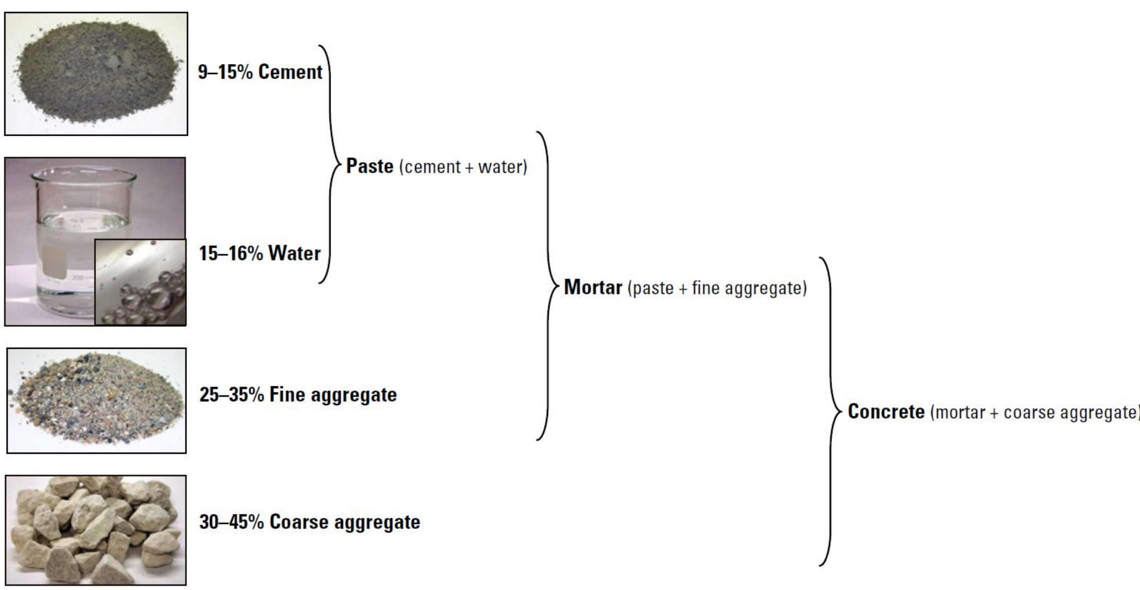
PCC Pavement Mixture Selection

A. General Information

Concrete is basically a mixture of two components, paste and aggregates. Cement and water form the paste, which binds the aggregates, usually sand and gravel or crushed stone, into a solid rocklike mass. The paste hardens due to a chemical reaction of the cement and water, known as hydration. In addition to the basic ingredients, supplementary cementitious materials (SCMs) and chemical admixtures may be included in the paste. This section will introduce the pavement designer to the PCC mixture components and their characteristics and behaviors so the optimum mixture selection for concrete pavements can be determined. It should be noted, the SUDAS Specifications reference the Iowa DOT Specifications for concrete mix materials, design, and proportions.

Figure 5E-1.01: Concrete is Basically a Mixture of Cement, Water/Air, and Aggregates (percentages are by volume)



Sources: Taylor et al, 2006

B. Cementitious Materials

Cementitious materials are classified as either hydraulic cements or pozzolans. The difference between the two is their reaction when mixed with water.

1. **Hydraulic Cements:** Hydraulic cements chemically react with water through a process called hydration. The compounds produced during hydration affect the setting, hardening, and strength gains of hydraulic cement mixtures. The hydration process occurs until the hardening of the concrete is complete and the strength gains have ceased. Portland cement, the most common type of hydraulic cement, contains hydraulic calcium silicates, calcium aluminates, calcium aluminoferrites, and calcium sulfate (gypsum). The reaction of the water being in contact with

the hydraulic cement produces a byproduct of calcium silicate hydrate (C-S-H) and calcium hydroxide (CH). Blended cements, a manufactured blend of Portland cement and one or more supplementary cementitious materials (SCMs), are also hydraulic cements.

a. Types of Hydraulic Cements: As outlined by ASTM C 1157, a performance specification, there are six types of hydraulic cements.

1) **Type GU:** General use
2) **Type HE:** High early strength
3) **Type MS:** Moderate sulfate resistance
4) **Type HS:** High sulfate resistance
5) **Type MH:** Moderate heat of hydration
6) **Type LH:** Low heat of hydration

If an "R" is added after the type name, HE-R, it denotes low reactivity with alkali-reactive aggregates.

b. Types of Portland Cement: There are five different types of Portland cements that are required to meet the specifications of ASTM C 150/AASHTO M 85.

