

## CHEMICAL ADMIXTURES FOR CONCRETE PAVING MIXTURES

### INTRODUCTION

Hydraulic cement concrete (hereafter referred to simply as concrete) is composed of aggregates bound together by a hydrated cement paste. Concrete is readily available, affordable, and is known for its longevity. Fresh concrete used in paving must possess the workability to be mixed, transported, placed, consolidated, and finished to a homogenous condition using the means and methods dictated by specification and the given project constraints. Concrete paving often entails placement with a slipform paver, which requires a mixture that readily consolidates under vibration but resists edge sloughing once the paver sideforms pass. The hardened concrete must possess the required physical properties needed to achieve design expectations while also exhibiting adequate durability characteristics over the service life. To achieve these fresh and hardened concrete properties, it is often necessary to use chemical admixtures.

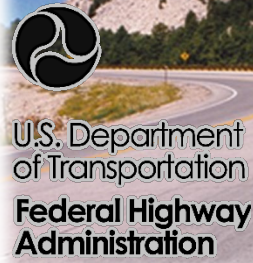
The proper use of chemical admixtures requires the following (Kosmatka and Wilson 2016):

- Adherence to manufacturer's information to confirm that the admixture under consideration is appropriate for the proposed application.
- Following the manufacturer's recommendations regarding admixture dosage and establish the optimum dosage through laboratory testing.
- Trial batching with the admixture and other job-mix concrete constituents under temperature conditions that are expected to exist at time of placement to assess the potential for interactions on fresh and hardened concrete properties.

Whether using a single admixture or a combination of many admixtures, their use provides an additional means of controlling the quality of concrete by modifying one or more mixture properties in a beneficial way. However, admixtures must not be used in an attempt to correct for poor-quality materials, improper proportioning of the concrete, and/or inappropriate placement procedures (ACI 2012).

It is important that the cost effectiveness of the admixture not be judged on the increase in cost to the concrete alone, but instead on the overall cost of the concrete in place as the proper use of chemical admixtures can provide significant savings with regards to transporting, placing, and finishing concrete (ACI 2016b). In addition, the performance of the concrete in service must be considered as admixtures can significantly improve longevity at little additional cost (e.g., enhance freeze-thaw resistance due to entraining air). A number of excellent resources exist that provide detailed information on chemical admixtures (ACI 2012; ACI 2016b; Kosmatka and Wilson 2016).

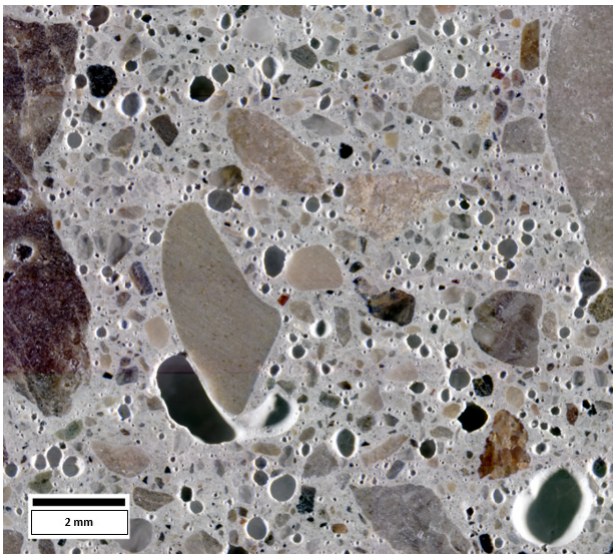
This Tech Brief focuses on enhancing the fresh and/or hardened properties of paving grade concrete through the use of chemical admixtures. The chemical admixtures most commonly used in paving concrete are discussed in detail, specifically those used to entrain air, reduce water, and modify set. Other admixtures that are occasionally used in paving concrete are also introduced, including those for hydration control, shrinkage reduction, inhibition of the alkali-silica reaction (ASR), and for coloration.



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## AIR ENTRAINING ADMIXTURES

As concrete freezes, ice first forms within the larger pores. The formation of ice is expansive and results in changes in the pore solution chemistry, together resulting in the generation of stress within the concrete (Powers 1945; Powers 1954; Powers 1955; Powers and Helmut 1956; Marchand, Pleau, and Gagné 1995; Penttala 1998; Scherer and Valenza 2005). The presence of a network of uniformly dispersed entrained air bubbles (such as shown in figure 1) can provide the needed empty space to relieve stress generated as the concrete freezes. A more thorough discussion on protecting concrete against freeze-thaw damage can be found in ACI (2016a), Kosmatka and Wilson (2016), in the commentary to AASHTO PP 84-17, and in a recent FHWA Tech Brief (Van Dam 2019).



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Figure 1. Stereo micrograph of entrained air voids (spherical bubbles) in hardened concrete. Larger, irregular voids are entrapped air.

