrete be used in mild climates?

Air-entrained concrete is recommended and is used to a considerable extent in southern climates. The beneficial effects of entrained air on fresh concrete are sufficient in themselves to greatly improve the quality of concrete placed in any type of climate exposure. Benefits of entrained air on hardened concrete, through elimination of excessive capillaries, channels and voids, increases the durability of the hardened concrete in hot or mild as well as severe climates.

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