Chapter 6

Selection of concrete materials

The successful use of concrete as a construction material extends back two millennia to the days of the Romans. On the other hand, some concrete structures and facilities built since then have had considerably shorter service lives. Careful selection of concrete materials and careful mixture design and proportioning, combined with good design and construction practices, is a key contributor to success. Durability is addressed in Guide to Durable Concrete, 201.2R-08, (ACI Committee 201, 2008).

Pasko (1998) states that “a good pavement designer should also be a concrete expert. Some facts to be kept in mind are:

- In the United States, there are 118 cement plants, each producing a variety of ‘unique’ products under broad specifications. From personal experience on a research project, five Type I cements from different plants ranged in 28-day strength from 2738 to 4975 psi (19 to 34 MPa).
- There are 420 coal-burning plants in this country, and 28 percent of their fly ash is acceptable for use in concrete in accordance with ASTM C618. These products react differently with various cements, and the result is dependent on the quantities used. This is particularly important with respect to alkali aggregate reaction and sulfate resistance (and, possibly, delayed ettringite formation).
- Thousands of aggregate sources are available for use. Unfortunately, aggregate is not an inert filling. In addition to some aggregates reacting with the cementious materials, there are other characteristics that can cause problems.”

Clearly, variability of source materials must be addressed by engineers. Concrete in its simplest form consists of cement, water, and aggregates. In modern practice, chemical admixtures are almost always used, particularly for pavements. The use of supplementary cementitious materials, also called mineral admixtures, is also very common, because these materials reduce the cost and improve the performance and durability of concrete.
Three excellent overall references on concrete are Kosmatka and Wilson (2011), Mindess et al. (2003), and Neville (1995).


CEMENT

Cement is the hydraulic glue that holds concrete together. In U.S. practice, portland cements are numbered using the Roman numerals I through V. Type I is a general purpose cement suitable for all uses where no special properties are required. In much of the United States it is by far the most common cement. Type II cement is used where it is important to protect against moderate sulfate attack. Sulfates are found in soils and groundwater, particularly in the western states of the United States, and may attack concrete made with type I cement. In regions where sulfates are commonly found, type II cement is the more common type, and not type I. Some cements meet both type I and II and are designated type I/II. Type III cement is ground finer to achieve higher early strength, or may have a different chemical composition. Type IV cement has slower strength gain for applications where heat of hydration must be minimized—it is now rarely available because the same effect may be achieved, at lower cost, with addition of supplementary cementitious materials. Type V cement provides higher sulfate resistance than type II, for more severe environments (Kosmatka and Wilson 2011: 29–39). Portland cements are manufactured to meet ASTM C150, Standard Specification for Portland Cement (ASTM C150 2005).

In Canada, types I–V are termed types 10–50 (Mindess et al. 2003: 26). Blended hydraulic cements also exist, with several designations depending on whether slag cement or pozzolans are added, along with hydraulic cements and hydraulic slag cements (Kosmatka and Wilson 2011: 40–41). Blended cements can be made to either ASTM C595/AASHTO M 240 or ASTM C1157 (Taylor et al. 2007: 30).

SUPPLEMENTARY CEMENTITIOUS MATERIALS

Supplementary cementitious materials, or mineral admixtures, include fly ash, slag cement, and silica fume, as well as other materials. Fly ash and slag cement are commonly used in pavements. Typically, these materials retard early strength gain of concrete, but improve the ultimate strength and durability. Overall heat of hydration and the rate of heat buildup are
both reduced. Workability is improved, and the concrete surface is often easier to finish. Durability is improved, because the porosity of the concrete is decreased and susceptibility to sulfate attack and alkali–silica reaction (ASR) is reduced (Mindess et al. 2003: 107–109). However, it is important to understand the environmental and durability benefits, as well as the effects on fresh concrete properties such as workability, air content, and setting time (Taylor et al. 2007: 36–38).

