coating to form around the air bubbles. A stable air system typically affects concrete in the following ways:

- Improves workability.
- Increases yield.
- Improves frost resistance.

Water Reducers

Water reducers primarily operate by applying a surface charge to cement particles, which forces them apart so that water trapped between them is freed and they move past each other more easily. Water reducers therefore reduce the amount of water needed to achieve a given workability (see figure 3).

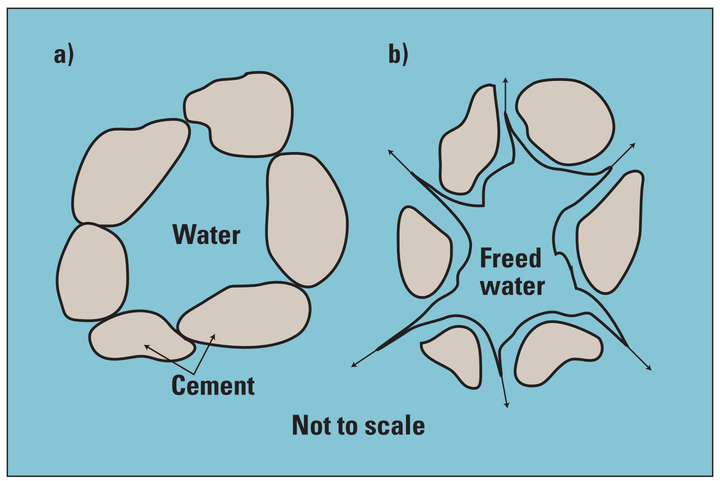

Figure 3. One mechanism by which water reducers work is dispersion. (a) Charged cement particles cling together, trapping water. (b) Water reducers separate cement grains, releasing the water and making it available for hydration.

Set-Modifying Admixtures

Set-modifying admixtures can help regulate setting and strength gain. They can also be useful in fast-track construction and hot- and cold-weather paving:

- Retarders can be used to delay setting during hot-weather paving or under difficult or unusual placement conditions.
- Accelerators can increase early strength gain, which can be useful during cold weather operations.

Material Specifications

Specifications for the materials discussed in this technical summary are listed in table 4.

Table 4. Specifications for Concrete Materials

Material	Specification
Portland cement	ASTM C 150 / AASHTO M 85
Blended cements	ASTM C 595 / AASHTO M 240
Hydraulic cements	ASTM C 1157
Fly ash and natural pozzolans	ASTM C 618 / AASHTO M 295
Highly reactive pozzolans	AASHTO M 321
Ground, granulated blast furnace slag	ASTM C 989 / AASHTO M 302
Silica fume	ASTM C 1240
Mixing water	ASTM C 1602 / AASHTO T 26
Coarse aggregate gradation or particle size distribution	ASTM C 33 / AASHTO T 27 (sieve analysis)
Fine aggregate (sand) gradation	ASTM C 33 / AASHTO M 6

National Concrete Pavement Technology Center

August 2007

This technical summary is based on chapter 3 of the IMCP Manual (Taylor, P.C., et al. 2006. *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual*, Ames, Iowa, Iowa State University [FHWA HIF-07-004] [www.cptechcenter.org/publications/imcp/]) and was sponsored by the Federal Highway Administration. (References for any citations in this summary are at the end of the chapter.)

CP Tech Center Mission

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

For More Information

Marcia Brink, Managing Editor
CP Tech Center, Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103, mbrink@iastate.edu
www.cptechcenter.org/

Center for Transportation Research and Education
Iowa State University

3

A summary of chapter 3 (pages 27–68) of the *IMCP Manual* (reference information on page 4)

Concrete Materials Basics

This document is one of a set of technical summaries of chapters 1 through 10 of the *Integrated Materials and Construction Practices for Concrete Pavements: A State-of-the-Practice Manual* (IMCP manual). Together, these summaries provide a general overview of information in the manual and introduce its important concepts. To be useful as training documents, the technical summaries should be used in conjunction with the manual.

This summary covers chapter 3, basic information about concrete mix materials and the importance of these materials in optimizing pavement performance. Each of four basic materials included in concrete mixtures is defined. Then hydraulic cements are differentiated from pozzolans, common supplementary cementitious materials (SCMs) and chemical admixtures are described, and aggregate properties and selection criteria are summarized.

What Materials Comprise Concrete?

Materials in a concrete mixture include the following:

- Cementitious materials.
- Mixing water.
- Chemical admixtures.
- Aggregates.

Aggregates comprise the majority of the volume of a concrete mix (figure 1).

Why are Materials Important?

The material components of a concrete mixture contribute differently to the overall mix properties. Materials can be used to influence the mix in specific ways. Knowledge of materials' characteristics can be used to design mixes with specific characteristics and make proper field adjustment decisions.