1) **Type I:** Normal
2) **Type II:** Moderate sulfate resistance
3) **Type III:** High early strength
4) **Type IV:** Low heat of hydration
5) **Type V:** High sulfate resistance

c. Types of Blended Cements: Blended hydraulic cements are a combination of two or more types of fine materials. They can be used the same way as Portland cements. Typical materials that are combined are Portland cement and SCMs, including ground granulated blast-furnace slag (GGBF slag), fly ash, silica fume, calcined clay, pozzolans, or hydrated lime. These combinations that make blended hydraulic cements must conform to ASTM C 595 requirements. The two main classes of ASTM C 595 cements are:

1) **Type IS (X):** Portland blast-furnace slag cement
2) **Type IP (X):** Portland-pozzolan cement

The "X" stands for a percentage of the SCM included in the blend. Type IS (40) contains 40% by mass of slag.

d. Selection of Cement: The selection of cement is important when considering which type to use on the job. The main aspect to consider when selecting which cement is right for the job is the availability of cements. Types I and II are available almost everywhere, where Types III, IV, and V are less common in certain areas. Blended cements are available almost everywhere. The Iowa DOT and SUDAS Specifications allow Types I and II cements to be used in pavements, in addition to Types IP and IS blended cements.

2. Pozzolans: Pozzolans do not react when solely mixed with water; they require a source of calcium hydroxide (CH) to hydrate. The most common source of CH comes from the hydration of hydraulic cements, which produces both calcium silicate hydrates (C-S-H) and CH (a less desirable product). When combined with water and CH, pozzolans form additional C-S-H. This additional C-S-H contributes to concrete strength and impermeability of the cement mixtures. Common pozzolans include fly ash, silica fume, and natural pozzolans such as calcined clay, calcined shale, and metakaolin.

Table 5E-1.01: Cementitious Materials

Cementitious Materials

	Hydraulic cements	Pozzolans (or materials with pozzolanic characteristics)
	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

Simple Definitions

Cement (hydraulic cement)—material that sets and hardens by a series of nonreversible chemical reactions with water, a process called hydration.

Portland cement—a specific type of hydraulic cement.

Pozzolan—material that reacts with cement and water in ways that improve microstructure.

Cementitious materials—all cements and pozzolans.

Supplementary cementitious materials—cements and pozzolans other than portland cement.

Blended cement—factory mixture of portland cement and one or more SCM.

Source: Taylor et al, 2006

C. Supplementary Cementitious Materials

Supplementary Cementitious Materials (SCMs) are a common addition to the mix in modern concrete mixtures. SCMs can contribute to the concrete through either hydraulic or pozzolanic activity or both. For example, GGBF slags are hydraulic materials, and Class F fly ashes are typically pozzolanic. Class C fly ash has both hydraulic and pozzolanic characteristics. There are four main types of SCMs are fly ash, ground granulated blast furnace slag (GGBF slag), natural pozzolans, and silica fume.

Fly ash is the most commonly used SCM and includes two types, Class C and Class F. Substituting fly ash in concrete mixes can reduce the amount of water required for workability but delays the setting time of the concrete. The addition of fly ash causes a slower but longer reaction rate in the concrete. As a result, the heat of hydration is reduced, and the setting time of the mix is delayed.

1. **Effects of SCMs:** The addition of SCMs to a concrete mixture affects a wide variety of properties for the concrete. Tables 5E-1.02 and 5E-1.03 indicate the effects of SCMs on fresh and hardened concrete properties. The modified properties include the following:

   a. **Fresh Properties:** Fly ash and GGBF slag increase the workability of the concrete, while silica fume can reduce workability at concentrations greater than 5%.

   b. **Durability/Permeability:** SCMs generally increase the durability of the concrete by reducing the permeability of the concrete mix. As a result, the concrete is less susceptible to chloride penetration. The quality of the SCMs and the work practices of the contractor are important to realize these benefits.

c. Resistance: Alkali-silica reactivity can be controlled with SCMs. The optimum dosage of fly ash has proven to reduce reactivity. Silica resistance is also improved with the addition of SCMs by reducing the reactive elements that contribute to expansive sulfate reactions. Class F fly ash is more effective than Class C, and GGBF slag is beneficial in sulfate environments. SCM content in concretes subject to freezing should not exceed 50%; however, they are still durable if over 50% is used.