Supplementary cementitious materials may have pozzolanic properties, cementitious properties, or both. The pozzolanic reaction works with the reaction products of cement hydration to improve strength and decrease porosity of hardened cement paste and concrete (Mindess et al. 2003: 95).

**Fly ash**

Fly ash, the most widely used supplementary cementitious material in concrete, is a by-product of the combustion of pulverized coal in electric power-generating plants. It produces spherical glassy particles that are finer than portland cement. Two types of fly ash are available, depending on the type of coal that was burned to make the ash. Class F fly ash has pozzolanic properties, and class C fly ash has both pozzolanic and cementitious properties. Class F fly ash is typically used at 15–25% by mass of the cementitious material, and class C at 15–40% by mass (Kosmatka and Wilson 2011: 68–69). Requirements for class C and F fly ash are provided in ASTM C618 (ASTM C618 2005).

**Slag cement**

Slag cement, formerly called ground granulated blast furnace slag (GGBFS), is a by-product of metallurgical processes, generally the production of iron from ore. Slag cements are classified as grade 80, 100, or 120 based on reactivity, which is roughly 80%, 100%, or 120% of the 28-day strength of a reference mortar made with pure cement (Mindess et al. 2003: 102–103). Requirements for slag cement are provided in ASTM C989 (ASTM C989 2005). Slag cement should be distinguished from slag as an aggregate, which has no cementitious properties.

Ternary blend mixtures, which use portland cement, fly ash, and slag cement, can produce very durable, low permeability concrete. The Department of Aviation for the City of Houston, Texas, had experienced problems of durability of high early strength concrete. For a runway expansion at George Bush Intercontinental Airport (IAH) in 2002, a concrete with type I cement (50%), class F fly ash (25%), and grade 120 slag cement (25%) was developed and extensively tested, and was predicted to have a service life of 120 years (Sarkar and Godiwalla 2003).
Other supplementary cementitious materials

Another material, silica fume or microsilica, is often used in high performance, low permeability structural concrete but rarely if at all in pavements. It is a by-product obtained during the manufacture of silicon metal and alloys (Mindess et al. 2003: 95). It is more expensive than fly ash or slag cement and less widely available, and the most likely application in pavements would be for repair materials or thin bonded concrete overlays.

Other materials with potential use in paving concrete include rice husk ash, metakaolin, natural pozzolans, and limestone filler. Rice husk ash is not yet commercially available, but it has the potential to become another important ingredient in concrete. The other three materials are not by-products and have less potential for paving concrete (Malhotra 2006).

AGGREGATES AND WATER

“Aggregates generally occupy 70 to 80 percent of the volume of concrete and therefore can be expected to have an important influence on its properties” (Mindess et al. 2003: 121). Aggregate is not simply an inert filler in concrete, and its properties deserve careful consideration.

Aggregates are granular materials, usually natural rock (crushed rock or natural gravels) and sands. Aggregates are classified as normal weight, heavyweight, and lightweight, based on specific gravity. For concrete pavements, normal weight aggregates are generally used because they are most available. Aggregates for concrete must meet ASTM C33 Standard Specification for Concrete Aggregates (ASTM C33 2003). Aggregate properties that affect concrete pavement performance include shape and texture, size gradation, absorption and surface moisture, specific gravity, unit weight, physical durability, chemical durability, and strength. Strength of the aggregate particles rarely governs concrete strength, because the lower strength of the paste or the aggregate-paste bond is likely to govern instead.

Aggregate shapes may be rounded or angular, with rounded materials occurring naturally and angular materials produced by crushing and processing. Within those two main divisions, aggregate shapes may be further classified as spherical, irregular, highly irregular, flat or oblate/flaky, and elongated. Textures may be glassy, smooth, granular, rough, crystalline, or honeycombed. Rounded aggregates are more workable, but angular particles may develop higher flexural strength, which is important for pavements (Mindess et al. 2003: 122–125).

