Guidelines for Control of Air Content in Concrete

The entrainment of air in portland cement concrete has long been recognized as an effective means of improving the durability of pavements and other concrete exposed to freeze-thaw cycles and deicing chemicals. However, the control and measurement of entrained air in the finished product has not always been adequate.

To address this problem, studies were initiated by the National Academy of Sciences as part of National Cooperative Highway Research Program (NCHRP) Project 10-18 (Reference 1). For the initial phase of the study, Construction Technology Laboratories, a division of Portland Cement Association, was employed to prepare a comprehensive state-of-the-art report on the use of entrained air in concrete (Reference 2).

These studies contain a review of previous research and experience on air entrainment, a tabulation of current specifications, identification of field problems in controlling air content, results of laboratory investigations involving low-slump concrete, and guidelines for control of entrained air during mixing and placing concrete. Over 1000 references to the published literature were reviewed during compilation of the state-of-the-art report.

One of the most useful consequences of this study was information gathered on the effect of certain variables in achieving adequate control of air content. These variables were grouped into five major categories: (1) mix design, (2) concrete materials, (3) production procedures, (4) construction practices, and (5) environmental factors.

The categorization of variables, although the end product of a lengthy process, was a relatively straightforward task. However, assessment of the impact of the variables on air content—that is, how a change in one or more variables will quantitatively influence air content—is much more difficult. It is apparent from review of the literature that a quantitative assessment is not possible at this time. One may know, for instance, that an increase in sand content of a mix will result in an increase in air content, all other things being equal. However, the exact magnitude of the corresponding increase in air content for an increase of say 10% sand cannot be accurately predicted. The same holds true for the other variables in the categories listed.

Table 1. Effect of Mix Design and Concrete Constituents on Control of Air Content in Concrete

CONSTITUENT—TYPE	EFFECT ON AIR CONTENT	EFFECT ON AIR-VOID SYSTEM	CORRECTIVE ACTION
Mix design—cement content	Decreases with increase in cement content.	Smaller voids and greater number with increasing cement content.	Increase AEA* 50% for 200 lb per cubic yard (120 kg/m³) increase in cement. Increase AEA 10 times or more for very rich, low-slump mixtures.
Mix design—water content	Increases with increase in water content. Very fluid mixes show loss of air.	Becomes coarser at high water content.	1-in. (25-mm) slump increases air by ½% to 1%. Decrease AEA accordingly.
Cement—composition	Higher fineness Type III** requires more AEA. Alkali increases air content.	Effects not well defined.	Use 50% to 100% more AEA for Type III. Decrease AEA dosage 20% to 40% for high alkali.
Cement—contaminants	Oxidized oils increase air. Unoxidized oils decrease air.	Little apparent effect.	Obtain certification on cement. Test for contaminants if problems develop.
Sand aggregate	Increases with increase in sand content. Organic impurities may increase or decrease air content.	Surface texture may affect specific surface of voids.	Decrease AEA as sand content increases. Check sand with ASTM C40† prior to acceptance.
Coarse aggregate	Decreases as maximum size of aggregate increases. Crusher fines on coarse aggregate decrease air content.	Little effect.	No action needed as required air decreases with increase in aggregate size. Hold percentage fines below 4%.
Mix-water contaminants	Truck mixer wash water decreases air content. Algae increase air.	Unknown.	Do not use recycled wash water. Test water supplies for algae and other contaminants prior to acceptance.
Water reducers, retarders	Lignosulfonates increase air. Other types have less effect.	Spacing factors increase at higher dosages.	Decrease AEA 50% to 90% for lignosulfonates, especially at lower temperatures. Decrease AEA 20% to 40% for other types. Do not mix admixtures prior to batching.
Accelerators	Calcium chloride increases air content. Other types have little effect.	Unknown.	Decrease AEA when calcium chloride is used.
Superplasticizers	Naphthalene-based materials increase air content. Highly fluid mixtures may lose air.	Produces coarser air-void systems. Spacing factors increase.	Use less AEA with naphthalenes. Specify 1% to 2% higher air content if possible.
Fly ash	High loss on ignition or carbon decrease air content. Fineness of ash may have effect.	Little effect.	Increase AEA. May need up to 5 times more with high-carbon ash. Foam Index test is useful check procedure.
Pigments	Carbon-black-based pigments may absorb AEA, depress air content.	Unknown.	Prequalification of pigment with job materials.

*Air-entraining agent
**CSA Type 30
†CSA A23.2-7A

This limitation on quantification of effects, however, does not prohibit the assembling of information on the probable impact of each variable on air content. Such information is given in Tables 1 and 2. In Table 1 the categories of concrete materials and mix design are combined to some degree. For instance, both the properties of cement and the amount of cement will influence air content. Also included in Table 1 is an assessment of impact on the air-void system. Although quantitative data are not available on the effects of all variables, information in the tables does provide a firm starting point for evaluating air-void systems. In Table 2 information concerning effects of production procedures, construction practices, and environmental variables are presented in a similar format.