### Mechanisms for Air Entrainment

Air is most commonly entrained in concrete during batching through the addition of an air-entraining admixture (AEA) specified in AASHTO M 154 (ASTM C260). The most common AEAs are composed of salts of wood resins (e.g., Vinsol resin), organic salts of sulfonated hydrocarbons, fatty and resinous acids and their salts, salts of proteinaceous acids, and/or synthetic detergents (ACI 2016b; Kosmatka and Wilson 2016).

AEAs are surfactants that work at the air-water interface to create stable air bubbles in the fresh concrete as it is mixed. These bubbles remain once the concrete has hardened and, ideally, are uniformly dispersed throughout the mortar phase in the concrete. The stiffness of the concrete mixture, the type and duration of mixing, temperature, and many other factors are influential in the formation of the entrained air. Excellent summaries of these factors are provided by Nagi et al. (2007) and by Kosmatka and Wilson (2016).

### Air Content Requirements

The air content required to protect concrete is dependent on both the freeze-thaw exposure condition and the paste content (or mortar fraction) in the concrete (ACI 2016a). For most paving mixtures exposed to freezing and thawing and where deicers are used, the recommended air content should be between 5.0 and 8.0 percent or greater than 4 percent with a Super Air Meter (SAM) number less than 0.20 measured in accordance with AASHTO TP 118 (AASHTO PP 84-17).

### Properties of Air-Entrained Concrete

The principal reason to entrain air in concrete is to protect the concrete against damage from freezing and thawing. But air entrainment has other impacts on concrete, both positive and negative.

With regards to fresh concrete, entrained air improves workability, making the concrete more cohesive and allowing for significant reductions in water and sand content. Further, the tendency for segregation and bleeding is reduced and finishing qualities improved (Kosmatka and Wilson 2016). Although a reduction in bleeding can have positive impacts, one potential negative is that in highly evaporative environments (hot, windy, and/or dry), the risk of plastic shrinkage cracking is increased as bleeding is diminished (ACI 2016b).

With regards to hardened concrete, the addition of air reduces concrete strength, with a 1 percent increase in air commonly equated to a 5 to 6 percent reduction in strength (Kosmatka and Wilson 2016). Yet the improvement in workability allows for a reduction in water that can be used to reduce the water-to-cementitious materials ratio ( $w/cm$ ) in air entrained concrete. This can compensate for the loss in strength due to the increased air (ACI 2016b).

### Troubleshooting Air Entrainment Problems

In most cases, the total air content of the fresh concrete prior to placement is correlated with and similar to the total air content in the hardened concrete. Further, the total air content is usually a good indicator of the acceptability of the air-void system in offering protection against freeze-thaw damage. But this is not always the case as there are times when the total air content in the fresh concrete is acceptable prior to placement but an unacceptable air-void system is present in the hardened concrete. These problems can be generally classified into the following two categories:

- Air-void system instability results in loss of air through handling and consolidation.
- An irregular air-void system is produced with regards to bubble size and spacing.

With regards to air-void system instability, it is common to lose 1 to 2 percent of the air through the placement process when the concrete is placed and/or consolidated

(Whiting and Nagi 1998; Taylor et al. 2007; Ram et al. 2012). It is generally thought that the air that is lost is in the larger air bubbles, and those larger bubbles are not as critical to freeze-thaw protection as the smaller bubbles. But air loss beyond this is of concern, and may be a result of a number of other factors including AEA interactions with other chemical admixtures having a negative effect on air void stability (Nagi et al. 2007).

Organic impurities may also decrease the effectiveness of AEAs. This is of particular concern with regards to fly ash, in which carbon present due to incomplete coal combustion, or worse yet, activated carbon added to mitigate mercury emissions, can significantly destabilize air bubbles.

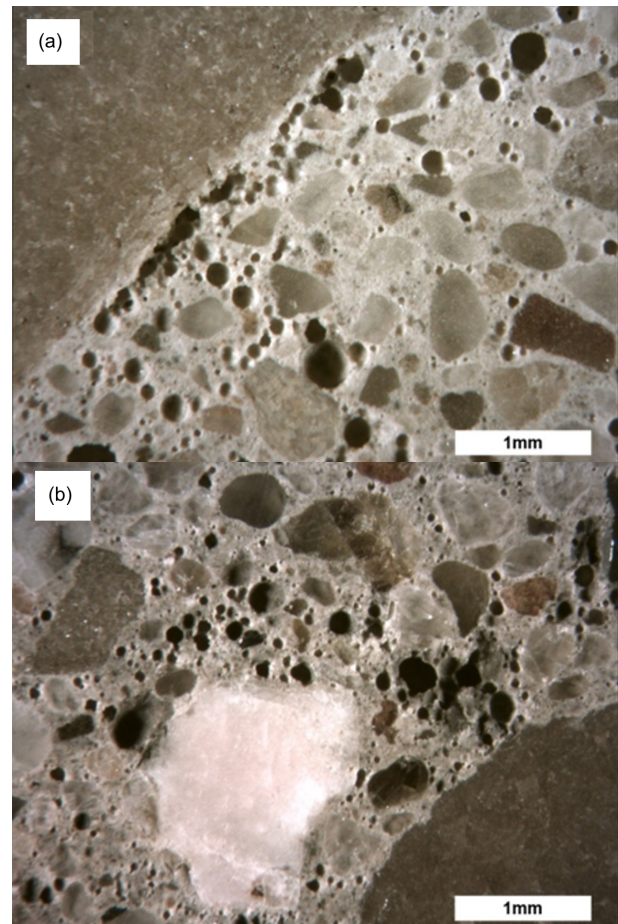
Assessing the air content of fresh concrete over time provides a good indication of the air-void system stability. Such testing is common when determining mixture proportions in the laboratory and should be repeated as materials change during construction. Furthermore, periodically testing the air content of the concrete after the paver will provide a good indication of air loss due to placement.