Grading of an aggregate is determined by a sieve analysis, where the mass of an aggregate sample retained on each of a number of standard sieves is recorded. Two key parameters are the maximum aggregate size and the shape of the gradation curve.
Absorption and surface moisture are of significance for calculating water that aggregate will add to or subtract from paste, and are used in mixture proportioning. Specific gravity is used to establish weight–volume relationships, also for mixture proportioning. Unit weight differs from specific gravity in that it includes not only the volume of the particles but the volume of the space between them when they are densely packed (Mindess et al. 2003: 133–140).

Physical durability of aggregates refers to soundness and wear resistance. Aggregates are unsound if they deteriorate due to volume changes caused by repeated cycles of freezing and thawing or of wetting and drying. Unsound aggregates lead to surface popouts and D-cracking. Wear resistance of aggregate plays some part in wear resistance of concrete under traffic, particularly in areas where studded tires are allowed (Mindess et al. 2003: 140–142).

For concrete pavements, the wear resistance of fine aggregates is more important than that of coarse aggregates for retaining skid resistance over time (Huang 2004: 408). Aggregates with poor wear resistance lead to polished pavement surfaces with poor skid resistance. It also seems logical that the wear resistance of coarse aggregates would also be an important factor in the performance of aggregate interlock joints over time.

“Most chemical-durability problems result from a reaction between reactive silica in aggregates and alkalis contained in the cement” (Mindess et al. 2003: 142). These encompass ASR and alkali–carbonate reaction, and lead to map cracking. Fly ash, class F in particular, and slag cement have been used to control ASR. Other measures include the use of low alkali cements and, when possible, the avoidance of susceptible aggregates (Mindess et al. 2003: 149–151).

It has been recognized that the concrete linear coefficient of thermal expansion (CTE) is an important performance parameter. Although older pavement design procedures ignored CTE, it is an important input for the MEPDG, as discussed in Chapter 10. This coefficient determines how much joints and cracks open and close, and how much concrete slabs curl due to temperature gradients. The concrete thermal coefficient may range from 7.4 to 13 με/°C (4.1–7.2 με/°F). Since aggregates make up such a large portion of the concrete, they effectively determine the thermal coefficient for the concrete. Limestone has a low thermal coefficient of 6 με/°C (3.3 με/°F), while sandstone has a higher thermal coefficient of 11–12 με/°C (6.1–6.7 με/°F) (Mindess et al. 2003: 460).

Therefore, for a given temperature differential, concrete made with sandstone will attempt to move nearly twice as much as concrete made with limestone, and will develop twice as much stress if the movement is restrained. Joints must be designed to accommodate the larger displacements. In addition, the temperature-induced curling of the slab will be twice as much.
It may not be economically feasible to change coarse aggregate sources on a paving project to reduce the concrete CTE. However, reducing the joint spacing will decrease curling stresses and the risk of cracking (Hall et al. 2005: 22).

Types and sources of aggregates, as well as gradations and durability, are discussed in detail by Taylor et al. (2007: 36–38). It is important, when possible, to use larger aggregate sizes and dense gradations to minimize the amount of paste required.

### Coarse aggregate

For pavements, it is generally preferable to use the largest available coarse aggregate size, limited to 1/3 or 1/4 of the thickness of the pavement. This is because using the largest available aggregate reduces the proportion of paste, thus reducing shrinkage. Most ready-mix concrete equipment can handle aggregates up to 50 mm (2 in) in size. One caveat is that if the aggregate is susceptible to freeze–thaw damage, or D-cracking, a reduction in aggregate size will improve durability (Mindess et al. 2003: 125–127). For aggregate interlock pavement joints, use of larger maximum size aggregate should improve load transfer.

Use of a continuously or densely graded aggregate will also reduce paste requirements, since the smaller aggregate fills gaps in the larger aggregate. This may require the addition of intermediate aggregates, in addition to the coarse and fine. Uniformly graded or gap-graded aggregates require more paste. Pervious concrete, unlike conventional concrete, uses a uniformly graded coarse aggregate (Mindess et al. 2003: 126–131).

