



## Admixtures for Concrete

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## CHAPTER 6

# Admixtures for Concrete

Admixtures are those ingredients in concrete other than portland cement, water, and aggregates that are added to the mixture immediately before or during mixing (Fig. 6-1). Admixtures can be classified by function as follows:

1. Air-entraining admixtures
2. Water-reducing admixtures
3. Plasticizers
4. Accelerating admixtures
5. Retarding admixtures
6. Hydration-control admixtures
7. Corrosion inhibitors
8. Shrinkage reducers
9. Alkali-silica reactivity inhibitors
10. Coloring admixtures
11. Miscellaneous admixtures such as workability, bonding, dampproofing, permeability reducing, grouting, gas-forming, antiwashout, foaming, and pumping admixtures

Table 6-1 provides a much more extensive classification of admixtures.

Concrete should be workable, finishable, strong, durable, watertight, and wear resistant. These qualities can often be obtained easily and economically by the selection of suitable materials rather than by resorting to admixtures (except air-entraining admixtures when needed).

The major reasons for using admixtures are:

1. To reduce the cost of concrete construction
2. To achieve certain properties in concrete more effectively than by other means
3. To maintain the quality of concrete during the stages of mixing, transporting, placing, and curing in adverse weather conditions
4. To overcome certain emergencies during concreting operations



**Fig. 6-1. Liquid admixtures, from left to right: antiwashout admixture, shrinkage reducer, water reducer, foaming agent, corrosion inhibitor, and air-entraining admixture. (69795)**

Despite these considerations, it should be borne in mind that no admixture of any type or amount can be considered a substitute for good concreting practice.

The effectiveness of an admixture depends upon factors such as type, brand, and amount of cementing materials; water content; aggregate shape, gradation, and proportions; mixing time; slump; and temperature of the concrete.

Admixtures being considered for use in concrete should meet applicable specifications as presented in Table 6-1. Trial mixtures should be made with the admixture and the job materials at temperatures and humidities anticipated on the job. In this way the compatibility of the admixture with other admixtures and job materials, as well as the effects of the admixture on the properties of the fresh and hardened concrete, can be observed. The amount of admixture recommended by the manufacturer or the optimum amount determined by laboratory tests should be used.

**Table 6-1. Concrete Admixtures by Classification**

Type of admixture	Desired effect	Material
Accelerators (ASTM C 494 and AASHTO M 194, Type C)	Accelerate setting and early-strength development	Calcium chloride (ASTM D 98 and AASHTO M 144) Triethanolamine, sodium thiocyanate, calcium formate, calcium nitrite, calcium nitrate
Air detrainers	Decrease air content	Tributyl phosphate, dibutyl phthalate, octyl alcohol, water-insoluble esters of carbonic and boric acid, silicones
Air-entraining admixtures (ASTM C 260 and AASHTO M 154)	Improve durability in freeze-thaw, deicer, sulfate, and alkali-reactive environments Improve workability	Salts of wood resins (Vinsol resin), some synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous material, fatty and resinous acids and their salts, alkylbenzene sulfonates, salts of sulfonated hydrocarbons
Alkali-aggregate reactivity inhibitors	Reduce alkali-aggregate reactivity expansion	Barium salts, lithium nitrate, lithium carbonate, lithium hydroxide
Antiwashout admixtures	Cohesive concrete for underwater placements	Cellulose, acrylic polymer
Bonding admixtures	Increase bond strength	Polyvinyl chloride, polyvinyl acetate, acrylics, butadiene-styrene copolymers
Coloring admixtures (ASTM C 979)	Colored concrete	Modified carbon black, iron oxide, phthalocyanine, umber, chromium oxide, titanium oxide, cobalt blue
Corrosion inhibitors	Reduce steel corrosion activity in a chloride-laden environment	Calcium nitrite, sodium nitrite, sodium benzoate, certain phosphates or fluosilicates, fluoaluminates, ester amines
Dampproofing admixtures	Retard moisture penetration into dry concrete	Soaps of calcium or ammonium stearate or oleate Butyl stearate Petroleum products
Foaming agents	Produce lightweight, foamed concrete with low density	Cationic and anionic surfactants Hydrolyzed protein
Fungicides, germicides, and insecticides	Inhibit or control bacterial and fungal growth	Polyhalogenated phenols Dieldrin emulsions Copper compounds
Gas formers	Cause expansion before setting	Aluminum powder
Grouting admixtures	Adjust grout properties for specific applications	See Air-entraining admixtures, Accelerators, Retarders, and Water reducers
Hydration control admixtures	Suspend and reactivate cement hydration with stabilizer and activator	Carboxylic acids Phosphorus-containing organic acid salts
Permeability reducers	Decrease permeability	Latex Calcium stearate
Pumping aids	Improve pumpability	Organic and synthetic polymers Organic flocculents Organic emulsions of paraffin, coal tar, asphalt, acrylics Bentonite and pyrogenic silicas Hydrated lime (ASTM C 141)
Retarders (ASTM C 494 and AASHTO M 194, Type B)	Retard setting time	Lignin Borax Sugars Tartaric acid and salts
Shrinkage reducers	Reduce drying shrinkage	Polyoxyalkylene alkyl ether Propylene glycol
Superplasticizers* (ASTM C 1017, Type 1)	Increase flowability of concrete Reduce water-cement ratio	Sulfonated melamine formaldehyde condensates Sulfonated naphthalene formaldehyde condensates Lignosulfonates Polycarboxylates

**Table 6-1. Concrete Admixtures by Classification (Continued)**

Type of admixture	Desired effect	Material
Superplasticizer* and retarder (ASTM C 1017, Type 2)	Increase flowability with retarded set Reduce water–cement ratio	See superplasticizers and also water reducers
Water reducer (ASTM C 494 and AASHTO M 194, Type A)	Reduce water content at least 5%	Lignosulfonates Hydroxylated carboxylic acids Carbohydrates (Also tend to retard set so accelerator is often added)
Water reducer and accelerator (ASTM C 494 and AASHTO M 194, Type E)	Reduce water content (minimum 5%) and accelerate set	See water reducer, Type A (accelerator is added)
Water reducer and retarder (ASTM C 494 and AASHTO M 194, Type D)	Reduce water content (minimum 5%) and retard set	See water reducer, Type A (retarder is added)
Water reducer—high range (ASTM C 494 and AASHTO M 194, Type F)	Reduce water content (minimum 12%)	See superplasticizers
Water reducer—high range—and retarder (ASTM C 494 and AASHTO M 194, Type G)	Reduce water content (minimum 12%) and retard set	See superplasticizers and also water reducers
Water reducer—mid range	Reduce water content (between 6 and 12%) without retarding	Lignosulfonates Polycarboxylates

\* Superplasticizers are also referred to as high-range water reducers or plasticizers. These admixtures often meet both ASTM C 494 (AASHTO M 194) and ASTM C 1017 specifications.