Another problem is that concrete having acceptable volumes of air may remain susceptible to freeze-thaw damage because of an irregular air-void system. Irregularity may include:

- **Large bubbles spaced far apart** – This can occur due to interactions between the AEA and another chemical admixture, most notably some high-range water-reducers.
- **Air voids accumulating at coarse aggregate interfaces** (see figure 2a) – This can be due to retempering (the late addition of water) concrete containing non-Vinsol resin AEA (Kozikowski et al. 2005). Others have found that air voids can form along the aggregate interface if porous aggregates are batched dry of SSD (Buenfeld and Okundi 1999). Air void accumulation at coarse aggregate interfaces often results in loss of strength.
- **Air void coalescence in mortar** (see figure 2b) – In some cases, the coalescence of air voids in the mortar has been observed (Ram et al. 2012). The major cause of such clustering is uncertain, but it is thought to be due, at least in part, to insufficient concrete mixing. In some cases, the coalescence was observed in concrete with high air void content.

Addressing irregular air-void systems is difficult as the problem will likely not be observed through normal construction testing (other than strength loss that may accompany air void accumulation at aggregate interfaces). Such problems are usually only detected in the course of a study or forensic investigation in which petrographic analysis is conducted. The use of the sequential pressure method (AASHTO TP 118), commonly referred to as the Super Air Meter, during

construction has the potential to identify some air-void system problems during construction (AASHTO PP-84-17; Van Dam 2019).



Source: public domain (WisDOT, WHRP).

Figure 2. Stereo micrographs showing (a) air void accumulating at interface with coarse aggregate, and (b) coalescing in paste (Ram et al. 2012).

### WATER-REDUCING ADMIXTURES

As the name implies, water-reducing admixtures (WRAs) reduce the water required to obtain concrete with a given workability. A WRA can be used to reduce the amount of water added while maintaining the same workability or can be used to increase workability of the concrete without the need for additional water. WRAs conform to AASHTO M 194 (ASTM C494) and can be formulated to have normal, retarding, or accelerating setting characteristics (ACI 2016b). They are classified based on water-reducing capabilities and set-control characteristics, as follows (Kosmatka and Wilson 2016):

- Type A, water-reducing.
- Type D, water-reducing and retarding.
- Type E, water-reducing and accelerating.
- Type F, water-reducing, high-range.
- Type G, water-reducing, high-range and retarding.

It is common to characterize WRAs based on their effectiveness in reducing water requirements as follows (ACI 2016b; Kosmatka and Wilson 2016):

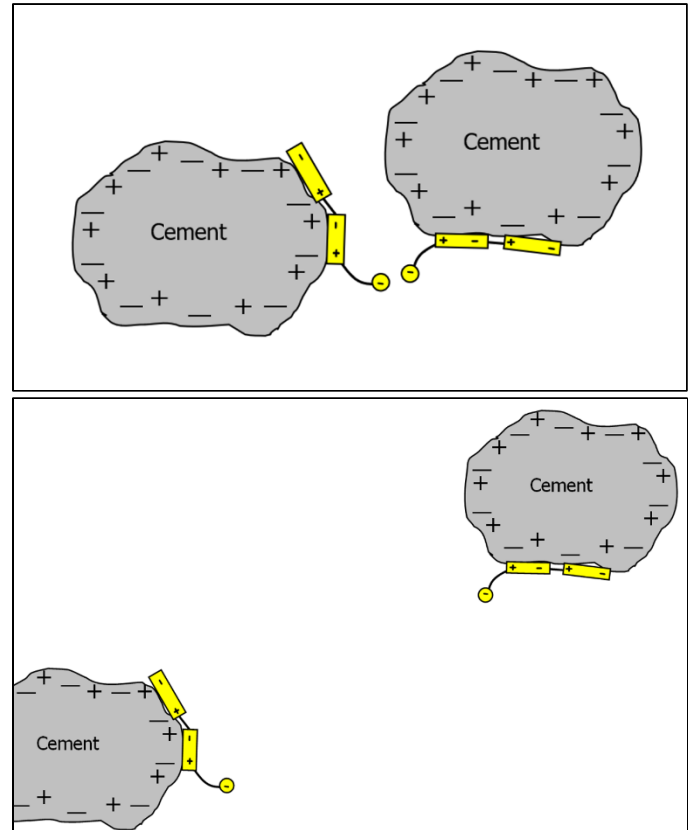
- **Normal (conventional) water-reducers** – These can reduce water content by approximately 5 to 10 percent without exceeding the AASHTO M 194 time of set limit. These are typically classified as Type A, D, or E.
- **Mid-range water-reducers** – These provide water reduction between 6 and 12 percent without retardation associated with high dosages of normal water-reducers. These products should show compliance with AASHTO M 194 Type A and often meet Type F requirements.
- **High-range water-reducers** – These provide water reduction between 12 and 40 percent, and are often used to produce high strength concrete with very good workability and extremely low  $w/cm$ . These products often meet the requirements of AASHTO M 194 Type F or G. Not often used in paving grade concrete.