Table 5E-1.02: Effects of SCMs on Fresh Concrete Properties

	Fly ash				Natural pozzolans		
	Class F	Class C	GGBF slag	Silica fume	Calcined shale	Calcined clay	Metakaolin
Water requirements	↓↓	↓↓	↓	↑↑	↔	↔	↑
Workability	↑	↑	↑	↓↓	↑	↑	↓
Bleeding and segregation	↓	↓	↕	↓↓	↔	↔	↓
Air content	↓↓ *	↓ *	↓	↓↓	↔	↔	↓
Heat of hydration	↓	↕	↓	↔	↓	↓	↓
Setting time	↑	↕	↑	↔	↑	↑	↔
Finishability	↑	↑	↑	↕	↑	↑	↑
Pumpability	↑	↑	↑	↑	↑	↑	↑
Plastic shrinkage cracking	↔	↔	↔	↑	↔	↔	↔

Sources: Thomas and Wilson (2002b); Kosmatka, Kerkhoff, and Panarese (2003)

* Effect depends on properties of fly ash, including carbon content, alkali content, fineness, and other chemical properties.

Key:
↓ reduced
↓↓ significantly reduced
↑ increased
↑↑ significantly increased
↔ no significant change
↕ effect varies

Source: Taylor et al, 2006

Table 5E-1.03: Effects of SCMs on Hardened Concrete Properties

	Fly ash				Natural pozzolans		
	Class F	Class C	GGBF slag	Silica fume	Calcined shale	Calcined clay	Metakaolin
Early strength	↓	↔	↓	↑↑	↓	↓	↑↑
Long-term strength	↑	↑	↑	↑↑	↑	↑	↑↑
Permeability	↓	↓	↓	↓↓	↓	↓	↓↓
Chloride ingress	↓	↓	↓	↓↓	↓	↓	↓↓
ASR	↓↓	↕	↓↓	↓	↓	↓	↓
Sulfate resistance	↑↑	↕	↑↑	↑	↑	↑	↑
Freezing and thawing	↔	↔	↔	↔	↔	↔	↔
Abrasion resistance	↔	↔	↔	↔	↔	↔	↔
Drying shrinkage	↔	↔	↔	↔	↔	↔	↔

Sources: Thomas and Wilson (2002b); Kosmatka, Kerkoff, and Panarese (2003)

Key:
- ↓ reduced
- ↓↓ significantly reduced
- ↑ increased
- ↑↑ significantly increased
- ↔ no significant change
- ↕ effect varies

Source: Taylor et al, 2006

2. **Limitations on the Use of SCMs:** Table 5E-1.04, which is adapted from ACI 218, provides recommended maximum amounts of SCMs for concrete exposed to deicing chemicals, such as Iowa concrete pavements. The Iowa DOT and SUDAS Specifications limit the usage of SCMs below the ACI maximum amounts. By those specifications, the maximum allowable fly ash substitution rate is 20%, and the GGBF slag substitution rate is limited to no more than 35% by weight (mass). The total mineral admixture substitution rate cannot exceed 40%. When Type IP or IS cement is used in the concrete mixture, only fly ash substitution is allowed.

Table 5E-1.04: Cementitious Materials Requirements for Concrete Exposed to Deicing Chemicals

Cementitious Materials*	**Maximum Percent by Total Cementious Materials by Mass****	
	ACI Values	***Iowa Values***
Fly ash and natural pozzolans	25	20
GGBF slag	50	35
Silica fume	10	0
Total of fly ash, GGBF slag, silica fume, and natural pozzolans	50***	40
Total of natural pozzolans and silica fume	35***	20

* Includes portion of supplementary cementitious materials in blended cements.

** Total cementitious materials include the summation of portland cements, blended cements, fly ash, slag, silica fume, and other pozzolans.

*** Silica fume should not constitute more than 10% of total cementitious materials and fly ash or other pozzolans must not constitute more than 25% of cementitious materials.

Source: Taylor et al, 2006

D. Aggregates

Aggregates account for 60% to 75% of concrete by volume and are seldom susceptible to moisture and chemical changes, making them an important ingredient in concrete mixtures. Aggregates influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. They must be durable and free of any absorbed materials, clay, and materials that effect the interaction with the cement.

1. **Types of Aggregates:**
   a. **Carbonate Rock:** Mainly limestone and dolomite with low porosity and low absorption rate.
   b. **Granite:** Igneous rocks composed mainly of silica and silicates with the highest modulus of elasticity of any rock type available.
   c. **Gravel and Sand:** Typically mixtures of many minerals and rocks. Gravel and sand from shale, siltstone, or unsound material rich rocks tend to be unsound and not recommended. Sand and gravel from higher elevations and that have been smoothed by water are best.
   d. **Manufactured Aggregates:** Produced by crushing rocks into smaller pieces. Least likely to be contaminated, but mixtures with manufactured aggregates tend to be harder to work with and require more water.
   e. **Recycled Aggregates:** Made from crushing concrete pavement and mixed with new aggregates. Typically has a higher absorption rate.