## AIR-ENTRAINING ADMIXTURES

Air-entraining admixtures are used to purposely introduce and stabilize microscopic air bubbles in concrete. Air-entrainment will dramatically improve the durability of concrete exposed to cycles of freezing and thawing (Fig. 6-2). Entrained air greatly improves concrete's resistance to surface scaling caused by chemical deicers (Fig. 6-3). Furthermore, the workability of fresh concrete is improved significantly, and segregation and bleeding are reduced or eliminated.

Air-entrained concrete contains minute air bubbles that are distributed uniformly throughout the cement paste. Entrained air can be produced in concrete by use of an air-entraining cement, by introduction of an air-entraining admixture, or by a combination of both methods. An air-entraining cement is a portland cement with an air-entraining addition interground with the clinker during manufacture. An air-entraining admixture, on the other hand, is added directly to the concrete materials either before or during mixing.

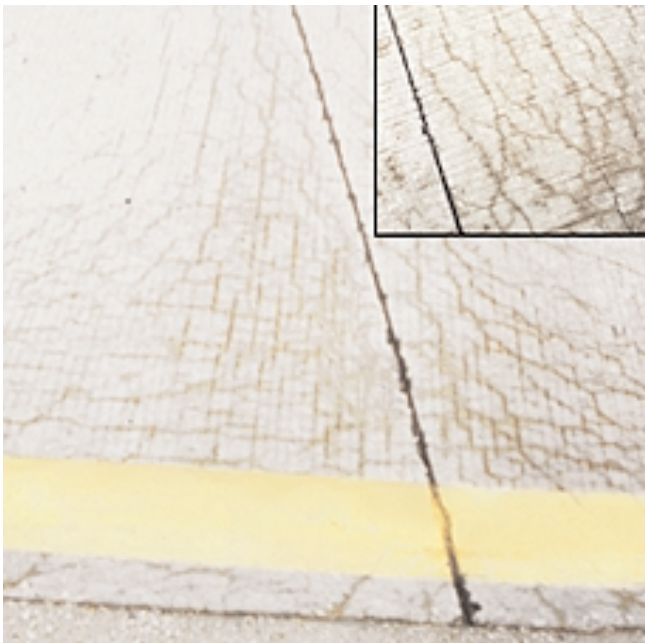
The primary ingredients used in air-entraining admixtures are listed in Table 6-1. Specifications and methods of testing air-entraining admixtures are given in

ASTM C 260 and C 233 (AASHTO M 154 and T 157). Air-entraining additions for use in the manufacture of air-entraining cements must meet requirements of ASTM C 226. Applicable requirements for air-entraining cements are given in ASTM C 150 and AASHTO M 85. See Chapter 8, Air-Entrained Concrete, Klieger (1966), and Whiting and Nagi (1998) for more information.

## WATER-REDUCING ADMIXTURES

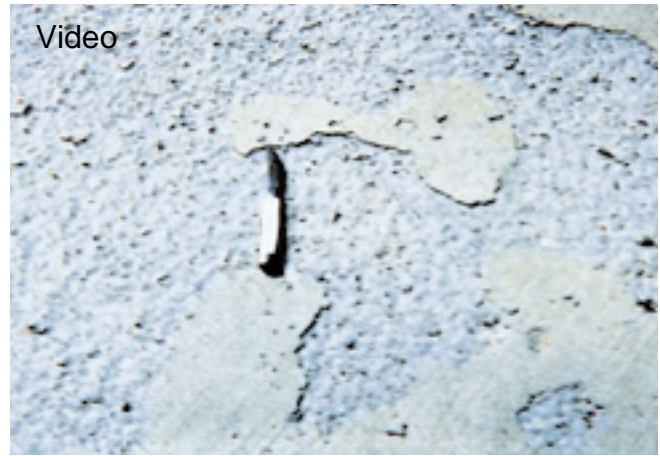
Water-reducing admixtures are used to reduce the quantity of mixing water required to produce concrete of a certain slump, reduce water-cement ratio, reduce cement content, or increase slump. Typical water reducers reduce the water content by approximately 5% to 10%. Adding a water-reducing admixture to concrete without reducing the water content can produce a mixture with a higher slump. The rate of slump loss, however, is not reduced and in most cases is increased (Fig. 6-4). Rapid slump loss results in reduced workability and less time to place concrete.

An increase in strength is generally obtained with water-reducing admixtures as the water-cement ratio is



**Fig. 6-2.** Frost damage (crumbling) at joints of a pavement (top), frost induced cracking near joints (bottom), and enlarged view of cracks (inset). (61621, 67834, 67835)

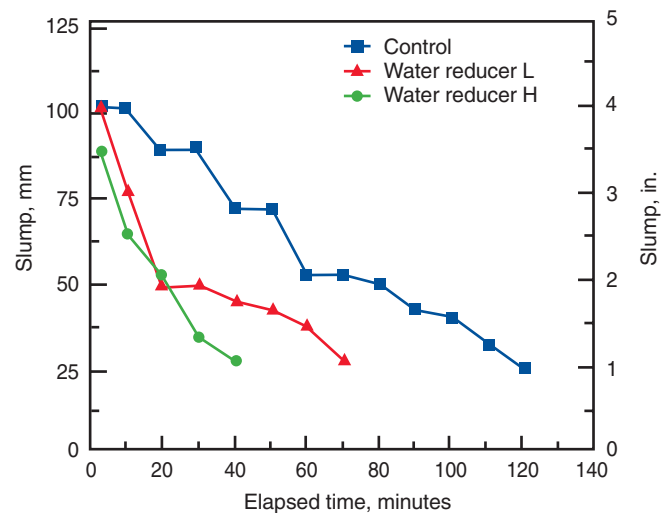
reduced. For concretes of equal cement content, air content, and slump, the 28-day strength of a water-reduced concrete containing a water reducer can be 10% to 25% greater than concrete without the admixture. Despite reduction in water content, water-reducing admixtures may cause increases in drying shrinkage. Usually the effect of the water reducer on drying shrinkage is small compared to other more significant factors that cause shrinkage



**Fig. 6-3.** Scaled concrete surface resulting from lack of air entrainment, use of deicers, and poor finishing and curing practices. (52742)

cracks in concrete. Using a water reducer to reduce the cement and water content of a concrete mixture—while maintaining a constant water-cement ratio—can result in equal or reduced compressive strength, and can increase slump loss by a factor of two or more (Whiting and Dziedzic 1992).