#### Mechanisms of Water Reduction

Most WRAs disperse cement grains through electrostatic and steric repulsive forces (Kosmatka and Wilson 2016). The water-reducing compounds will electrostatically bind to the cement grains giving them a slight negative charge as well as creating a layer on the surface as illustrated in figure 3. In combination, these electrostatic and steric repulsive forces separated the cement grains, breaking up particle agglomerations and making the mixing water much more efficient. To a lesser degree, electrostatic forces also repel aggregates and entrained air bubbles (Kosmatka and Wilson 2016).

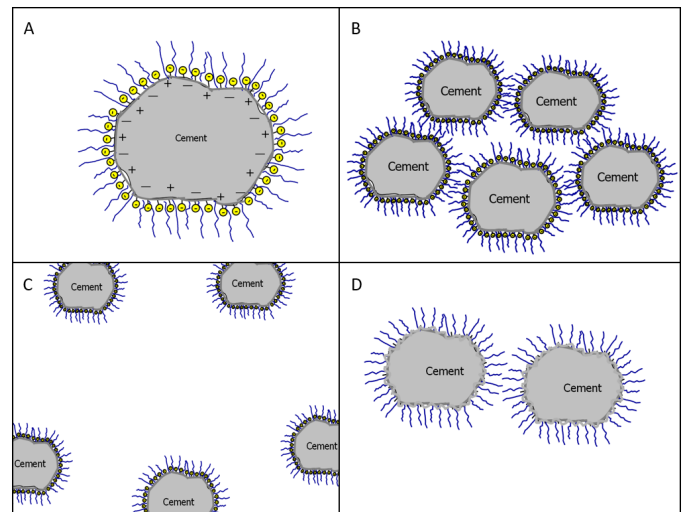
Polycarboxylates represent the newest WRA technology. They use the same concepts as other WRAs, only are far more efficient as the longer polycarboxylate molecular chains adhere to the surface of cement grains dispersing them in a mechanism referred to as steric hindrance as illustrated in figure 4 (Kosmatka and Wilson 2016). Frame A shows the polycarboxylate-based water-reducer molecules absorbed onto the surface of the cement grain with the long side chains physically dispersing the cement grains through steric hindrance as shown in Frame B, allow water to totally surround the cement grains. The dispersion is promoted further by electrostatic repulsion of the negatively charged molecular chains as shown in Frame C. As the electrostatic repulsion effect wears off, the long side chain molecules keep the cement grains dispersed as shown in Frame D. Because the mechanism is highly dependent on physical separation, the effectiveness of polycarboxylate-based WRAs is not influenced by the dissolved ions in solution to the same extent as is the electrostatic repulsion mechanism. Thus the water-reducing effect is longer-lasting and highly efficient. Polycarboxylate-based high-range WRAs are very common, and this technology is becoming more

common as a mid-range WRA and are thus seeing increased application in paving grade concrete.



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Figure 3. Illustration of how water-reducing admixture molecules (small blocks) adhere to cement grains and result in cement grain dispersion as the negatively charged un-adhered end of the molecules creates electrostatic and steric repulsion (Thomas and Wilson 2002).



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Figure 4. Mechanism of steric hindrance used by polycarboxylate-based water-reducers (Thomas and Wilson 2002).

### *Properties of Concrete with Water-Reducers*

As discussed, WRAs are used to reduce the water required in the mixture while maintaining the same level of concrete workability. For paving grade concrete mixtures that are typically low slump, the use of normal-range and mid-range WRA (Type A, and to a lesser degree Types D and E) is common practice to reduce the  $w/cm$  and/or cementitious materials content while maintaining workability. It is not common to use high-range WRAs for paving grade concrete as high slumps and/or high strength are not often sought.