The following aggregate properties are important to consider when mixing concrete: gradation, durability, particle shape, surface texture, absorption, coefficient of thermal expansion, and resistance to freezing and thawing

2. **Gradation:** Gradation is a measure of the size distribution of aggregate particles, determined by passing aggregate through sieves of different sizes (ASTM C 136 / AASHTO T 27). Grading is most commonly shown as the percentage of material passing sieves with designated hole sizes. Aggregates are classified as coarse or fine by ASTM C 33/AASHTO M 6/M 80 as follows:

   a. **Coarse Aggregate:** Coarse aggregate consists of gravel, crushed gravel, crushed stone, or crushed concrete that is retained on the No. 4 sieve. The maximum size of a coarse aggregate is generally 3/8 inch to 1 1/2 inch.
      1) Coarse aggregate requirements allow a wide range in selection.
      2) If the proportion of fine aggregate to total aggregate produces concrete of good workability, the grading for a given maximum size coarse aggregate can be varied moderately without appreciably affecting a mixture's cement and water requirements.
      3) Coarse aggregate size is limited by local availability, the maximum fraction of the minimum concrete thickness or reinforcing spacing, and the ability of the equipment to handle the concrete.

   b. **Fine Aggregate:** Fine aggregate consists of natural sand, manufactured sand, or combinations of the two that pass the No. 4 sieve. Very fine particles (passing the No. 100 sieve) are limited by specifications because they have extremely high surface-to-volume ratios that require more paste.
      1) A relatively wide range in fine aggregate gradation is allowed.
      2) If the water to cementitious materials (w/cm) ratio is kept constant and the ratio of fine to coarse aggregate is chosen correctly, a wide range in grading can be used without a measurable effect on strength.
      3) Generally, increasing amounts of fine material will increase the water demand of concrete.

c. **Well-graded Aggregate:** It is important to maximize the amount of aggregate in concrete mixtures because they are more chemically and dimensionally stable than cement paste. This is done by selecting the best aggregate grading for the job.
   1) Aggregates with a variety of sizes are optimum because smaller particles fill the voids between larger particles, maximizing the aggregate volume.
   2) Aggregate size and grading is important when trying to achieve the preferred water content. Smaller aggregates require more paste because of the high surface to volume ratios, and vice versa.
   3) Mixtures with properly graded aggregates tend to have less permeability and shrinkage, will be easier to handle, and will be the most economical.

d. **Combined Aggregate Grading:** The most important grading in a concrete mixture is the combined aggregate, utilizing the coarse and fine aggregates. Aggregates with a smooth grading curve will generally provide better performance than a gap-graded system.
   1) Research on air-entrained concrete has indicated the w/cm ratio could be reduced by more than 8% using combined aggregate gradation.
   2) If problems develop due to a poor gradation, consider using alternative aggregates, blending aggregates, or conducting a special screening of existing aggregates.

3. **Durability:** Aggregates containing minerals (see Table 3-12 in *Design and Control of Concrete Mixtures*) can react with alkali hydroxides and expand when exposed to moisture, cracking the concrete. Some rock types are potentially susceptible to alkali-silica reactivity (ASR) (shown in Table 3-13 from *Design and Control of Concrete Mixtures*). ASR and alkali carbonate reactivity can be avoided by expansion tests and petrography. Aggregates with coarse surfaces may be susceptible to freeze-thaw damage and cause D-cracking, damaging the concrete. The abrasion resistance of an aggregate indicates the quality; the higher the resistance, the higher the quality. The maximum percent of abrasion allowed for crushed stone is 50% and for gravel is 35% by the Iowa DOT and SUDAS Specifications, as determined according to AASHTO T 96.

   a. **Durability Determination:** Durability of aggregates allowed for use in pavements by the Iowa DOT and SUDAS Specifications is based on service history; geologic correlation; and testing, including abrasion, freeze-thaw, and objectionable materials.

   b. **Durability Classes:** Based on the durability determination, aggregates are designated as follows.
      1) Class 2 Durability: No deterioration of pavements of non-interstate segments of the road system after 15 years and only minimal deterioration in pavements after 20 years of age. Class 2 is the default durability requirement by the SUDAS Specifications for aggregates used in mixes for urban pavements.
      2) Class 3 Durability: No deterioration of pavements of non-interstate segments of the road system after 20 years of age and less than 5% deterioration of the joints after 25 years.
      3) Class 3i Durability: No deterioration of pavements of the interstate road system after 30 years of service and less than 5% deterioration of the joints after 35 years.