### Fine aggregate

ASTM C33 sets limits for fine and coarse aggregates separately. For fine aggregates, the particle distribution is represented by a fineness modulus (FM), which is the sum of the cumulative percentage retained on seven standard sieves (150 μm–9.5 mm or no. 100–3/8 in), divided by 100. The FM is typically between 2.3 and 3.1, with a smaller number indicating finer sand. FM determines the effect of the fine aggregate on workability, which is important for mixture proportioning (Mindess et al. 2003: 126–131). Traditionally, natural sands have been used for concrete, but where these deposits are being depleted; manufactured sands made from crushed rock are used instead.

Hall et al. (2005: 20–21) suggest instead using a well-graded coarse sand with an FM in the range of 3.1–3.4, particularly with the high cement contents often used in airfield pavement construction. Coarser sands reduce volumetric shrinkage.
Optimized combined aggregate grading

"Aggregate grading research for soils, base, asphalt, and other applications has proven that the best performance is derived from that blend of equidi-
mensional particles that are well-graded from coarsest to finest. Optimum combined aggregate grading is important for portland cement concrete because it minimizes the need for the all-important second mix component—the paste—and has a significant effect on the air-void structure in the paste. The paste volume should be no more than is necessary to provide lubrication during placement and bind the inert aggregate particles together to resist the forces that will affect the mass during its service life... Gap grading (especially at the no. 4 and 8 sieves) and excessive fine sand and cementitious materials content were found to cause problems. Corrections to fill gaps in the aggregate grading led to significant reductions in water, improvements in mobility and finishability, and increases in strength" (Shilstone and Shilstone 2002: 81). The no. 4 and 8 sieves are 2.36 and 4.75 mm, respectively.

Shilstone and Shilstone (2002) discuss aggregate gradation. More detailed information is provided by Shilstone (1990). A key feature of the Shilstone approach is the use of the combined aggregate relationship nomograph, shown in Figure 6.1.

![Figure 6.1 Combined aggregate relationship (coarseness factor) chart. (Courtesy of Shilstone and Shilstone 2002.)](image-url)
The x-axis of the chart represents the coarseness factor of the combined aggregates. This is the percentage of aggregate retained on the 2.36 mm (no. 8) sieve that is also retained on the 9.75 mm (3/8 in) sieve. The y-axis of the chart is the combined aggregate workability factor. This is the percentage of aggregate passing the number 8 sieve, adjusted for cementitious content. To adjust for the cementitious material content, add or subtract 2.5 percentage points on the y-axis for every 43 kg/m³ (94 lb/yd³) of cementitious material more or less than 335 kg/m³ (564 lb/yd³) (Shilstone and Shilstone 2002: 82).

The chart provides a trend bar and five zones. “The diagonal bar is the Trend Bar that divides sandy from rocky mixtures. Zone I mixtures segregate during placement. Zone II is the desirable zone. Zone III is an extension of Zone II for 0.5 in (13 mm) and finer aggregate. Zone IV has too much fine mortar and can be expected to crack, produce low strength, and segregate during vibration. Zone V is too rocky” (Shilstone and Shilstone 2002: 82). Paving concrete should fall into zone II since the coarse aggregate is almost always larger than 13 mm (1/2 in).

Kohn and Tayabji (2003: 63) note that concrete produced with well-graded aggregate combinations will have less water, provide and maintain adequate workability, require less finishing, consolidate without segregation, and improve strength and long-term performance. In contrast, gap-graded aggregate combinations tend to segregate, contain more fines, require more water, shrink more, and impair long-term performance.

Shilstone and Shilstone (2002) pointed out that the coarseness factor chart is a guide. Two other graphics, percent retained on each sieve and the 0.45 power chart, define details not reflected in the three size groupings in the nomograph. Gaps in grading can occur in other sieve sizes such as the 1.18 mm and 600 μm (nos. 16 and 30). Optimized mixtures have produced excellent results for building construction, highways, and airfields.