### *Troubleshooting*

Type A WRA are often formulated with a water-reducing retarding component, and an accelerating compound is added to achieve normal set. In these formulations, this limits water reduction to around 10 percent before excessive retardation occurs and is one reason why Type A WRA are often used in hot weather (ACI 2016b). A difficulty can arise under these circumstances as the accelerating compound may accelerate the aluminate phase, which can lead to false or early set. The problem can be particularly acute when some supplementary cementitious materials, particularly AASHTO M 295 Class C fly ash, are used. Under these circumstances, the problem can be alleviated by trying another Type A WRA, cooling the concrete mixture, or changing the batching sequence by delaying the WRA addition (Taylor et al. 2007).

Some problems have been encountered in the air-void system with the use of polycarboxylate-based WRA (Concrete Producer 2012). Some early studies noted that mixtures made with polycarboxylate-based WRA had acceptable total air contents, but that the air bubble were large and spaced far apart (Van Dam et al., 2005). Others have reported issues of uncontrollable air in the presence of polycarboxylate-based WRA. Polycarboxylate-based WRA are surfactants that will have a tendency to entrain air and most all are currently formulated with a defoamer to counteract this tendency (MacDonald 2009; Jeknavorian 2016). If not properly balanced, this can either entrain more air than desired or result in air-void instability. For this reason, additional care should be exercised when using polycarboxylate-based WRA to ensure that the total air content and the air-void system are adequate for the anticipated environmental conditions.

### **SET-RETARDING ADMIXTURES**

Set-retarding admixtures, commonly referred to as retarders, are used to delay the rate of setting of concrete. Retarders are often used during hot weather to offset the increased rate of hydration that occurs under these circumstances, but are also used delay set to maintain monolithic behavior of large placements, to permit the delayed delivery of concrete due to long transport distances and/or other source of delay, or to facilitate the

application of special finishing techniques such as an exposed aggregate surface (Kosmatka and Wilson 2016).

### *Description*

Set-retarding admixtures are specified under AASHTO M 194/ASTM C494 Type B as set-retarding without affecting water requirements and Type D as set-retarding and water-reducing. A third category is AASHTO M 194/ASTM C494 Type G, which is set-retarding and high-range water-reducing.

### *Types and Mechanisms*

Set-retarding admixtures are commonly composed of one or more of the following four general categories of compounds (ACI 2016b; Kosmatka and Wilson 2016):

- Lignosulfonic acids and their salts including derivations and modifications.
- Hydroxylated carboxylic acids and their salts including derivations and modifications.
- Carbohydrate-based compounds such as sugars, sugar acids, and polysaccharides.
- Inorganic salts such as borate and phosphates.

Although some materials are available that solely have a set-retarding influence, the vast majority of set-retarding admixtures are also water-reducing (ACI 2016b). This is especially true of the lignosulfonate category. It is noted however that the specific effects of any one admixture can vary greatly with different cements, addition sequence, changes in  $w/cm$ , mixing temperature, ambient temperature, and other factors (ACI 2016b).

As described by Kosmatka and Wilson (2016), retarders slow cement hydration through complex processes, inhibiting the growth of certain crystalline phases by delaying nucleation. Some categories of set retarders also form a shell or coating on the surface of the cement grains, limiting access to water (Mindess, Young, and Darwin 2003). Eventually this shell ruptures, allowing water access and hydration to resume.

### *The Use and Effects of Set-Retarders on Concrete*

In the absence of specific information, a testing program should be executed to assess admixture effectiveness using job mix constituent materials and temperature conditions expected on the project site (ACI 2016b). In particular, temperature can have a big influence on the behavior of retarders and thus a range of temperatures should be investigated during laboratory trial batching that represent the range expected over the duration of the project.

Also, the sequencing and timing of the admixture addition during batching are important. This must be considered during production.

The use of retarders at normal dosages will delay both the initial and final set of concrete. They also will likely result in some reduction in early-age strength (within the first 3 days), but very likely result in higher long-term strength. Dosing an excessive amount of retarder may result in excessive delay in setting and permanently hinder cement hydration (Kosmatka and Wilson 2016).

Other concrete properties such as slump, air content, bleeding, early-age strength development, resistance to freezing and thawing, and shrinkage can all be affected by the use of a retarder and therefore the impact on these properties should be tested during laboratory trial batching (Kosmatka and Wilson 2016; ACI 2016b).

### *Troubleshooting*

Retarders tend to have a direct impact on the hydration of the tricalcium aluminate ( $C_3A$ ) phase in the cement in what is often a complex interaction that involves absorption of the retarder into the early  $C_3A$  hydration products. This can have the following effects (Mindess, Young, and Darwin 2003):

- The effectiveness of the retarder depends on the  $C_3A$  content of the cement, with more retarder required as  $C_3A$  content increases.
- The effectiveness of the retarder increases as the time of addition is delayed.
- Abnormal setting, including early stiffening or abnormal retardation can occur with certain cements. Taylor et al. (2007) described interactions resulting from the presence of certain fly ashes during hot weather.
- Although setting can be delayed, due to early  $C_3A$  reactions, workability may not be significantly improved.

