



A summary of chapter 6 (pages 171–190) of the *IMCP Manual* (reference information on page 4)

- Air content.
- Material proportions, especially water.

Stiffening and Setting

Stiffening and setting can be affected by the following aspects of a concrete mixture:

- Cementitious materials (cement content, chemistry, and fineness influence rate of stiffening).
- Chemical admixtures (retarders and accelerators can help control this process).
- Temperature (high temperatures accelerate hydration and can increase the risk of incompatibility issues).

- Water-cementitious materials ratio (lowering the ratio reduces set time).

Strength

Strength and rate of strength gain are affected by the following factors:

- Water-cementitious materials ratio ratio (lowering the ratio increases strength).
- Cementitious materials chemistry.
- Admixture type and dosage.
- Type and dosage of supplementary cementitious materials.

Development of Concrete Mixtures

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). The summaries provide an overview of the manual and introduce its important concepts. To be useful for training, the summaries should be used in conjunction with the manual.

This document summarizes the basic elements of concrete mix design, including the selection of appropriate materials, the optimization of mix proportions, and the process of evaluating and adjusting trial mixes.

What is Mix Design?

Mix design is the process of determining the required properties of a concrete mixture.

Why is Mix Design Important?

Mix design aims to balance out the following characteristics in order to obtain an optimum mix for a specific project:

- Uniformity.
- Constructability (for particular placement conditions).
- Strength.
- Durability.
- Economy.

What is Mix Proportioning?

Mix proportioning determines the appropriate quantities of materials needed to meet the design characteristics.

Calculating Mix Proportions

Mix calculations center around the critical components of water, cementitious materials, and aggregates. The approach provided below is based on the volumetric method, ACI 211.

Determining Total Water Content and Ratio

The water-to-cementitious materials (w/cm) ratio should be as low as is reasonable. In determining a mixture's ideal w/cm ratio, consider the following principles:

- Reducing the w/cm ratio places cement grains closer together, reducing voids and thereby improving strength and permeability.
- Below about 0.40, there is not enough water in the system to hydrate all the cement.

Water content required for a mix depends on the following factors:

- Amount of cementitious materials.
- Type(s) of supplementary cementitious materials (SCMs).
- Aggregate gradation and aggregate water requirement.
- Air content (air-entrained concrete requires less water than non-air-entrained concrete).
- Admixture choice and quantity (can reduce the required water content directly or by altering the air content).
- Slump requirements.
- Concrete temperature.

Determining Cementitious Materials Content

Calculate the required amount of cementitious materials as follows:

- In general, this is equal to the required water content divided by the w/cm ratio.
- It is not uncommon for minimum cement content to be specified for a particular job.

Choose type(s) of SCMs in accordance with the following principles:

- SCMs are often selected early in the mix design process, since SCMs affect other calculations.
- Selection of SCMs is based on the following:
 - Maximizing durability.

National Concrete Pavement Technology Center



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This technical summary is based on chapter 6 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.)

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- Achieving appropriate economy.
- Maximizing strength.
- Meeting other special requirements (such as alkali-silica reactivity, sulfate resistance, low permeability, or low heat).

Determining Admixture Content

Water reducing admixtures are used to achieve or alter the required amount of water. Air-entraining admixtures are often used to attain specific air-void system parameters, including the size of individual air voids and the spacing between them. Dosages are based on the performance of the product and the required properties of the concrete.

Determining Aggregate Content and Gradation

Aggregate comprises the majority of the volume of a concrete mixture. Aggregate gradation and the aggregate-paste ratio are important characteristics to consider in developing a mixture.

Paste-aggregate proportioning

The proportions of aggregate sizes, total aggregate contents, and total paste content are chosen to achieve the required fresh and hardened concrete properties. Guidelines for optimizing paste-to-aggregate ratio are as follows:

- Minimizing paste content can reduce heat and shrinkage issues.
- Enough paste must be included to fill all voids and adequately coat the aggregates.
- Well-graded aggregate limits particle voids, allowing workability to be achieved with as little paste as possible.
- High aggregate content helps minimize paste quantity.
- A high fines content requires more water, leading to more shrinkage.