4. **Particle Shape:** Aggregate shapes are described as either cubic, flat, or elongated. The use of flat and elongated particles should be limited to 15% the total mass of aggregate in an effort to reduce water demands. Rough textured, angular, and elongated particles require more water to make concrete mixtures smooth and workable. Angular aggregates have higher flexural and compressive strengths along with a higher skid resistance.

5. **Surface Texture:** Different textures may be used in a mixture as long as the mixture is properly proportioned with the varying textures. Rough textures are advantageous because of better

bonding and interlocking. If coarse surfaces are used, the particle sizes should be reduced and drainage should be improved around the base.

6. **Absorption:** It is important to know what state of moisture the aggregates are in during batching so that the w/cm ratio can be adjusted.

   a. Wet aggregates contribute undesired moisture.

   b. Saturated surface dry - neither absorbing water from nor contributing water to the concrete mix - is the ideal moisture level.

   c. An increased w/c ratio increases shrinkage and reduces strength.

   d. Aggregates with high absorption values result in variations of concrete quality.

7. **Coefficient of Thermal Expansion (CTE):** Similar to freeze-thaw resistance, an aggregate's CTE is how much it changes in size during temperature changes. Low CTE values are desirable because their size changes the least and tend to crack less. In Iowa, CTE is generally not a problem because of the prevalent use of limestone aggregate, which has a low CTE as illustrated in Table 5E-1.05.

Table 5E-1.05: Typical CTE Values for Common PCC Ingredients

	Coefficient of Thermal Expansion 10^{-6}/°F
Aggregate	
Granite	4 to 5
Basalt	3.3 to 4.4
Limestone	3.3
Dolomite	4 to 5.5
Sandstone	6.1 to 6.7
Quartzite	6.1 to 7.2
Marble	2.2 to 4
Cement paste (saturated)	10 to 11
Steel	6.1 to 6.7

Note: These values are for aggregates from specific sources, and different aggregate sources may provide values that vary widely from these values.

Source: Taylor et al, 2006

8. **Freeze-thaw Resistance:** The freeze-thaw resistance of aggregates is related to its porosity, absorption, permeability, and pore structure. If too much water is absorbed and the concrete aggregates freeze, the expanding aggregates can potentially destroy the concrete. This degradation of the concrete aggregate is known as D-cracking (see photo below). D-cracking can be reduced by selecting aggregates that have a better freeze-thaw resistance, reducing the maximum particle size, and by installing an effective drainage system to pull water out from underneath the pavement. The use of higher quality aggregates is recommended to increase freeze-thaw resistance. As noted, Class III limestone aggregates will provide greater freeze-thaw resistance than Class II. Some gravel sources will also outperform the Class II aggregates, but the actual freeze-thaw resistance should be verified prior to use.

E. Chemical Admixtures

Any ingredient other than portland cement, supplementary cementitious materials, water, and aggregates is considered an admixture. There are eleven different types of chemical admixtures, the four most common are air-entraining admixtures, water-reducing admixtures, retarding admixtures, and accelerating admixtures. Reasons for using admixtures are to reduce the cost of concrete construction, assist in construction operations, obtain certain properties in concrete, and maintain the quality of concrete over longer periods of time. Admixtures are used to complement acceptable cementing practices and should not be used to substitute them.

1. **Air-entraining Admixtures:** Air-entraining admixtures are the most common type of admixture used. Air-entraining admixtures have the ability to control and entrap air bubbles in concrete, providing the user with a more durable and workable concrete. These admixtures affect concrete by improving freeze-thaw resistance, increasing workability, improving deicer resistance, and reducing sulfate and alkali reactivity.

   Keep in mind for every 1% entrained air, concrete loses about 5% of its compressive strength. The Iowa DOT and SUDAS Specifications require air content of the unconsolidated concrete ahead of the paver to be 8% ± 2%, with the goal to have a minimum of 5% air entrained in the hardened concrete.

2. **Water-reducing Admixtures:** Water-reducing admixtures are implemented to control and reduce the amount of water in a concrete mixture. They typically reduce water content 5% to 10% by sacrificing the reduction of slump. However, strength is increased anywhere from 10% to 25% because of the reduction in the w/cm ratio, and concrete with water-reducing admixtures tend to have good air retention.