Early stiffening has been noted as issue when lignosulfonate-based Type D water-reducing and retarding admixtures have been used with certain Class C fly ashes, particularly during periods of high temperature. If early stiffening becomes an issue, the following should be done (Taylor et al. 2007):

- Verify that the source of cementitious materials (e.g. cement and fly ash) have not changed. If they have and the original source is unavailable, the mixture should be re-evaluated.
- In the short-term, consideration should be given to changing the admixture if possible.
- Cooling the concrete mixture may eliminate the problem.
- Delaying the addition of the admixture or changing the batching sequence might have immediate positive effect.

## SET-ACCELERATING ADMIXTURES

Set-accelerating admixtures, commonly referred to as accelerators, are used to accelerate the rate of hydration and thus promote early setting and strength gain. For pavement applications, they are most often used to support early strength gain to facilitate the early opening to traffic, and often in conjunction with other mixture strategies including the use of a high-early strength cement (e.g., Type III), a WRA that permits the use of a low  $w/cm$ , and increased cementitious materials content (Van Dam et al. 2005; Kosmatka and Wilson 2016). Accelerators are also often used during cold weather placements to initiate hydration so that the heat generated by the exothermic reactions can be used, in conjunction with insulation, to support continued hydration.

### *Description*

Accelerators are specified under AASHTO M 194/ASTM C494 Type C as set-accelerating without affecting water requirements and Type E as set-retarding and water-reducing. Type C accelerators are also commonly characterized as being chloride-based (calcium chloride is the most widely used accelerator) or non-chloride (NC). Currently a new generation of accelerators based on nano-particles is being brought to market with early results showing promise (Kosmatka and Wilson 2016; ACI 2016b).

### *Types and Mechanisms*

The most common accelerator for non-reinforced concrete is calcium chloride (Kosmatka and Wilson 2016). The popularity of calcium chloride is based on its reliability, ease of use, and cost effectiveness (ACI 2016b). Calcium chloride is commonly used in dosages of up to 2 percent by mass of cementitious materials, although local specifications will dictate the allowable maximum dosage. AASHTO M 144 (ASTM D98), *Standard Specification of Calcium Chloride* specifies the properties of calcium chloride for use in concrete. Calcium chloride is available as flakes, pellets, or in solution. It can be assumed that the flake form (dihydrate) contains a minimum of 77 percent pure calcium chloride, the pellet form (anhydrous) contains a minimum of 94 percent calcium chloride, and in solution there is commonly 29 percent calcium chloride (Kosmatka and Wilson 2016; ACI 2016b). To aid in the selection of appropriate amounts of calcium chloride by form, ACI provides a table that shows the amount each of flake, pellet, or solution that needs to be added to achieve a given mass of pure calcium chloride as well as the amount of chloride ions added in percent (ACI 2016b).

A major drawback of calcium chloride as an accelerator is that the chlorides can initiate and propagate corrosion in embedded steel. If steel corrosion is of concern, non-chloride accelerators should be used. Commercially available non-chloride accelerators are most often based on organic compounds such as triethanolamine (TEA) and inorganic salts such as sodium and calcium salts of

formate, nitrate, nitrite, thiocyanate, and lactate (Kosmatka and Wilson 2016).

Inorganic accelerators act by accelerating the hydration of the tricalcium silicate ( $C_3S$ ) phase, significantly shortening the dormant period in cement hydration. In contrast, organic accelerators such as TEA accelerate the hydration of  $C_3A$ , expediting the formation of ettringite and its subsequent conversion to monosulfate (Kosmatka and Wilson 2016).

In addition to the conventional accelerators discussed above are newly commercialized accelerators based on aqueous solutions of nanoparticles. These “nanoscale nucleation seeds” act as nucleation sites for the rapid growth of cement hydration products, most notably calcium silicate hydrate (CSH), away from the cement grains themselves, resulting in dramatically improved early strength gain (ACI 2016b; Kosmatka and Wilson 2016).

### *The Use Accelerators in Concrete*

In concrete paving, accelerators are commonly used to accelerate set and strength gain when 1) low temperature paving is encountered and/or, 2) when early opening to traffic is desired. With regards to the former, the proper use of accelerators, along with other cold temperature concrete pavement construction techniques, will permit construction under climatic conditions that would normally shut down operations; however, calcium chloride is not an anti-freeze and thus the concrete must still be protected. The latter application of accelerators addresses a common complaint that concrete is too slow in gaining strength, and that long curing times prevents access to homes and business making concrete paving infeasible in many urban settings. As a result, accelerating concrete strength have allowed the opening of concrete pavements to traffic within a day, and even within 4 to 6 hours, of paving (Van Dam et al. 2005; ACI 2016b).