Water reducers decrease, increase, or have no effect on bleeding, depending on the chemical composition of the admixture. A reduction of bleeding can result in finishing difficulties on flat surfaces when rapid drying conditions are present. Water reducers can be modified to give varying degrees of retardation while others do not signifi-



**Fig. 6-4.** Slump loss at 23°C (73°F) in concretes containing conventional water reducers (ASTM C 494 and AASHTO M 194 Type D) compared with a control mixture (Whiting and Dziedzic 1992).

cantly affect the setting time. ASTM C 494 (AASHTO M 194) Type A water reducers can have little effect on setting, while Type D admixtures provide water reduction with retardation, and Type E admixtures provide water reduction with accelerated setting. Type D water-reducing admixtures usually retard the setting time of concrete by one to three hours (Fig. 6-5). Some water-reducing admixtures may also entrain some air in concrete. Lignin-based admixtures can increase air contents by 1 to 2 percentage points. Concretes with water reducers generally have good air retention (Table 6-2).

The effectiveness of water reducers on concrete is a function of their chemical composition, concrete temperature, cement composition and fineness, cement content, and the presence of other admixtures. The classifications and components of water reducers are listed in Table 6-1. See Whiting and Dziedzic (1992) for more information on the effects of water reducers on concrete properties.

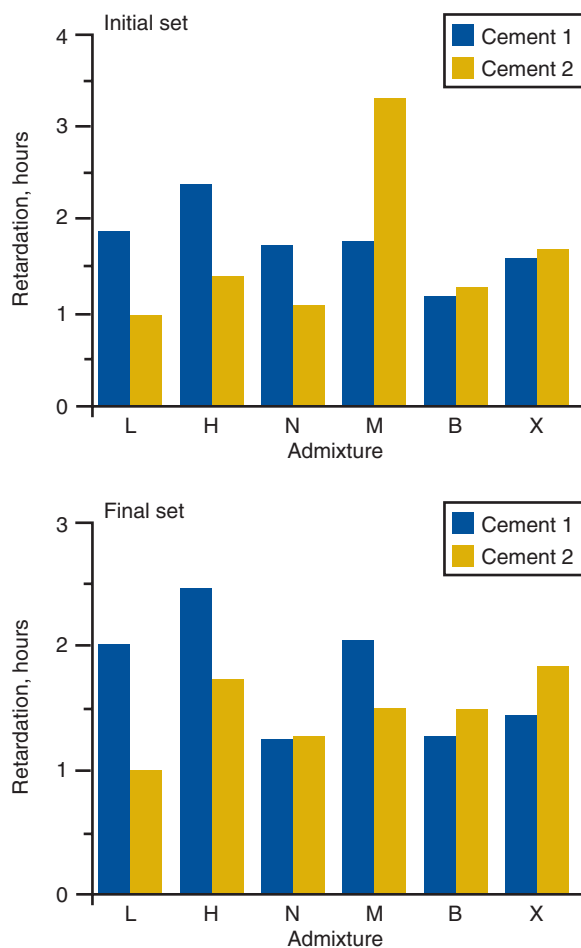


Fig. 6-5. Retardation of set in cement-reduced mixtures relative to control mixture. Concretes L and H contain conventional water reducer, concretes N, M, B, and X contain high-range water reducer (Whiting and Dziedzic 1992).

## MID-RANGE WATER REDUCING ADMIXTURES

Mid-range water reducers were first introduced in 1984. These admixtures provide significant water reduction (between 6 and 12%) for concretes with slumps of 125 to 200 mm (5 to 8 in.) without the retardation associated with high dosages of conventional (normal) water reducers. Normal water reducers are intended for concretes with slumps of 100 to 125 mm (4 to 5 in.). Mid-range water reducers can be used to reduce stickiness and improve finishability, pumpability, and placeability of concretes containing silica fume and other supplementary cementing materials. Some can also entrain air and be used in low slump concretes (Nmai, Schlagbaum, and Violetta 1998).

## HIGH-RANGE WATER REDUCING ADMIXTURES

High-range water reducers, ASTM C 494 (AASHTO M 194) Types F (water reducing) and G (water reducing and retarding), can be used to impart properties induced by regular water reducers, only much more efficiently. They can greatly reduce water demand and cement contents and make low water-cement ratio, high-strength concrete with normal or enhanced workability. A water reduction of 12% to 30% can be obtained through the use of these admixtures. The reduced water content and water-cement ratio can produce concretes with (1) ultimate compressive strengths in excess of 70 MPa (10,000 psi), (2) increased early strength gain, (3) reduced chloride-ion penetration, and (4) other beneficial properties associated with low water-cement ratio concrete (Fig. 6-6).



Fig. 6-6. Low water to cement ratio concrete with low chloride permeability—easily made with high-range water reducers—is ideal for bridge decks. (69924)

High-range water reducers are generally more effective than regular water-reducing admixtures in producing workable concrete. A significant reduction of bleeding can result with large reductions of water content; this can result in finishing difficulties on flat surfaces when rapid drying conditions are present. Some of these admixtures can cause significant slump loss (Fig. 6-7). Significant retardation is also possible, but can aggravate plastic shrinkage cracking without proper protection and curing (Fig. 6-5). Drying shrinkage, chloride permeability, air retention (Table 6-2), and strength development of concretes with high-range water reducers are comparable to concretes without them when compared at constant water-cement ratios (reduced cement and water contents) (Fig. 6-8).

Concretes with high-range water reducers can have larger entrained air voids and higher void-spacing factors than normal air-entrained concrete. This would generally indicate a reduced resistance to freezing and thawing; however, laboratory tests have shown that concretes with a moderate slump using high-range water reducers have

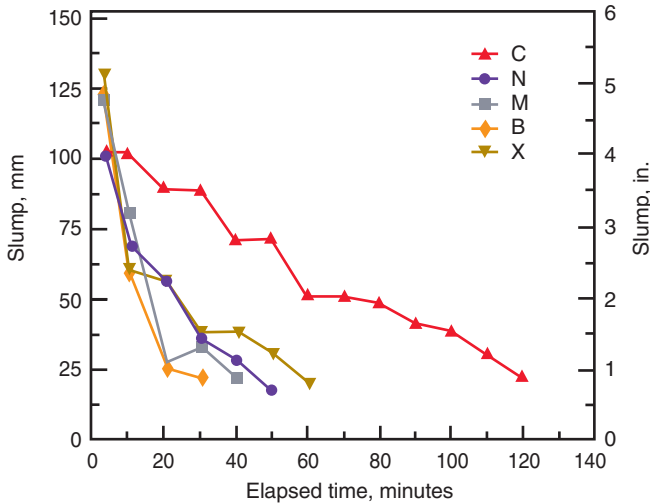


Fig. 6-7. Slump loss at 23°C (73°F) in mixtures containing high-range water reducers (N, M, B, and X) compared with control mixture (C) (Whiting and Dziedzic 1992).