3. **Retarding and Accelerating Admixtures:** Retarding admixtures delay the setting time of concrete; therefore decreasing the rate of slump loss and extending the workability of the concrete. The bleeding capacity and rate of concrete is also increased. Retarding admixtures allow more time to place concrete on difficult jobs, allow for special finishing techniques, and offset the adverse effects hot weather has on setting time.

   Accelerating admixtures are used to accelerate the setting of concrete. The accelerating admixtures speed up the hydration process, setting, and strength gains at early ages. Calcium Chloride ($CaCl_2$) is the most commonly used accelerating admixture. It should be added as part of the mixing water.

F. Water

Any drinkable, potable water may be used as mixing water for concrete. ASTM C 1602 provides specifications for using mixing water in concrete mixtures. Sources of water in a concrete mixture come from batch water, ice (if used during high-temp weather), free moisture on aggregate, and water in admixtures.

Any non-potable water may have adverse effects on the strength and set time of the concrete and should be tested for strength, setting time, alkali levels, sulfate levels, chloride levels, total solids, and corrosion of reinforcements

G. Air-entrainment

Air-entrained concrete is used to improve freeze-thaw resistance when exposed to water and deicing chemicals. Air-entrained concrete is produced by using air-entrained cement or by adding an air-entraining admixture. The Iowa DOT and SUDAS Specifications require air content of the unconsolidated concrete ahead of the paver to be 8% ± 2%. The goal is to have a minimum of 5% entrained air in the hardened concrete.

1. **Benefits:** The primary benefits of air-entrained concrete include the following.

   a. Significant improvement of freeze-thaw and deicer-scaling resistance
      1) Air bubbles are created during the entrainment process. The air bubbles allow the pressure of freezing water to be released in air voids instead of in the concrete, which would eventually destroy it. Figure 11-16 in *Design and Control of Concrete Mixtures* demonstrates the improved durability of air-entrained concrete.
      2) Air voids on the surface of the concrete relieve pressure buildups and reduce surface scaling that have detrimental effects on the life of the concrete.

   b. Higher resistance to sulfate and alkali-silica reactivity

   c. Improved workability

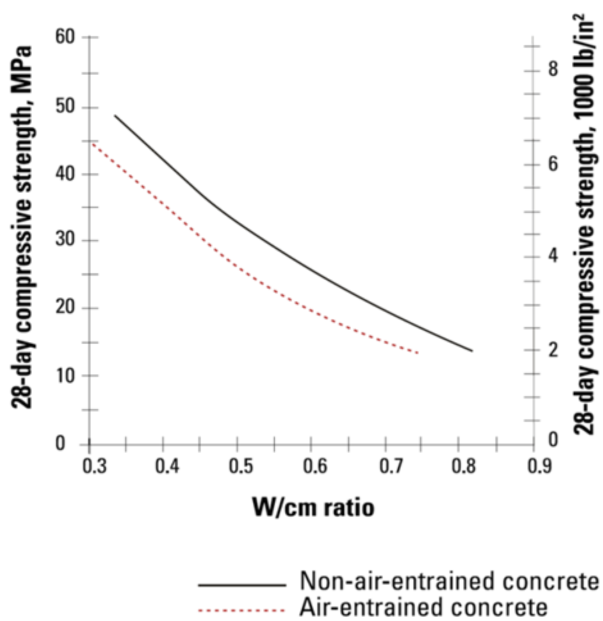
   d. Reduced segregation and bleeding in freshly mixed concrete

2. **Factors that Affect the Air Content:**
   - Cement
   - Aggregates
   - Mixing water
   - Slump
   - Temperature
   - Supplementary cementitious materials
   - Admixtures
   - Mixing acting
   - Transportation and handling
   - Finishing techniques

H. Slump

The slump of concrete is an indicator of the workability and a measurement of concrete consistency. Slump is not an indicator of the quality of the concrete. The slump of concrete is affected by changes in aggregates, cements, admixtures, water, and air. Workability, along with air content, is one of the primary concrete properties that can be manipulated during the process. Keep in mind that adding water to the mix will increase the w/cm ratio and lower the strength of the concrete. The SUDAS Specifications require that slump be no less than 1/2 inch or no more than 2 1/2 inches for machine finish and no less than 1/2 inch and no more than 4 inches for hand finish. Figure 5E-1.02 is an example of the strength values for mixes with differenct w/cm ratios; the higher the w/cm ratio, the lower the strength.