These tables should be a useful tool for the field engineer, inspector, contractor, and others who must decide which variables need to be more closely controlled in production and use of air-entrained concrete, and which have a lesser impact.

References*

1. Whiting, D., and Stark, D., *Control of Air Content in Concrete*, National Cooperative Highway Research Program Report 258, Transportation Research Board, National Research Council, Washington, D.C., May 1983, 84 pages.
2. Whiting, D., *Addendum to NCHRP Report 258, Control of Air Content in Concrete, Appendix F, State-of-the-Art Report*, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., March 1983, 263 pages.

*These publications are available from Cooperative Research Programs, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, D.C. 20418; Reference 1 costs $8.40; Reference 2 is available on a loan basis or for the cost of reproduction.

Table 2. Effect of Production Procedures, Construction Practices, and Environment on Control of Air Content in Concrete

VARIABLE	EFFECTS	CORRECTIVE ACTION
Batching sequence	Simultaneous batching lowers air.	Avoid slurry-mix addition of AEA.*
	Late addition of AEA raises air.	Do not batch AEA onto cement. Maintain uniformity in batching sequence.
Mixer capacity	Air increases as capacity is approached.	Run mixer close to full capacity, avoid overloading, clean mixer frequently.
Mixing time	Central mixers—air increases up to 90 seconds. Truck mixers—air increases up to 10 minutes. Air decreases after optimum time is reached.	Establish optimum mixing time for particular mixer. Avoid overmixing.
Mixing speed	Air increases up to approximately 20 rpm. Decreases at higher speeds.	Avoid high drum speeds.
Admixture metering	Accuracy, reliability of metering system will affect uniformity of air content.	Avoid manual-dispensing gravity-feed system, timers. Positive displacement devices preferred. Establish frequent maintenance and calibration program.
Haul time	Long hauls reduce air, especially in hot weather.	Optimize delivery schedules. Maintain concrete temperatures in recommended ranges.
Retempering	Air content increases after retempering. Ineffective beyond 4 hours.	Retemper only enough to restore workability. Avoid addition of excess water.
Consolidation	Air content decreases under prolonged vibration or at high frequencies.	Do not overvibrate. Avoid high-frequency vibrators. Avoid multiple passes of vibratory screeds.
Transport	Some air (1% to 2%) normally lost during transport. Air lost in pumping and on belt conveyors, especially at higher air contents.	Avoid high air contents in pumped concrete. Do not use aluminum pipelines, dump trucks.
Finishing	Air content reduced in surface layer by excessive finishing.	Avoid finishing with bleed water still on surface. Avoid overfinishing. Do not sprinkle water on surface prior to finishing.
Temperature	Air content decreases with increase in temperature.	Increase AEA dosage as temperature increases.

*Air-entraining agent

Wintertime Safety for Outdoor Concrete

Concrete sidewalks, driveways, parking lots, and steps can be maintained in safe condition this winter by following a few simple practices. If your concrete is new, it is probably advisable to refrain from using any deicers the first winter. Clean off loose snow before it turns to ice and use sand or other gritty material to assure firm footing. A well-cured, air-entrained concrete with a compressive strength of 4000 psi (28 MPa) is durable against salt scaling; but if new concrete has not had a chance to cure fully and air dry for 30 days, it can be damaged by early deicer applications.

Use Rock Salt Liberally

The most used and least expensive deicer is still common rock salt, which is sodium chloride. When you use salt you should use it liberally. This reduces alternate freezing and thawing of the moisture on the concrete. For example, a 3% salt solution freezes at 29° F (-2° C), while a 10% solution does not freeze until 20° F (-7° C). If the daytime temperature hovers around freezing and only a light application of salt is applied, ice may still form when the temperature drops at night. You then could be in for a nasty surprise when you go for the morning paper.

Beware of Some Deicers

Be cautious of deicers sold as beneficial to lawns and shrubs. While they will melt snow and ice, many of these materials contain ammonium nitrate and ammonium sulfate fertilizers. Unfortunately, such materials react chemically with concrete. Their extensive use could turn your sidewalk or driveway into a rustic gravel path.

All common chemical deicers produce, by a physical action, some salt scaling of non-air-entrained concrete. Protected concrete—that is, properly air-entrained concrete—will withstand this action throughout its normal life.

If you plan a concrete project next year, be sure to specify air-entrained concrete. Your ready mix producer can provide air-entrained concrete at no extra cost. The billions of tiny air bubbles in the concrete give you assurance of increased durability against scaling when salts are used as deicers.