As is true of all admixtures, the supplier’s guidance must be followed in the use of accelerators. As noted previously, calcium chloride can be used in dosages of up to 2 percent by mass of cementitious materials, but lower dosages should be used if possible. For all accelerators, laboratory trial batching should be conducted to determine the dosage needed to achieve the desired set time and early strength development as well as ensuring that all other mixture properties are achieved. The laboratory testing should use job mix materials and testing should be conducted over a range of temperatures simulating what is expected to be encountered in the field. It is common to test mixtures with a variety of dosages so that dosage can be varied as ambient conditions change.

### *Effects of Accelerators on Concrete Properties*

The primary effect of accelerators on fresh concrete is what they are designed to do; that is, accelerate setting and early strength gain. However, accelerators can also negatively impact air entrainment requiring increased

dosage of air entraining admixture. In some cases, it has been observed that accelerators increased bubble size and spacing factor, effectively reducing the benefit of entrained air (ACI 2016b). In areas where freeze-thaw cycles and chemical deicing are common, it might be advantageous to microscopically examine the nature of the entrained air-void system in accordance with ASTM C457 during the mixture qualification process to ensure that the bubble sizing and spacing is adequate.

One of the most noticeable effects of calcium chloride accelerator on hardened concrete is a discoloration, which depending on the alkalis, can be mottling characterized by light spots on a dark background or dark spots on a light background (ACI 2016b). The discoloration is permanent and increases as the dosage levels increase.

Other effects of calcium chloride accelerators include increased creep and drying shrinkage, reduced long-term strength, and increased susceptibility to sulfate attack and alkali-silica reactivity (ASR) (Kosmatka and Wilson 2016; ACI 2016b). It is recommended that calcium chloride not be used if external sulfate attack or ASR is of concern. And overdosing concrete with calcium chloride can be especially problematic as it can result in placement problems due to rapid stiffening, large increases in dry shrinkage, and loss of strength at later ages.

Of greatest concern when using calcium chloride is corrosion of embedded steel. The general recommendation is to use calcium chloride accelerator with caution if the concrete is reinforced with steel. As even plain jointed concrete pavement typically has embedded steel dowels and tie bars, this should be considered.

### *Troubleshooting*

As with most other admixtures, accelerators are sensitive to the properties of multiple mixture constituents as well as ambient conditions. Evaluating the impact when changing a mixture component and thoroughly testing the admixture during mixture design over a range of temperatures can help avoid problems. Specifically, the following should be considered when using set-accelerating admixtures:

- It is known that accelerators can impact the effectiveness of air-entraining admixtures. Verify compatibility during mixture design and closely monitor for changes during construction.
- Avoid high doses of accelerators. For calcium chloride, do not exceed 2 percent calcium chloride by mass of cementitious materials. Excessive dosing of organic accelerators may actually result in extending set time, as do high dosages of calcium nitrate (ACI 2016b).
- The use of accelerators in hot weather may result in very rapid setting as well as placement and finishing

problems. Be prepared to adjust accelerator dosage as temperatures increase.

- Calcium chloride is not an effective anti-freeze for concrete at recommended dosages and thus good cold-weather concreting practices must be followed to protect the concrete if a risk of freezing exists (Kosmatka and Wilson 2016).
- It is recommended that calcium chloride be added in solution as part of the mixing water. If added as flake or pellet, not all may dissolve resulting in popouts or dark spots on the concrete surface (Kosmatka and Wilson 2016).

## OTHER ADMIXTURES

In addition to the admixtures above, there are others that might occasionally be used in the course of concrete paving. A brief summary of some of these is provided below, with additional details provided elsewhere (ACI 2016b; Kosmatka and Wilson 2016).

### *Hydration Control Admixtures*

Hydration control admixtures, also referred to as extended set-control admixtures, are principally used during long hauls or when concrete placements are delayed. They are very potent retarders that stop or severely retard the hydration of both the silicate and aluminate phases. In some systems, two components are used; the first component is added to stop hydration and the second component is added to “wake it up” at the desired time. Using such a system, fresh concrete can be stored for a day or more (Kosmatka and Wilson 2016). Some issues have been noted with maintaining air content when hydration control admixtures are used. It is therefore recommended that additional testing be conducted during mixture qualification to ensure that the entrained air-void system remains adequate when the admixture has been used as planned.

### *Shrinkage-Reducing Admixtures*

The use of shrinkage-reducing admixtures (SRAs) is becoming more common for concrete bridge decks and may start to see some use in paving grade concrete. These admixtures reduce the surface tension of the mixing water and thus limit the formation of menisci in the capillary pores, significantly reducing shrinkage as the concrete dries.

### *Alkali-Silica Reaction Inhibiting Admixtures*

When aggregates that are potentially susceptible to ASR are used, the reaction is commonly mitigated through the addition of a pozzolan (e.g., fly ash, natural pozzolan) and/or slag cement in accordance with AASHTO R 80 (ASTM C1778). Another potential mitigation strategy is to use an alkali-silica reaction inhibiting admixture. Most of these are based on lithium compounds, with lithium nitrate being the most common. Shortages of lithium are developing as lithium is a critical component in storage batteries.