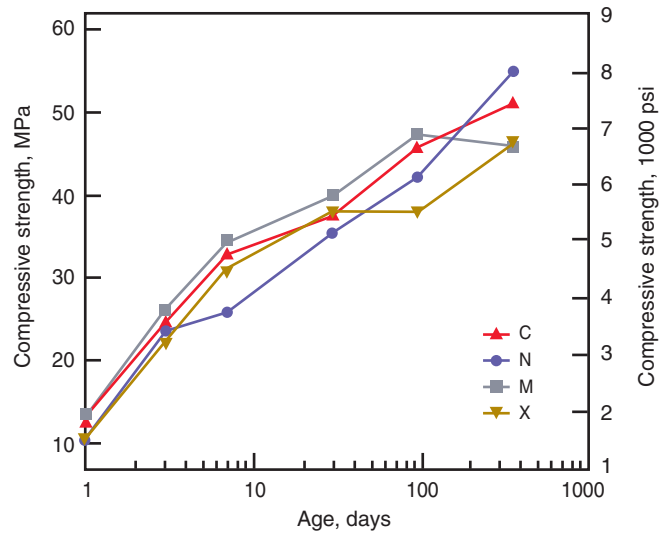


Fig. 6-8. Compressive strength development in cement-reduced concretes: control mixture (C) and concretes containing high-range water reducers (N, M, and X) (Whiting and Dziedzic 1992).

good freeze-thaw durability, even with slightly higher void-spacing factors. This may be the result of lower water-cement ratios often associated with these concretes.

When the same chemicals used for high-range water reducers are used to make flowing concrete, they are often called plasticizers or superplasticizers (see discussion below).

### PLASTICIZERS FOR FLOWING CONCRETE

Plasticizers, often called superplasticizers, are essentially high-range water reducers meeting ASTM C 1017; these admixtures are added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete (Fig. 6-9). Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction while still remaining essentially

Table 6-2. Loss of Air from Cement Reduced Concrete Mixtures

Mixture	Initial air content, %*	Final air content, %†	Percent air retained	Rate of air loss, %/minute
C Control	5.4	3.0	56	0.020
L } Water reducer	7.0	4.7	67	0.038
H } Water reducer	6.2	4.6	74	0.040
N } High-range water reducer	6.8	4.8	71	0.040
M } High-range water reducer	6.4	3.8	59	0.065
B } High-range water reducer	6.8	5.6	82	0.048
X } High-range water reducer	6.6	5.0	76	0.027

\* Represents air content measured after addition of admixture.

† Represents air content taken at point where slump falls below 25 mm (1 in.).

Whiting and Dziedzic 1992.



**Fig. 6-9.** Flowable concrete with a high slump (top) is easily placed (middle), even in areas of heavy reinforcing steel congestion (bottom). (47343, 69900, 47344)

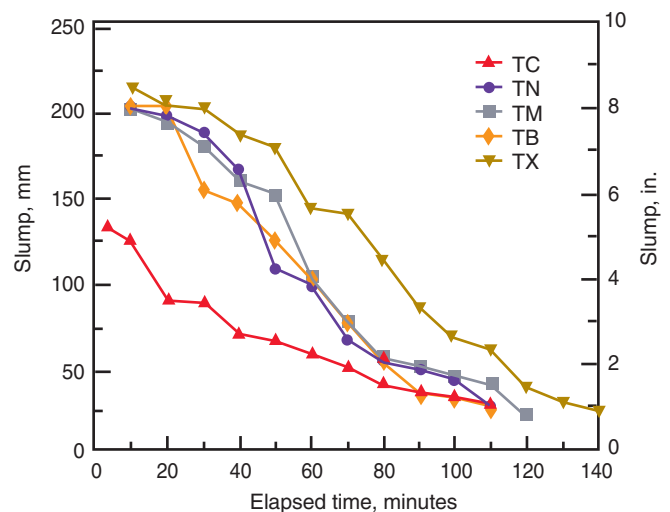
free of excessive bleeding or segregation. Following are a few of the applications where flowing concrete is used: (1) thin-section placements (Fig. 6-10), (2) areas of closely spaced and congested reinforcing steel, (3) tremie pipe (underwater) placements, (4) pumped concrete to reduce pump pressure, thereby increasing lift and distance capacity, (5) areas where conventional consolidation methods are impractical or can not be used, and (6) for reducing handling costs. The addition of a plasticizer to a 75-mm



**Fig. 6-10.** Plasticized, flowing concrete is easily placed in thin sections such as this bonded overlay that is not much thicker than 1½ diameters of a quarter. (69874)

(3-in.) slump concrete can easily produce a concrete with a 230-mm (9-in.) slump. Flowing concrete is defined by ASTM C 1017 as a concrete having a slump greater than 190 mm (7½ in.), yet maintaining cohesive properties.

ASTM C 1017 has provisions for two types of admixtures: Type 1—plasticizing, and Type 2—plasticizing and retarding. Plasticizers are generally more effective than regular or mid-range water-reducing admixtures in producing flowing concrete. The effect of certain plasticizers in increasing workability or making flowing concrete is short-lived, 30 to 60 minutes; this period is followed by a rapid loss in workability or slump loss (Fig. 6-11). High temperatures can also aggravate slump loss. Due to their propensity for slump loss, these admixtures are some-



**Fig. 6-11.** Slump loss at 32°C (90°F) in flowing concretes (TN, TM, TB, and TX) compared with control mixture (TC) (Whiting and Dzedzic 1992).



times added to the concrete mixer at the jobsite. They are available in liquid and powder form. Extended-slump-life plasticizers added at the batch plant help reduce slump-loss problems. Setting time may be accelerated or retarded based on the admixture's chemistry, dosage rate, and interaction with other admixtures and cementing materials in the concrete mixture. Some plasticizers can retard final set by one to almost four hours (Fig. 6-12). Strength development of flowing concrete is comparable to normal concrete (Fig. 6-13).

While it was previously noted that flowing concretes are essentially free of excessive bleeding, tests have shown that some plasticized concretes bleed more than control concretes of equal water-cement ratio (Fig. 6-14); but plasticized concretes bleed significantly less than control concretes of equally high slump and higher water content. High-slump, low-water-content, plasticized concrete has less drying shrinkage than a high-slump, high-water-content conventional concrete; however this concrete has similar or higher drying shrinkage than conventional low-

slump, low-water-content concrete (Whiting 1979, Gebler 1982, and Whiting and Dziedzic 1992).

The effectiveness of the plasticizer is increased with an increasing amount of cement and fines in the concrete. It is also affected by the initial slump of the concrete.