Figure 5E-1.02: Effect of w/cm Ratio on Strength of Concrete



I. Concrete Mixtures

1. **Concrete Mix Design and Mix Proportioning:** The terms mix design and mix proportioning are often incorrectly used interchangeably.

   a. **Mix Design:** Mix design is the process of determining required and specifiable properties of a concrete mixture, i.e., concrete properties required for the intended use, geometry, and exposure conditions. Workability, placement conditions, strength, durability, and cost should be considered in concrete mix designs.

   b. **Mix Proportioning:** Mix proportioning is the process of determining the quantities of concrete ingredients for a given set of requirements. The objective of proportioning concrete mixtures is to determine the most economical and practical combination of readily available materials to produce a concrete that will have the required properties.

2. **Concrete Mix Specifications:** There are two types of concrete mix specifications, prescriptive and performance mixes. With prescriptive mixes, the materials, proportions, and construction methods are specified, and satisfactory performance is anticipated. If performance requirements are utilized, functional requirements, such as strength, durability, and volume changes are specified, and the contractor and concrete producer are expected to develop concrete mixtures that meet those requirements.

   a. **SUDAS Concrete Mix Design Specifications:** The SUDAS Specifications for PCC pavement refer to the Iowa DOT's PCC pavement specifications and materials instructional memorandums (I.M.s) for concrete mix designs, proportions, and materials. Iowa DOT mixes are prescriptive and include specifications for concrete mix materials, proportions, and construction methods. There are no concrete performance requirements, and satisfactory performance is expected if all specifications are followed.

   b. **SUDAS Concrete Mix Material Specifications:** SUDAS references the Iowa DOT Specifications for concrete mix material, including the following.

Material	Iowa DOT Specifications Section	Iowa DOT Materials I.M.
Cement	4101	401
SCMs		
Fly Ash	4108	491.17
GGBF Slag	4108	491.14
Fine Aggregate	4110	409 (Source)
Coarse Aggregate (3 gradations)	4115	409 (Source)
Water	4102	
Admixtures		
Air entrainment	4103	403
Retarding and water reducing	4103	403
Accelerating (calcium chloride)	2529.02	403

c. SUDAS Concrete Mix Proportioning Specifications: The concrete mixes currently used in Iowa were developed in the 1950s. Classes A, B, and C were specified for concrete paving. As originally developed, Classes A and B, with minimum design compressive strengths of 3,500 psi and 3,000 psi respectively, were utilized for rural county paving. Class C concrete, with a higher compressive strength of a minimum of 4,000 psi and a w/cm ratio of less than 0.45, was the standard for primary roads. With its history of proven performance, Class C concrete is now the standard for all concrete road paving in Iowa. In areas where early opening strength is desired, such as intersections and driveways, an M mix can be substituted for C mix. M mix has a higher cement content, which accelerates the heat of hydration and set time of the concrete.

Unless the designer otherwise specifies, the contractor can choose any of the Iowa DOT Class C mixes and the materials that are allowed within the specifications. Generally, economy, workability, and availability of materials are key factors in the decision making process of the contractor and the concrete supplier.

Iowa DOT Materials I.M. 529 establishes the mix proportions for the various concrete mixes used by the Iowa DOT and SUDAS. Each mixture has specific requirements for the coarse and fine aggregates as well as the type of cement, including SCMs. The mix proportions include unit volumes for all materials.

If the concrete mix for a project is specifically needed to address joint durability, consideration should be given to the C-SUD mixes that are included in Table 4 of Iowa DOT Materials I.M. 529. Two main differences highlight these mixes. The first is the water-cement ratio. Using a lower water-cement ratio will create lower paste permeability and higher strength. The basic w/c ratio is 0.40 with the maximum set at 0.42. In addition to the w/c ratio, use of pozzolanic materials (SCMs) for substitution of cement will improve freeze-thaw durability in the presence of deicers. Consideration should be given to provide cement replacement rates of 20-25% Class F fly ash or 30-35% Class C fly ash or a combination of 20% slag and 20% Class C fly ash.

1) Mix Designation:

Example: C-4WR-S35

- The first letter indicates the class of concrete
- The first number indicates the percentages of fine aggregate and coarse aggregate
  - 2 is composed of 40% fine and 60% coarse
  - 3 is composed of 45/55
  - 4 is composed of 50/50
  - 5 is composed of 55/45
  - 6 is composed of 60/40
  - 7 is composed of 65/35
  - 8 is composed of 70/30
  - 57 is composed of 50/50
- The WR indicates water reducer is used in the mixture
- SCMs are then indicated with their percentage of cementitious material substitution. C and F fly ashes are indicated with a C and F, respectively. GGBF slag is indicated with an S. The percentage of substitution is indicated after the SCM letter.
- The example designates a Class C concrete mix, a combined aggregate composed of 50% fine aggregate and 50% coarse aggregate, water reducer admixture, and 35% GGBF slag cementitious material substitution.