## *Coloring Admixtures*

In some instances it is desired to color paving concrete to achieve a specific aesthetic appeal. There is a wide range of natural and synthetic color agents available in powder and liquid form. Generally such coloring admixtures should not be used in quantities exceeding 10 percent by weight of cementitious materials (Kosmatka and Wilson 2016). Pigments should conform to ASTM C979 and should be tested with job mix constituents to ensure compatibility and color fastness under sunlight.

## SUMMARY

Chemical admixtures are an essential ingredient in modern paving-grade concrete. Their use increases freeze-thaw durability (i.e. air-entraining admixtures), permits the reduction of water while maintaining workability (water-reducers), facilitates placement during hot temperatures or after long hauls (retarders), and if desired, expedites opening of concrete to traffic (accelerators).

Table 1 summarizes common chemical admixtures used in paving grade concrete. Regardless of the admixture used, rigorous laboratory and field testing should be used to ensure its effectiveness with the job materials, including other admixtures, over the range of temperature conditions expected during construction.



Table 1. Summary of common chemical admixtures used in paving grade concrete.

Admixture	Standard	Description	Comments
<b>Air Entraining</b>	AASHTO M 154 ASTM C260	Surfactants that entrain stable microscopic air bubbles in fresh concrete, which remain in the hardened concrete to protect it against freeze-thaw damage.	A wide variety of compounds are used to entrain air. Must ensure that the bubble size and spacing is sufficient to protect concrete against freeze-thaw damage.
<b>Water-Reducing</b>	AASHTO M 194 ASTM C494 Type A	Conventional WRAs can reduce water content by 5 to 10 percent.	Most conventional WRA disperse cement grains through electrostatic and steric repulsion. Can affect setting, with retardation more common as dosage increased. Can also be sensitive to temperature, and due to interactions with other mixture constituents, can result in flash setting or severe retardation.
<b>Water-Reducing and Retarding</b>	AASHTO M 194 ASTM C494 Type D	Conventional WRAs can reduce water content by 5 to 10 percent and retards setting.	Most conventional WRA disperse cement grains through electrostatic and steric repulsion. Can affect setting, with retardation more common as dosage increased. Can also be sensitive to temperature, and due to interactions with other mixture constituents, can result in flash setting or severe retardation.
<b>Water-Reducing and Accelerating</b>	AASHTO M 194 ASTM C494 Type E	Conventional WRAs can reduce water content by 5 to 10 percent and accelerates set.	Most conventional WRA disperse cement grains through electrostatic and steric repulsion. Can affect setting, with retardation more common as dosage increased. Can also be sensitive to temperature, and due to interactions with other mixture constituents, can result in flash setting or severe retardation.
<b>Water-Reducing, Mid-Range</b>	AASHTO M 194 ASTM C494 Type A and often Type F	Water reduction between 6 and 12 percent without retardation associated with high dosages of normal WRAs.	These bridge the gap between conventional WRAs and high-range WRAs. Depending on chemistry, they may entrain air.
<b>Water-Reducing, High-Range</b>	AASHTO M 194 ASTM C494 Type F	Water reduction between 12 and 40 percent without retardation. Not often used with paving grade concrete	Various compositions with the latest generation being based on polycarboxylate technology, resulting in improved long-term slump stability. Polycarboxylates have a tendency to entrain larger air bubbles and thus are often defoamed. This can impact air entrainment.
<b>Water-Reducing, High-Range and retarding</b>	AASHTO M 194 ASTM C494 Type G	Water reduction between 12 and 40 percent with retardation. Not often used with paving grade concrete	Various compositions with the latest generation being based on polycarboxylate technology, resulting in improved long-term slump stability. Polycarboxylates have a tendency to entrain larger air bubbles and thus are often defoamed. This can impact air entrainment.
<b>Set-Retarding</b>	AASHTO M 194 ASTM C494 Type B	Set-retarders are used to delay set, especially during hot weather and/or when delivery of concrete is delayed.	Various compounds are used that delay the hydration of the aluminate phase, calcium silicate phase, or both phases. Sensitive to temperature and other mixture constituents and thus must be evaluated for interactions.
<b>Set-Accelerating</b>	AASHTO M 194 ASTM C494 Type C	Set-accelerators are used to accelerate set, especially during cold weather and/or when rapid setting and strength gain are required for early-opening-to traffic.	The most common accelerator is calcium chloride although non-chloride accelerators are available. Calcium chloride accelerates the hydration of calcium silicate. The biggest drawback of calcium chloride is it increases the risk of chloride induced corrosion of embedded steel.

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**Researcher**—This Tech Brief was developed by Thomas J. Van Dam (NCE) and prepared under FHWA's Concrete Pavement Best Practices Program (DTFH61-14-D-00006). Applied Pavement Technology, Inc. of Urbana, Illinois served as the contractor to FHWA.

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**Key Words**—concrete mixes, admixtures, additives, air entrainment, water reducers, accelerators, retarders

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