Plasticized flowing concrete can have larger entrained air voids and greater void-spacing factors than conventional concrete. Air loss can also be significant. Some research has indicated poor frost- and deicer-scaling resistance for some flowing concretes when exposed to a continuously moist environment without the benefit of a drying period (Whiting and Dziedzic 1992). However, field performance of flowing concretes with low water to portland cement ratios has been good in most frost environments.

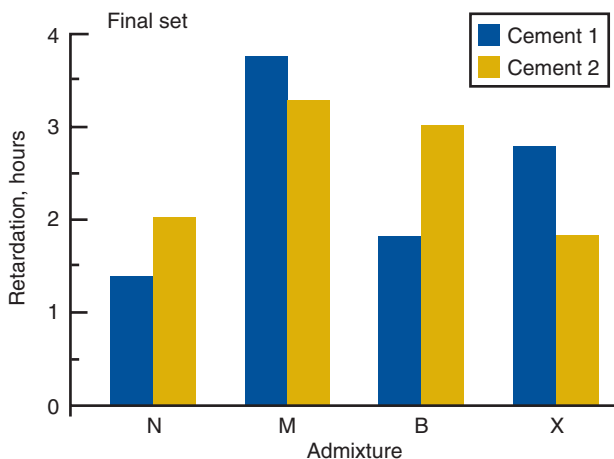
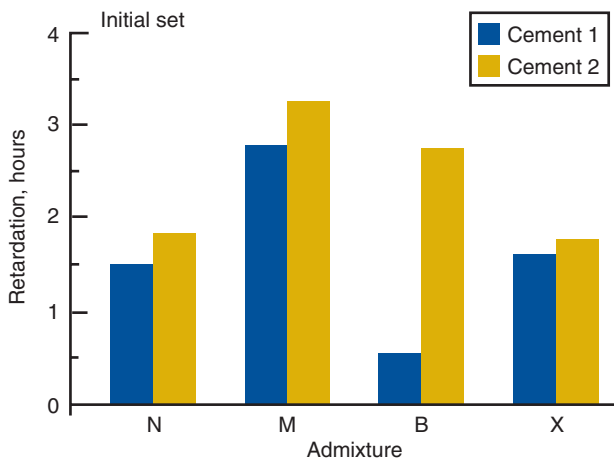


Fig. 6-12. Retardation of set in flowing concrete with plasticizers (N, M, B, and X) relative to control mixture (Whiting and Dziedzic 1992).

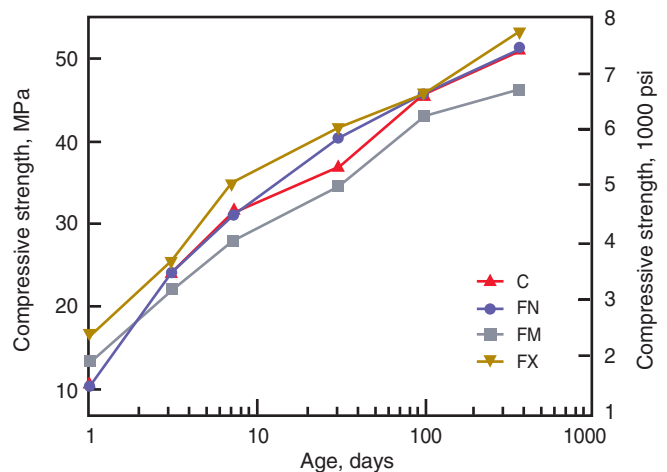


Fig. 6-13. Compressive strength development in flowing concretes. C is the control mixture. Mixtures FN, FM, and FX contain plasticizers (Whiting and Dziedzic 1992).

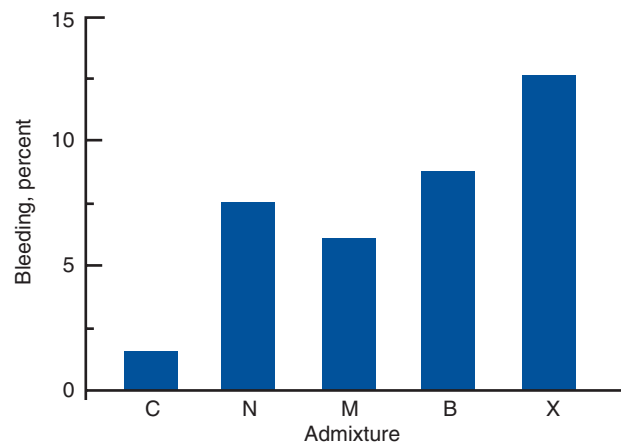


Fig. 6-14. Bleeding of flowing concretes with plasticizers (N, M, B, and X) compared to control (C) (Whiting and Dziedzic 1992).

Table 6-1 lists the primary components and specifications for plasticizing (superplasticizer) admixtures.

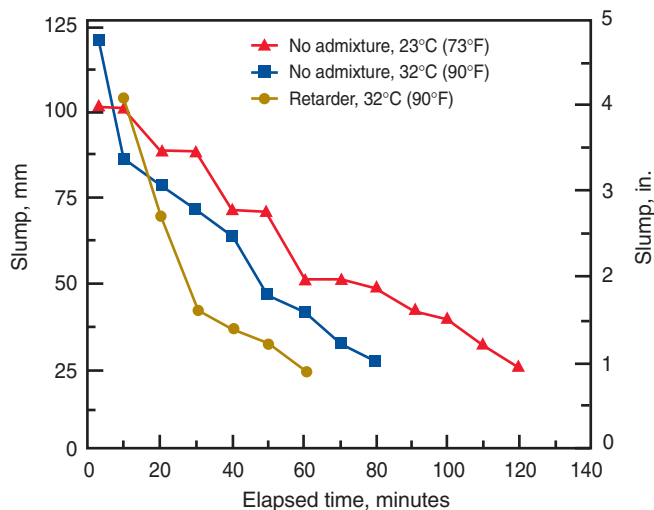
## Video RETARDING ADMIXTURES

Retarding admixtures are used to delay the rate of setting of concrete. High temperatures of fresh concrete (30°C [86°F]) are often the cause of an increased rate of hardening that makes placing and finishing difficult. One of the most practical methods of counteracting this effect is to reduce the temperature of the concrete by cooling the mixing water and/or the aggregates. Retarders do not decrease the initial temperature of concrete. The bleeding rate and bleeding capacity of concrete is increased with retarders.

Retarding admixtures are useful in extending the setting time of concrete, but they are often also used in attempts to decrease slump loss and extend workability, especially prior to placement at elevated temperatures. The fallacy of this approach is shown in Fig. 6-15, where the addition of a retarder resulted in an increased rate of slump loss compared to the control mixtures (Whiting and Dziedzic 1992).

Retarders are sometimes used to: (1) offset the accelerating effect of hot weather on the setting of concrete; (2) delay the initial set of concrete or grout when difficult or unusual conditions of placement occur, such as placing concrete in large piers and foundations, cementing oil wells, or pumping grout or concrete over considerable distances; or (3) delay the set for special finishing techniques, such as an exposed aggregate surface.