Aggregate gradation

Combined aggregate must be well-graded and consistent between batches.

Well-graded aggregate contains a good balance of different-sized aggregate. The smaller particles fill the voids between larger particles. This maximizes the aggregate volume in the mixture, optimizes the amount of paste (and thus water) required to coat the particles, and generally results in less shrinkage and permeability.

Consistent grading helps ensure uniformity between batches and thus consistent performance of the pavement.

ASTM C 136-04 / AASHTO T 27 and ASTM C 33 / AASHTO M 6/M 80 provide a good starting place for selecting well-graded combined aggregate. However, finetuning is generally required. Shilstone recommends

three tools for analyzing combined aggregate gradation:

- The Coarseness Factor Chart (figure 1) provides an overview of a mixture's workability based on aggregate gradation.
- The 0.45 Power Chart (figure 2) provides a method for comparing the amounts of aggregate of various sizes to the amounts in an "ideal" combined aggregate.

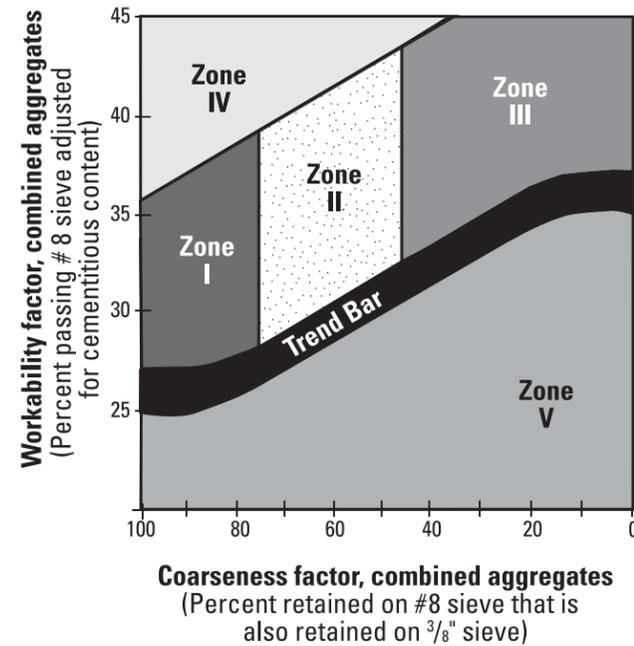


Figure 1. Shilstone's Coarseness Factor Chart helps mix designers balance aggregate coarseness with workability. Optimum mixtures fall within zones II and III.

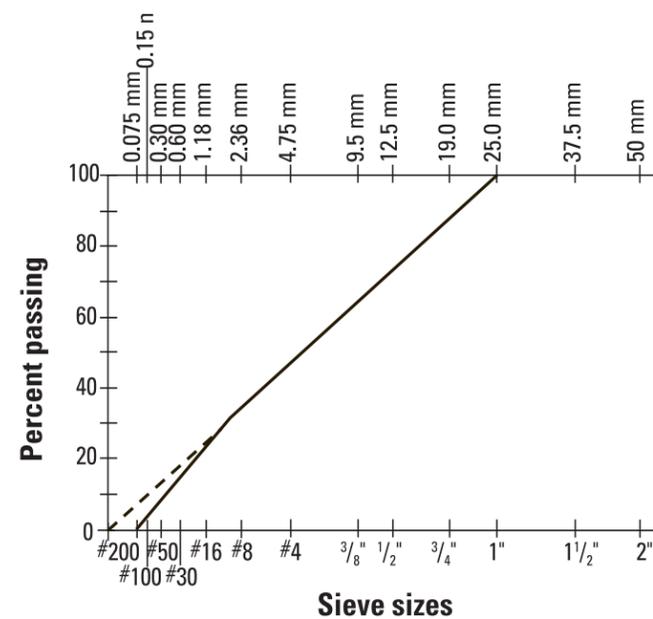


Figure 2. Shilstone's 0.45 Power Chart can be used to describe an ideal aggregate gradation. Deviations from this line identify deviations from the optimum.