The maximum density grading or 0.45 power chart is more widely used in asphalt paving than in concrete paving. This relationship may be represented as

$$P = 100 \left(\frac{d}{D}\right)^{0.45}$$ (6.1)

where d is the sieve size in question, P the percent finer than (passing) sieve d, and D the maximum size of aggregate. This may need to be adjusted for aggregate angularity, shape, surface roughness, size, and compaction method (Barksdale, 1991: 3-22–3:23). A gradation that follows Equation 6.1 closely would use the least paste, but would probably need to be modified to allow for workability.

**Lightweight aggregate**

Lightweight aggregates have been used in bridges and buildings to reduce dead load. Since dead load is not significant for pavements, there has not
been perceived to be a benefit to the use of lightweight aggregate. There are, however, potential advantages that have not been traditionally considered.

Some key references on lightweight aggregate concrete are provided by the American Concrete Institute, including ACI 213R-03 Guide for Structural Lightweight-Aggregate Concrete (ACI Committee 213 2003). These documents focus on structural concrete rather than pavement, but they identify some of the desirable characteristics of LWA concrete that also apply to pavements:

- Lower modulus of elasticity, which in pavements translates to less tensile stress (cracking risk) for the same deformation or strain.
- Flexural and splitting tension strengths comparable with conventional concrete.
- Freeze–thaw durability may be equal to or better than that of conventional concrete.
- Reduced risk of alkali–aggregate reactions.
- Some types of LWA provide superior abrasion resistance.
- Typical lightweight aggregates are expanded shales, slates, clays, and similar materials, with dry unit weights of 550–1050 kg/m³ (35–65 lb/ft³) and 5–15% absorption of water by weight. They are heated in rotary kilns and bloat up similar to popcorn (Mindess et al. 2003: 158–159).

In 1963 and 1964, a CRCP lightweight aggregate concrete test section was built on an interstate highway frontage road in Houston, Texas, along with a standard aggregate CRCP test section for comparison. The sections were evaluated in 1974, 1984, and 1988. A 24-year performance survey in Texas found that the CRCP pavements built with lightweight aggregate concrete had relatively less surface distress than standard aggregate sections (Won et al. 1989, Sarkar 1999). At 34 years, another detailed investigation was carried out. The lightweight aggregate section showed high durability, low permeability, and little cracking and spalling (Sarkar 1999).

Research has recently focused on the use of a replacement of a portion of fine normal weight aggregate with saturated lightweight aggregate, which has much higher absorption, in order to improve concrete curing (Bentz et al. 2005). Since pavements have high surface-to-volume ratios and are exposed to the environment, and are thus hard to cure, this concept seems to hold considerable promise for concrete pavement engineering. ACI has published a committee report on benefits and applications of internal curing (ACI Committees 308 and 213 2013).

**Waste materials as aggregates**

As supplies of natural aggregates deplete and landfills fill up, interest in recycling waste materials as aggregates increases. There is a need to proceed
with caution, however, because there would be little benefit to turning our concrete pavements into "linear landfills" with all of the maintenance and performance problems that the term implies.

Solid wastes that have been considered as aggregate for concrete include mineral wastes from mining and mineral processing, blast furnace slags, metallurgical slags, bottom ash, fly ash not meeting class C or F specifications, municipal wastes (including commercial or household), incinerator residues, and building rubble (including demolished concrete). Factors that must be considered when deciding whether to use these materials include economy, compatibility with other materials, and concrete properties. The latter two factors often rule out the use of waste materials (Mindess et al. 2003: 156–158). However, hard mineral wastes and slags offer some potential for improving surface friction if used as fine aggregate.

On occasion, use of recycled materials has led to problems. "Heaving of pavements and a building foundation became progressively worse on a project at Holloman Air Force Base (AFB) NM. The cause of heaving was identified as sulfate attack on recycled concrete used as fill and base course below the buildings and pavements. This recycled concrete came from sulfate-resistant airfield Portland concrete pavement that had existed for decades at Holloman AFB without distress. However, severe sulfate exposure conditions, ready availability of water, the more permeable nature of the crushed recycled concrete, less common thaumasite attack, possible soil contamination as a secondary source of alumina, or some combination of these factors allowed sulfate attack to develop in the recycled material even though it had not in the original concrete pavement" (Rollings et al. 2006: 54).