The amount of water reduction for an ASTM C 494 (AASHTO M 194) Type B retarding admixture is normally



**Fig. 6-15. Slump loss at various temperatures for conventional concretes prepared with and without set-retarding admixture (Whiting and Dziedzic 1992).**

less than that obtained with a Type A water reducer. Type D admixtures are designated to provide both water reduction and retardation.

In general, some reduction in strength at early ages (one to three days) accompanies the use of retarders. The effects of these materials on the other properties of concrete, such as shrinkage, may not be predictable. Therefore, acceptance tests of retarders should be made with actual job materials under anticipated job conditions. The classifications and components of retarders are listed in Table 6-1.

## HYDRATION-CONTROL ADMIXTURES

Hydration controlling admixtures became available in the late 1980s. They consist of a two-part chemical system: (1) a stabilizer or retarder that essentially stops the hydration of cementing materials, and (2) an activator that reestablishes normal hydration and setting when added to the stabilized concrete. The stabilizer can suspend hydration for 72 hours and the activator is added to the mixture just before the concrete is used. These admixtures make it possible to reuse concrete returned in a ready-mix truck by suspending setting overnight. The admixture is also useful in maintaining concrete in a stabilized non-hardened state during long hauls. The concrete is reactivated when it arrives at the project. This admixture presently does not have a standard specification (Kinney 1989).

## ACCELERATING ADMIXTURES

An accelerating admixture is used to accelerate the rate of hydration (setting) and strength development of concrete at an early age. The strength development of concrete can also be accelerated by other methods: (1) using Type III or Type HE high-early-strength cement, (2) lowering the water-cement ratio by adding 60 to 120 kg/m<sup>3</sup> (100 to 200 lb/yd<sup>3</sup>) of additional cement to the concrete, (3) using a water reducer, or (4) curing at higher temperatures. Accelerators are designated as Type C admixtures under ASTM C 494 (AASHTO M 194).

Calcium chloride (CaCl<sub>2</sub>) is the chemical most commonly used in accelerating admixtures, especially for non-reinforced concrete. It should conform to the requirements of ASTM D 98 (AASHTO M 144) and should be sampled and tested in accordance with ASTM D 345.

The widespread use of calcium chloride as an accelerating admixture has provided much data and experience on the effect of this chemical on the properties of concrete. Besides accelerating strength gain, calcium chloride causes an increase in drying shrinkage, potential reinforcement corrosion, discoloration (a darkening of concrete), and an increase in the potential for scaling.

*Calcium chloride is not an antifreeze agent.* When used in allowable amounts, it will not reduce the freezing point of concrete by more than a few degrees. Attempts to protect

concrete from freezing by this method are foolhardy. Instead, proven reliable precautions should be taken during cold weather (see Chapter 14, Cold-Weather Concreting).

When used, calcium chloride should be added to the concrete mixture in solution form as part of the mixing water. If added to the concrete in dry flake form, all of the dry particles may not be completely dissolved during mixing. Undissolved lumps in the mix can cause popouts or dark spots in hardened concrete.

The amount of calcium chloride added to concrete should be no more than is necessary to produce the desired results and in no case exceed 2% by mass of cementing material. When calculating the chloride content of commercially available calcium chloride, it can be assumed that:

1. Regular flake contains a minimum of 77%  $\text{CaCl}_2$
2. Concentrated flake, pellet, or granular forms contain a minimum of 94%  $\text{CaCl}_2$

An overdose can result in placement problems and can be detrimental to concrete. It may cause: rapid stiffening, a large increase in drying shrinkage, corrosion of reinforcement, and loss of strength at later ages (Abrams 1924 and Lackey 1992).

Applications where calcium chloride should be used with caution:

1. Concrete subjected to steam curing
2. Concrete containing embedded dissimilar metals, especially if electrically connected to steel reinforcement
3. Concrete slabs supported on permanent galvanized-steel forms
4. Colored concrete

Calcium chloride or admixtures containing soluble chlorides *should not be used* in the following:

1. Construction of parking garages
2. Prestressed concrete because of possible steel corrosion hazards
3. Concrete containing embedded aluminum (for example, conduit) since serious corrosion of the aluminum can result, especially if the aluminum is in contact with embedded steel and the concrete is in a humid environment
4. Concrete containing aggregates that, under standard test conditions, have been shown to be potentially deleteriously reactive
5. Concrete exposed to soil or water containing sulfates
6. Floor slabs intended to receive dry-shake metallic finishes
7. Hot weather generally
8. Massive concrete placements

The maximum chloride-ion content for corrosion protection of prestressed and reinforced concrete as recommended by the ACI 318 building code is presented in Table 6-3. Resistance to the corrosion of embedded steel is further improved with an increase in the depth of concrete cover

**Table 6-3. Maximum Chloride-Ion Content for Corrosion Protection of Reinforcement\***

Type of member	Maximum water soluble chloride-ion ( $\text{Cl}^-$ ) in concrete, percent by mass of cement
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

\* Requirements from ACI 318 tested per ASTM C 1218.

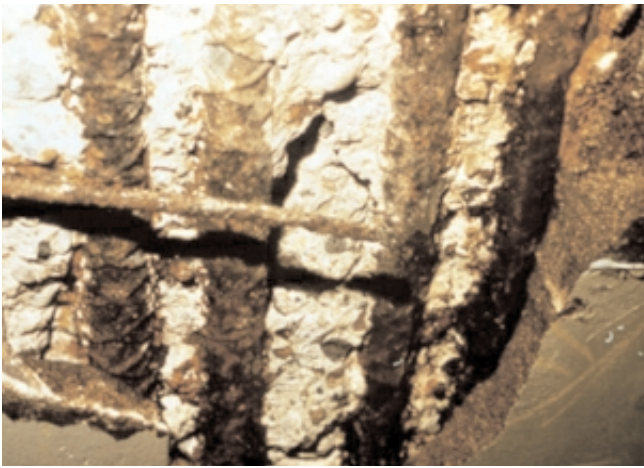
over reinforcing steel, and a lower water-cement ratio. Stark (1989) demonstrated that concretes made with 1%  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  by mass of cement developed active steel corrosion when stored continuously in fog. When 2%  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$  was used, active corrosion was detected in concrete stored in a fog room at 100% relative humidity. Risk of corrosion was greatly reduced at lower relative humidities (50%). Gaynor (1998) demonstrates how to calculate the chloride content of fresh concrete and compare it with recommended limits.