- The Percent of Aggregate Retained Chart (figure 3) provides a method for graphing the distribution of various sizes of aggregate in a combined aggregate. Deficiencies of specific sizes plot as gaps on the chart.

Since each of these tools provides a different type of analysis, all three should be used together to provide an overall analysis of the combined gradation.

Testing Mixes

Desktop calculations of mix proportions provide a starting point, but trial batches must be prepared and evaluated.

- Are the fresh properties acceptable for the type of equipment and systems being used?
- Are there signs of incompatibilities?
- Are the strengths from the field mix comparable to those from the laboratory mix (+-1.7 MPa [250 lb/in²])?

Adjusting Mixes

Following are examples of properties that may need to be adjusted, with lists of possible adjustments.

Workability

To improve workability, the following mix adjustments can be made:

- Increase water content (reduces strength, increases permeability, increases shrinkage, and may increase segregation).
- Add water-reducing or air-entraining admixtures (with some water-reducers, workability improvements are relatively brief).
- Reduce aggregate-to-cement ratio (may become sticky and difficult to finish if too much cement is used).

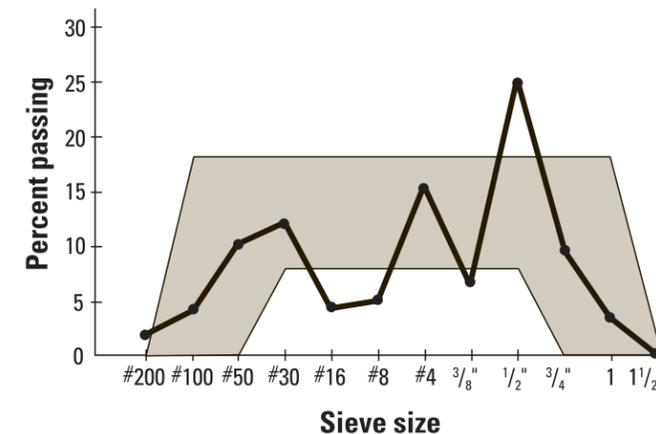


Figure 3. Plotting aggregate sizes on Shilstone's Percent of Aggregate Retained Chart can reveal unwanted gaps in particle sizes.

- Substitute smoother, more spherical aggregates.
- Reduce ambient temperature.

Bleeding

To reduce bleeding, the following mix design adjustments can be made:

- Reduce water content, w/cm ratio, and slump by increasing the amount of cement or SCMs.
- Increase fineness of the cementitious materials.
- Increase aggregate fines.

In addition, some air entraining agents may reduce bleeding.

Air-Void System

The air-void system of concrete, which is important for achieving freeze-thaw durability, can be controlled with the following mix adjustments:

- Increase the dosage of air-entraining admixtures.
- Increase workability.
- Increase the fine aggregate content, especially the amount of material retained on the 600- to 300- μ m (#30 to #50) sieves, to increase air entrainment.
- Increase large-size aggregate to decrease the air content requirement.

Volume Stability

The following techniques can increase the volume stability of a mixture and thus minimize the risk of cracking:

- Keep total coarse aggregate content as high as possible to minimize paste content.
- Avoid aggregates that have high drying shrinkage properties or excessive amounts of clay.

Permeability (Durability)

Permeability directly influences the potential durability of a concrete pavement system. Durability can be improved by making the following adjustments:

- Reduce w/cm ratio within limits (0.37–0.45).
- Consider using supplementary cementitious materials.
- Use aggregates resistant to D-cracking and reduce maximum coarse aggregate size.
- Use nonreactive aggregates or apply mitigating methods.
- Follow good curing practices.
- Provide a satisfactory air-void system.

Density (Unit Weight)

The density (unit weight) of conventional concrete is typically 2,200 to 2,400 kg/m³ (137 to 150 lb/ft³).

Density is influenced by the following factors:

- Density of materials in the mixture, especially aggregates.
- Aggregate moisture content.