**Water**

The traditional rule of thumb is that potable water is good for making concrete. It does not, however, follow that nonpotable water cannot be used, although there are limits on dissolved solids and organic material. Seawater should be avoided for any concrete containing reinforcement (Mindess et al. 2003: 115–120). With proper precautions, water recycled as part of ready mix concrete operations may also be used (Taylor et al. 2007: 53–54).

**ADMIXTURES**

Chemical admixtures are used in concrete to affect either the fresh or hardened concrete properties. While a wide variety of admixtures are available to the industry, concrete pavement almost always uses air entraining admixtures, with set-controlling admixtures (accelerators and retarders) and water reducers or plasticizers used under specific circumstances. Additional
information about the use of chemical admixtures in paving concrete is provided by Taylor et al. (2007: 55–60).

**Air entraining admixtures**

Air entraining admixtures are used to protect concrete from damage due to freezing and thawing. Their primary purpose is to develop an entrained air void system of tiny spherical bubbles, 0.05–1.25 mm (0.002–0.05 in) in diameter, throughout the concrete, with an average spacing of no more than 0.2 mm (0.008 in). The air should be 9% of the mortar fraction, or 7.5% of the total concrete volume for 9.5 mm (3/8 in) maximum size coarse aggregate to 4% for 64.5 mm (2½ in) aggregate. This is because the air void system protects the cement paste, and with larger coarse aggregate there is less paste. Air entrainment also makes concrete more workable (Mindess et al. 2003: 168–176).

Concrete pavements are exposed to the environment, and unless the climate makes freezing and thawing very unlikely, air entraining admixtures should be used. Some admixture manufacturers provide products specifically tailored for paving concrete.

**Accelerating admixtures**

Set accelerating admixtures hasten the normal processes of setting and strength development of concrete. Calcium chloride is a popular accelerator because of its low cost, but it has the major disadvantage of increasing the rate of corrosion of reinforcement, tie bars, and dowels. Nonchloride accelerators are available for reinforced concrete applications (Mindess et al. 2003: 185–187). For paving applications, accelerating admixtures are likely to be useful in cold weather or when a pavement repair or overlay must be opened to traffic quickly.

**Set-retarding admixtures**

Set-retarding admixtures delay set, allowing more time for placement, consolidation, and finishing. Subsequent strength development is not significantly affected (Mindess et al. 2003: 182–183). For paving applications, retarding admixtures are likely to be useful in hot weather or when haul distances between concrete production and placement are exceptionally long.

**Water-reducing admixtures**

Three types of water-reducing admixtures are currently available—low range (regular), mid-range, and high range (superplasticers). Low range
water reducers allow 5–10% water reduction, mid-range 10–15%, and high range 15–30%. These materials, particularly the latter, may be used to produce flowing concrete with very high slump (Mindess et al. 2003: 177–181).

Concrete pavements are typically placed at low slump, particularly when slipformed, so flowing concrete is not needed. However, water-reducing admixtures may be used to reduce water content, and thus the amount of cement required to achieve a specific water–cement ratio. A reduction in cement and paste reduces the amount of shrinkage and thermal deformation of the pavement during curing. Some water-reducing admixtures also act as set retarders. Water-reducing admixtures may be useful for fixed form paving or for small areas of hand work.

**COMPATIBILITY OF MATERIALS**

As more different materials are put into concrete, the compatibility of those materials becomes more of an issue. Mindess et al. (2003: 167) note that “effects that the admixtures may have on other concrete properties should be taken into account.” Other admixtures may alter the effectiveness of air entraining admixtures, as may finely divided mineral admixtures such as fly ash (Mindess et al. 2003: 172). Generally, admixtures from the same manufacturer will have been tested for compatibility with each other and are therefore less likely to present problems.