Several nonchloride, noncorrosive accelerators are available for use in concrete where chlorides are not recommended (Table 6-1). However, some nonchloride accelerators are not as effective as calcium chloride. Certain nonchloride accelerators are specially formulated for use in cold weather applications with ambient temperatures down to  $-7^\circ\text{C}$  ( $20^\circ\text{F}$ ).

## CORROSION INHIBITORS

Corrosion inhibitors are used in concrete for parking structures, marine structures, and bridges where chloride salts are present. The chlorides can cause corrosion of steel reinforcement in concrete (Fig. 6-16). Ferrous oxide and ferric oxide form on the surface of reinforcing steel in concrete. Ferrous oxide, though stable in concrete's alkaline environment, reacts with chlorides to form complexes that move away from the steel to form rust. The chloride ions continue to attack the steel until the passivating oxide layer is destroyed. Corrosion-inhibiting admixtures chemically arrest the corrosion reaction.

Commercially available corrosion inhibitors include: calcium nitrite, sodium nitrite, dimethyl ethanolamine, amines, phosphates, and ester amines. Anodic inhibitors, such as nitrites, block the corrosion reaction of the chloride-ions by chemically reinforcing and stabilizing the passive protective film on the steel; this ferric oxide film is created by the high pH environment in concrete. The



**Fig. 6-16.** The damage to this concrete parking structure resulted from chloride-induced corrosion of steel reinforcement. (50051)

nitrite-ions cause the ferric oxide to become more stable. In effect, the chloride-ions are prevented from penetrating the passive film and making contact with the steel.

A certain amount of nitrite can stop corrosion up to some level of chloride-ion. Therefore, increased chloride levels require increased levels of nitrite to stop corrosion.

Cathodic inhibitors react with the steel surface to interfere with the reduction of oxygen. The reduction of oxygen is the principal cathodic reaction in alkaline environments (Berke and Weil 1994).

## SHRINKAGE-REDUCING ADMIXTURES

Shrinkage-reducing admixtures, introduced in the 1980s, have potential uses in bridge decks, critical floor slabs, and buildings where cracks and curling must be minimized for durability or aesthetic reasons (Fig. 6-17). Propylene glycol and polyoxyalkylene alkyl ether have been used as shrink-

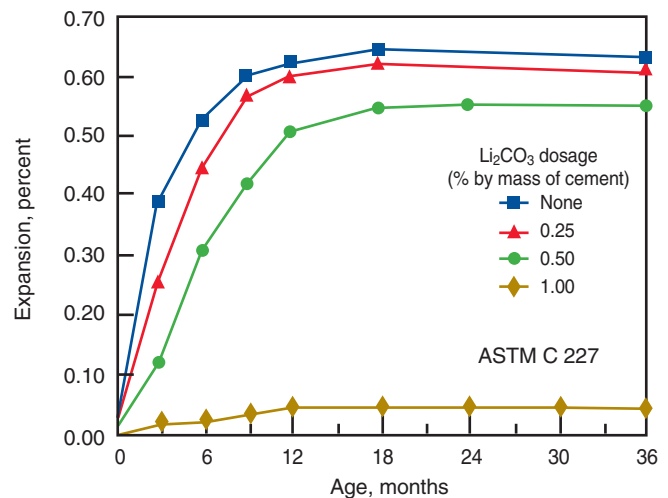


**Fig. 6-17.** Shrinkage cracks, such as shown on this bridge deck, can be reduced with the use of good concreting practices and shrinkage reducing admixtures. (69883)

age reducers. Drying shrinkage reductions of between 25% and 50% have been demonstrated in laboratory tests. These admixtures have negligible effects on slump and air loss, but can delay setting. They are generally compatible with other admixtures (Nmai, Tomita, Hondo and Buffenbarger 1998 and Shah, Weiss and Yang 1998).

## CHEMICAL ADMIXTURES TO REDUCE ALKALI-AGGREGATE REACTIVITY (ASR INHIBITORS)

Chemical admixtures to control alkali-silica reactivity (alkali-aggregate expansion) were introduced in the 1990s (Fig. 6-18). Lithium nitrate, lithium carbonate, lithium hydroxide, lithium aluminum silicate (decrepitated spodumene), and barium salts have shown reductions of alkali-silica reaction (ASR) in laboratory tests (Thomas and Stokes 1999 and AASHTO 2001). Some of these materials have potential for use as an additive to cement (Gajda 1996). There is little long-term field experience available on the effectiveness of these materials.



**Fig. 6-18.** Expansion of specimens made with lithium carbonate admixture (Stark 1992).

## COLORING ADMIXTURES (PIGMENTS)

Natural and synthetic materials are used to color concrete for aesthetic and safety reasons (Fig. 6-19). Red concrete is used around buried electrical or gas lines as a warning to anyone near these facilities. Yellow concrete safety curbs are used in paving applications. Generally, the amount of pigments used in concrete should not exceed 10% by weight of the cement. Pigments used in amounts less than 6% generally do not affect concrete properties.



Fig. 6-19. Red and blue pigments were used to color this terrazzo floor. (69873)

Unmodified carbon black substantially reduces air content. Most carbon black for coloring concrete contains an admixture to offset this effect on air. Before a coloring admixture is used on a project, it should be tested for color fastness in sunlight and autoclaving, chemical stability in cement, and effects on concrete properties. Calcium chloride should not be used with pigments to avoid color distortions. Pigments should conform to ASTM C 979.

## DAMP-PROOFING ADMIXTURES

The passage of water through concrete can usually be traced to the existence of cracks or areas of incomplete consolidation. Sound, dense concrete made with a water-cement ratio of less than 0.50 by mass will be watertight if it is properly placed and cured.

Admixtures known as damp-proofing agents include certain soaps, stearates, and petroleum products. They may, but generally do not, reduce the permeability of concretes that have low cement contents, high water-cement ratios, or a deficiency of fines in the aggregate. Their use in well-proportioned mixes, may increase the mixing water required and actually result in increased rather than reduced permeability.

Damp-proofing admixtures are sometimes used to reduce the transmission of moisture through concrete that is in contact with water or damp earth. Many so-called damp-proofers are not effective, especially when used in concretes that are in contact with water under pressure.

## PERMEABILITY-REDUCING ADMIXTURES

Permeability-reducing admixtures reduce the rate at which water under pressure is transmitted through

concrete. One of the best methods of decreasing permeability in concrete is to increase the moist-curing period and reduce the water-cement ratio to less than 0.5. Most admixtures that reduce water-cement ratio consequently reduce permeability.

Some supplementary cementing materials, especially silica fume, reduce permeability through the hydration and pozzolanic-reaction process. Other admixtures that act to block the capillaries in concrete have been shown to be effective in reducing concrete corrosion in chemically aggressive environments. Such admixtures, designed for use in high-cement content/low-water-cement ratio concretes, contain aliphatic fatty acid and an aqueous emulsion of polymeric and aromatic globules (Aldred 1988).