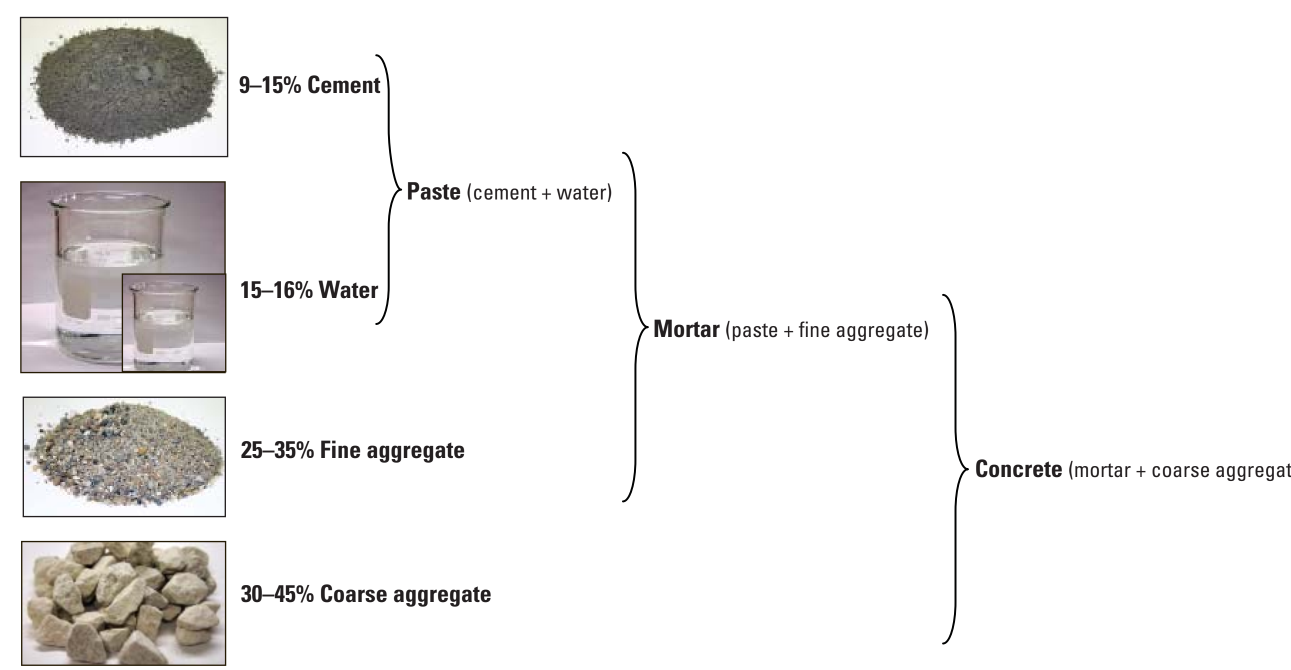

Figure 1. Concrete is basically a mixture of cement, water/air, and aggregates (percentages are by volume).

Cementitious Materials

Various cementitious materials are used in concrete mixtures for pavements. They are generally categorized as *hydraulic cements* or *pozzolans*, depending on how they react with water:

- When hydraulic cements are mixed with water, the cement and water undergo a series of irreversible chemical reactions, a process called hydration. The reactions produce calcium silicate hydrate (C-S-H) and calcium hydroxide (CH), which cause the cement-water paste to set, harden, and gain strength.
- When pozzolans are mixed with water, they, too, can hydrate, but only if calcium is also present. In concrete mixtures, the calcium is provided by a hydraulic cement in the mix. Pozzolans are desirable supplementary cementitious materials (SCMs) because they react with the CH produced during cement hydration to form C-S-H, the compound chiefly responsible for the strength and impermeability of the cement paste.

Portland cement is the most common type of hydraulic cement used in concrete (table 1). Blended cements are a manufactured blend of portland cement and one or more SCMs, including pozzolans (table 2).

Table 1. Portland Cement Classifications (ASTM C 150 / AASHTO M 85)

Type	Description
I	Normal
II	Moderate sulfate resistance
III	High early strength
IV	Low heat of hydration
V	High sulfate resistance

Table 2. Blended Cement Classifications (ASTM C 595 / AASHTO M 240)

Type	Blend
IS	Portland blast-furnace slag cement
IP and P	Portland-pozzolan cement
I(PM)	Pozzolan-modified portland cement
S	Slag cement
I(SM)	Slag-modified portland cement

Supplementary Cementitious Materials

In at least 60 percent of modern concrete mixtures in the United States, portland cement is supplemented with SCMs, including one or more of the following:

- Ground, granulated blast furnace (GGBF) slag.
- Fly ash (Class C or F).
- Silica fume.
- Natural pozzolans.