“Some concretes exhibit undesirable characteristics because of incompatibility among different concrete materials. Undesirable characteristics include:

1. Early loss of workability (early stiffening)
2. Delayed set (retardation)
3. Early-age cracking due to excessive autogenous and drying shrinkage of concrete
4. Lack of proper air-void system” (Kohn and Tayabji, 2003: 62).

Early stiffening problems may be attributed to individual cementitious materials, interactions between cementitious materials, admixtures, and temperature effects. The factors that result in incompatibility are poorly understood and difficult to determine through testing, and many problems are triggered by higher or lower temperatures (Kohn and Tayabji 2003: 62–63).

To minimize incompatibility problems, Kohn and Tayabji (2003: 63) recommend using admixtures only from a single manufacturer and keeping dosages under the manufacturers recommended maximums, and using only cementitious materials that meet project specifications and/or ASTM
A number of relatively simple field tests are available to warn of admixtures. Therefore, there is a greater potential for cement–admixtures that use high cement contents and a wider variety and greater quantity of admixtures in hot weather.

The Federal Highway Administration Techbrief (FHWA Techbrief 2006: 1) Protocol to Identify Incompatible Combinations of Concrete Materials defines incompatibility as “interactions between acceptable materials that result in unexpected or unacceptable performance.” Some of the findings on incompatibility include:

- A number of relatively simple field tests are available to warn of potential incompatibility.
- Use of a fly ash containing tricalcium aluminate may result in flash set because of insufficient sulfate to control hydration.
- Some type A water-reducing admixtures accelerate tricalcium aluminate hydration.
- Increasing temperatures increase the rate of chemical reactions and may make marginally compatible material combinations incompatible.
- Use of nonagitating transporters for paving concrete may exacerbate false set problems.
- Conversely, delayed setting increases the risk of plastic shrinkage cracking and makes timing joint sawing more difficult.
- Material chemistry can provide clues—fine cementitious materials with high tricalcium aluminate or low sulfate contents or fly ashes with high calcium oxide contents may cause problems.
- Possible field adjustments to correct problems include adjusting supplementary cementitious material type, source, or quantity; adjusting chemical admixture type or dosage; or changing the batching sequence or mix temperature (FHWA Techbrief 2006, Taylor et al. 2006a, b).

Van Dam et al. (2005) investigated durability of early-opening-to-traffic paving concrete. Because these concretes must typically achieve flexural strength in 6–8 or 20–24 h, based on the construction window available, they use high cement contents and a wider variety and greater quantity of admixtures. Therefore, there is a greater potential for cement–admixture interactions that can lead to later durability problems (Van Dam et al. 2005: 6).

FIBER REINFORCEMENT

Fiber-reinforced concrete has not been widely used for pavements. The exception is bonded concrete overlays and UTW, which have made use of
both steel and synthetic fibers, although synthetic fibers have been much more widely used. Fibers are intended to improve the flexural toughness and fatigue performance of the concrete (ACI Committee 325 2006: 9). The benefits, if any, of using fibers in concrete overlays and pavements have proven difficult to quantify. Fibers are incorporated into light duty pavement design in StreetPave 2 software, reviewed in Chapter 11.

Steel fiber-reinforced concrete has been used to design thinner pavements with longer joint spacings, but this has led to difficulties. “During the 1980s several steel fiber reinforced concrete airfield pavements were built at civil and Navy airfields using the new methodology. These tended to be relatively thin and large (sometimes only 100- to 150 mm (4- to 6 in) thick and 15 or even 30 m (50 and even 100 ft) between contraction joints. There were soon reports of widespread corner breaks at these airfields... the large plan dimension of the slabs relative to their thin cross section required very little differential shrinkage between the top and bottom of the slab to get curling in the field. ... Once opened to traffic, these slabs developed widespread corner breaks” (Rollings 2005: 170–171).