## PUMPING AIDS

Pumping aids are added to concrete mixtures to improve pumpability. Pumping aids cannot cure all unpumpable concrete problems; they are best used to make marginally pumpable concrete more pumpable. These admixtures increase viscosity or cohesion in concrete to reduce dewatering of the paste while under pressure from the pump.

Some pumping aids may increase water demand, reduce compressive strength, cause air entrainment, or retard setting time. These side effects can be corrected by adjusting the mix proportions or adding another admixture to offset the side effect.

A partial list of materials used in pumping aids is given in Table 6-1. Some admixtures that serve other primary purposes but also improve pumpability are air-entraining agents, and some water-reducing and retarding admixtures.

## BONDING ADMIXTURES AND BONDING AGENTS

Bonding admixtures are usually water emulsions of organic materials including rubber, polyvinyl chloride, polyvinyl acetate, acrylics, styrene butadiene copolymers, and other polymers. They are added to portland cement mixtures to increase the bond strength between old and new concrete. Flexural strength and resistance to chloride-ion ingress are also improved. They are added in proportions equivalent to 5% to 20% by mass of the cementing materials; the actual quantity depending on job conditions and type of admixture used. Some bonding admixtures may increase the air content of mixtures. Nonreemulsifiable types are resistant to water, better suited to exterior application, and used in places where moisture is present.

The ultimate result obtained with a bonding admixture will be only as good as the surface to which the concrete is applied. The surface must be dry, clean, sound, free of dirt, dust, paint, and grease, and at the proper temperature. Organic or polymer modified concretes are

acceptable for patching and thin-bonded overlayment, particularly where feather-edged patches are desired.

Bonding agents should not be confused with bonding admixtures. Admixtures are an ingredient in the concrete; bonding agents are applied to existing concrete surfaces immediately before the new concrete is placed. Bonding agents help “glue” the existing and the new materials together. Bonding agents are often used in restoration and repair work; they consist of portland cement or latex-modified portland cement grout or polymers such as epoxy resins (ASTM C 881 or AASHTO M 235) or latex (ASTM C 1059).

## **GROUTING ADMIXTURES**

Portland cement grouts are used for a variety of purposes: to stabilize foundations, set machine bases, fill cracks and joints in concrete work, cement oil wells, fill cores of masonry walls, grout prestressing tendons and anchor bolts, and fill the voids in preplaced aggregate concrete. To alter the properties of grout for specific applications, various air-entraining admixtures, accelerators, retarders, and nonshrink admixtures are often used.

## **GAS-FORMING ADMIXTURES**

Aluminum powder and other gas-forming materials are sometimes added to concrete and grout in very small quantities to cause a slight expansion of the mixture prior to hardening. This may be of benefit where the complete grouting of a confined space is essential, such as under machine bases or in post-tensioning ducts of prestressed concrete. These materials are also used in larger quantities to produce autoclaved cellular concretes. The amount of expansion that occurs is dependent upon the amount of gas-forming material used, the temperature of the fresh mixture, the alkali content of the cement, and other variables. Where the amount of expansion is critical, careful control of mixtures and temperatures must be exercised. Gas-forming agents will not overcome shrinkage after hardening caused by drying or carbonation.

## **AIR DETRAINERS**

Air-detraining admixtures reduce the air content in concrete. They are used when the air content cannot be reduced by adjusting the mix proportions or by changing the dosage of the air-entraining agent and other admixtures. However, air-detrainers are rarely used and their effectiveness and dosage rate should be established on trial mixes prior to use on actual job mixes. Materials used in air-detraining agents are listed in Table 6-1.

## **FUNGICIDAL, GERMICIDAL, AND INSECTICIDAL ADMIXTURES**

Bacteria and fungal growth on or in hardened concrete may be partially controlled through the use of fungicidal, germicidal, and insecticidal admixtures. The most effective materials are polyhalogenated phenols, dieldrin emulsions, and copper compounds. The effectiveness of these materials is generally temporary, and in high dosages they may reduce the compressive strength of concrete.

## **ANTIWASHOUT ADMIXTURES**

Antiwashout admixtures increase the cohesiveness of concrete to a level that allows limited exposure to water with little loss of cement. This allows placement of concrete in water and under water without the use of tremies. The admixtures increase the viscosity of water in the mixture resulting in a mix with increased thixotropy and resistance to segregation. They usually consist of water soluble cellulose ether or acrylic polymers.

## **COMPATIBILITY OF ADMIXTURES AND CEMENTITIOUS MATERIALS**

Fresh concrete problems of varying severity are encountered due to cement-admixture incompatibility and incompatibility between admixtures. Incompatibility between supplementary cementing materials and admixtures or cements can also occur. Slump loss, air loss, early stiffening, and other factors affecting fresh concrete properties can result from incompatibilities. While these problems primarily affect the plastic-state performance of concrete, long-term hardened concrete performance may also be adversely affected. For example, early stiffening can cause difficulties with consolidation of concrete, therefore compromising strength.

Reliable test methods are not available to adequately address incompatibility issues due to variations in materials, mixing equipment, mixing time, and environmental factors. Tests run in a laboratory do not reflect the conditions experienced by concrete in the field. When incompatibility is discovered in the field, a common solution is to simply change admixtures or cementing materials (Helmuth, Hills, Whiting, and Bhattacharja 1995, Tagni-Hamou and Aïcin 1993, and Tang and Bhattacharja 1997).

## **STORING AND DISPENSING CHEMICAL ADMIXTURES**

Liquid admixtures can be stored in barrels or bulk tankers. Powdered admixtures can be placed in special storage bins and some are available in premeasured plastic bags. Admixtures added to a truck mixer at the jobsite are often

in plastic jugs or bags. Powdered admixtures, such as certain plasticizers, or a barrel of admixture may be stored at the project site.

Dispenser tanks at concrete plants should be properly labeled for specific admixtures to avoid contamination and avoid dosing the wrong admixture. Most liquid chemical admixtures should not be allowed to freeze; therefore, they should be stored in heated environments. Consult the admixture manufacturer for proper storage temperatures. Powdered admixtures are usually less sensitive to temperature restrictions, but may be sensitive to moisture.

Liquid chemical admixtures are usually dispensed individually in the batch water by volumetric means (Fig. 6-20). Liquid and powdered admixtures can be measured by mass, but powdered admixtures should not be measured by volume. Care should be taken to not combine certain admixtures prior to their dispensing into the batch as some combinations may neutralize the desired effect of the admixtures. Consult the admixture manufacturer concerning compatible admixture combinations or perform laboratory tests to document performance.



**Fig. 6-20. Liquid admixture dispenser at a ready mix plant provides accurate volumetric measurement of admixtures. (44220)**

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