SCMs are generally categorized as hydraulic or pozzolanic, with some SCMs exhibiting both types of properties (table 3). SCMs can have a variety of effects, depending on the type, amount, and the other materials in the mix. In very general terms, SCMs alter concrete properties in the following ways:

- Reduce the water requirement.
- Reduce heat of hydration.
- Retard setting.
- Retard initial strength gain.
- Increase later strengths.
- Retard and/or reduce bleeding.
- Reduce permeability and improve potential durability.
- Reduce chloride penetration.
- Reduce alkali-silica reactivity expansion.
- Improve sulfate resistance.
- Change cracking risk.
- Change finishing and curing needs.
- May increase rate of stiffening.
- May increase air-entraining admixtures requirement.

Table 3. Cementitious Materials with Hydraulic and Pozzolanic Properties

	Hydraulic	Pozzolanic (or materials with pozzolanic characteristics)
Cements	Portland cement Blended cement	—
Supplementary cementitious materials	GGBF slag Class C fly ash	GGBF Slag Class C fly ash Class F fly ash Natural pozzolans (calcined clay, calcined shale, metakaolin) Silica fume

Substituting SCMs or altering their proportions in a specific mixture can drastically change concrete properties, so trial mixes are needed to verify concrete properties.

Mixing Water

All water contained in the mixture—including that contributed by aggregates and admixtures—must be of adequate quality. Potable water can be used without additional testing.

Impurities contributed by water source can affect strength and time of set. Only use non-potable water after testing the following:

- Time of set.
- Compressive strength.
- Chlorides.
- Sulfates.
- Alkalis.
- Total solids.

Aggregates

Aggregate is relatively stable in regards to chemical and volume changes, making it an important component of concrete mixtures. Aggregate characteristics such as the following can affect the properties of a concrete mixture:

- Gradation.
- Coefficient of thermal expansion (CTE).
- Durability.
- Particle shape.
- Surface texture.
- Absorption.

Gradation

Well-graded aggregate—that is, aggregate with a balanced variety of sizes from fines to coarse aggregates—is desirable because it can affect a concrete mixture in the following ways:

- Maximizes aggregate packing, with smaller particles filling spaces between larger ones.
- Improves workability.
- Reduces paste content and drying shrinkage.
- Reduces a mix's tendency to segregate.

Coefficient of Thermal Expansion

A material's coefficient of thermal expansion (CTE) is a measure of how much it changes in length or volume for a given temperature shift. Because aggregates make up a majority of a concrete's volume, the CTE of the aggregate particles will dominate the overall CTE of a concrete mix. Low CTE values are desirable, because they contribute to lower cracking risk.

Durability

Aggregate can influence a concrete system's long-term durability characteristics. Aggregates should be chosen according to the following desired properties:

- Low alkali reactivity or non-reactive.
- High frost resistance.
- High abrasion resistance.

Particle Shape and Surface Texture

The particle shape and surface texture of aggregates can affect concrete properties in the following ways:

- Rough, flat, or angular particles often reduce workability.
- Angular particles tend to increase the flexural strength of the concrete.

Absorption

The moisture state of the aggregate must be known during batching and adjustments made to maintain the desired water-to-cementitious materials ratio of the mix:

- The ideal moisture state is when the aggregate is saturated, but the surface is dry (SSD) (figure 2). This is the value used in proportioning mixes.
- Aggregates drier than the SSD state will suck water from the mix, reducing workability and increasing early stiffening.
- Wetter aggregates will contribute water to the mix.
- Increasing the water-to-cementitious materials ratio increases shrinkage and reduces strength.

Chemical Admixtures

Chemical admixtures are added to concrete to modify fresh or hardened concrete properties.

Air-Entraining Admixtures

Air-entraining admixtures stabilize millions of tiny air bubbles in the concrete mixture by causing a soap-like

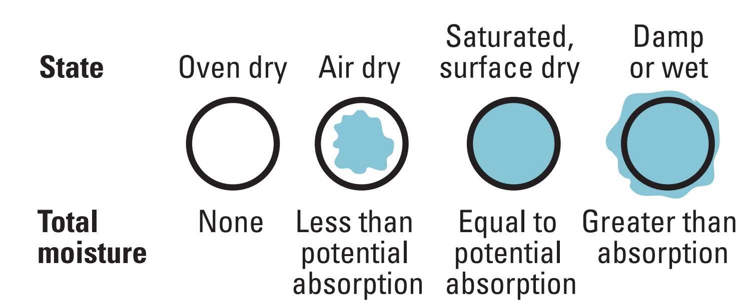

Figure 2. Saturated, surface dry (SSD) is typically the preferable aggregate moisture state.