2) **Mix Proportions:** Iowa DOT Materials I.M. 529 provides material proportioning for the various Iowa DOT concrete mixes and includes basic absolute volumes of cement, water, air, and fine and coarse aggregate per unit volume of concrete (cy/cy). Target and maximum w/cm ratios are provided for each of the mix classes. Also included is guidance for calculation of fly ash and GGBF slag cementitious material substitution of cement.
3) **Admixtures:** Sources of Iowa DOT approved admixtures are provided in Iowa DOT Materials I.M. 403, along with their maximum dosages. Generally, the maximum dosages are as recommended by the manufacturers. Do not exceed the maximum dosages according to the manufacturer's recommendations.

3. Modification of the Standard Concrete Mix Specifications: While care should be exercised, achieving the required properties in the concrete may require making adjustments to the materials selected, to materials proportions, or even to other factors such as temperature, as follows.

a. Workability: Water content, proportion of aggregate and cement, aggregate properties, cement characteristics, admixtures, and time and temperature can be adjusted to achieve the desired workability. The slump test (ASTM C 143 / AASHTO T 119) is most often used to measure the workability of fresh concrete.

b. Stiffening and Setting: The rates of stiffening and setting of a concrete mixture are important because they affect its ability to be placed, finished, and sawed. Stiffening and setting can be affected by the following in the concrete mixture: cementitious materials, chemical admixtures, aggregate moisture, temperature, and water-cementitious materials (w/cm) ratios.

c. Bleeding: Techniques can be used to prevent and minimize bleeding. These techniques (Kosmatka 1994) include reducing the water content, w/cm, and slump; increasing the amount of cement or supplementary cementitious materials in the mix; increasing the fineness of the cementitious materials; using properly graded aggregate; and using certain chemical admixtures such as air-entraining agents may reduce bleeding.

d. Air-void System: The air-void system is important to concrete durability in environments subject to freezing and thawing. It includes total air content, spacing factors, and specific surface. The air-void system can be controlled with cement, supplementary cementitious materials, aggregates, and workability. The air-void system in the field will be affected by changes in the grading of the aggregate, water, admixture dosage, delays, and temperature.

e. Density: Conventional concrete used in pavements has a density in the range of 137 to 150 lb/yd^3. Density varies depending on the amount and density of the aggregates, the amount of entrained air, the amount of water, and the cement content. Density is affected by the following factors: density of the material in the mixture, mostly from coarse aggregates; moisture content of the mixture; and relative proportions of the materials, mainly water.

f. Strength: Strength and rate of strength gain are influenced by water-cementitious materials ratio, cement chemistry, SCMs, chemical admixtures, aggregates, and temperature. Changes in the environmental conditions and variation in materials, consolidation, and curing affect the strength at a specified age and affect strength development with age. Increased temperatures will increase early strength but may decrease long-term strength gain.

g. Volume Stability: Concrete experiences volume changes as a result of temperature and moisture variations. To minimize the risk of cracking, it is important to minimize the tendency to change in volume by considering paste content, aggregates, and curing.

h. Permeability and Frost Resistance: Permeability is a direct measure of the potential durability of a concrete mixture. Lower permeability is achieved by the following factors.

- Increasing the cementitious materials content
- Reducing the water-cementitious materials ratio
- Using supplementary cementitious material at dosages appropriate to the expected likelihood of freezing water
- Using good curing practices
- Using materials resistant to the expected form of chemical attack
- Using aggregates that have proven to resist D-cracking. Reducing maximum coarse aggregate size will reduce the risk of damage if aggregates prone to damage are unavoidable.
- Ensuring that a satisfactory air-void system is provided

J. References

Kosmatka, S.H., B. Kerkhoff, W.C. Panarese. *Design and Control of Concrete Mixtures*. EB001.14. Skokie, IL: Portland Cement Association. 2002.

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Weiss, J., Ley, M.T., Sutter, L., Harrington, D., Gross, J., Tritsch, S. *Guide to the Prevention and Restoration of Early Joint Deterioration in Concrete Pavements*. National Concrete Pavement Technology Center/Institute for Transportation, Iowa State University. 2016.