CP ROAD MAP
shaping the future of **concrete pavement**

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ROAD MAP TRACK 1
Performance-Based Concrete Pavement Mix DesignSystems

PRIMARY SOURCE
From Concrete Mixture Design to Mixture Proportioning and Analysis with the FHWA COMPASS Software
J. Mauricio Ruiz and Sabrina I. Garber (from the International Conference on Optimizing Paving Concrete Mixtures and Accelerated Concrete Pavement Construction and Rehabilitation, Nov 7-9, 2007)

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Moving Advancements into Practice (MAP) Briefs describe promising technologies that can be used now to enhance concrete paving practices. MAP Brief 1-1 provides information relevant to Track 1 of the CP Road Map, Performance-Based Concrete Pavement Mix Design Systems.

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by TPF-5(185).

MAP Brief 1-1 is available at: http://www.cproadmap.org/publications/ MAPbrief1-1.pdf

"Moving Advancements into Practice"

MAP Brief 1-1:

Describing promising technologies that can be used now to enhance concrete paving practices

Job-Specific Optimization of Paving Concrete with COMPASS (Concrete Mixture Performance Analysis System)

Introduction

A number of factors including project-time constraints; demand for longer pavement design-lives; transfer of mixture proportioning responsibilities to the paving contractor; and environmental, social, and economic considerations are forcing the concrete paving industry to come up with new ways to proportion and optimize their concrete mixtures. In addition, a larger number of concrete materials choices are available today that add complexity to the mixture proportioning process.

The Problem

In the past, the concrete mixture design and proportioning process was guided by prescriptive specifications, which included only a few criteria such as slump, air content, and 28-day strength. Years of experience with local materials and environmental conditions guided the concrete paving industry in making appropriate "intuitive" adjustments for optimal handling, necessary performance, and reasonable cost. However, times are changing, and the mixture design and proportioning process is becoming more complicated as science and technology are revolutionizing the concrete industry, and as the public demands faster-built, better-performing pavements.

The complications are enhanced by an increasing array of chemical admixtures; a variety of aggregate sources, cement types, and supplementary cementitious materials; and the compatibility of these different materials within a concrete mixture and in a given environment.

These complications make it practically impossible for the mixture design and proportioning process to continue to be "intuitive."

Furthermore, there has been a recent shift of responsibility from state agencies to private contractors for the design and proportioning of concrete mixtures and a trend toward the use of warranties, which make concrete producers liable for the performance of their materials. This shift makes "intuitive" mixture proportioning much too risky for contractors (see Figure 1).

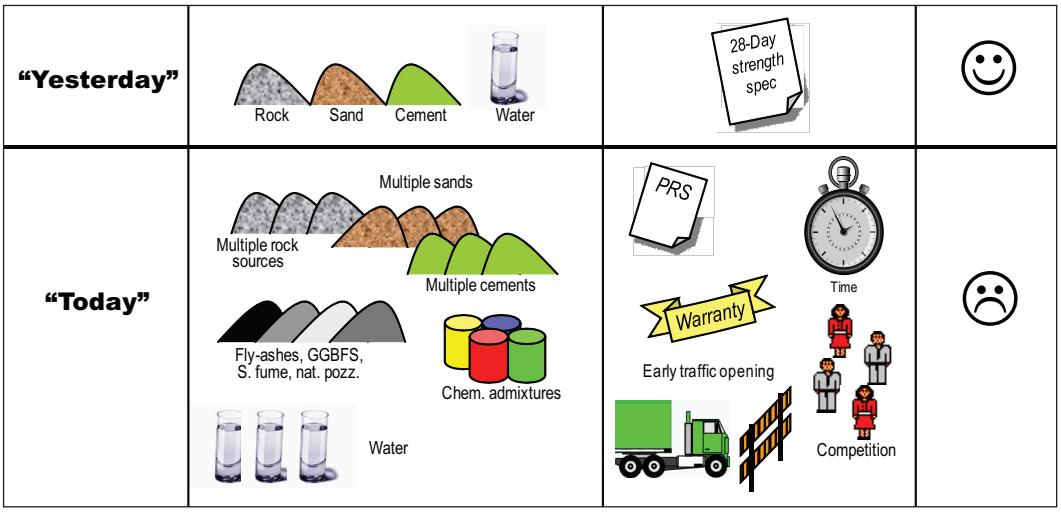

Figure 1. Concrete paving materials and mixture design requirements

A Solution

What, then, is the answer? The industry needs a concrete mixture optimization tool that can isolate properties of interest and simplify the approach to the mixture proportioning process based on site-specific conditions.

In response to this need, the Federal Highway Administration (FHWA) developed the Concrete Mixture Performance Analysis System (COMPASS), a windows-based application system that uses a proven statistical optimization approach and includes many practical features and analysis techniques to help users optimize concrete mixtures.

With COMPASS, a user can optimize the performance of a concrete mixture in a particular environment by properly selecting material constituents, such as types of aggregates, cementitious materials, and admixtures, that will benefit properties identified as important to a particular environment, project type, and degree of importance of the project.

The user can also determine the appropriate gradation and material constituent proportions that will enhance the performance of a mixture. The user can then take the guidance offered by COMPASS and apply it to the optimization of mixture proportions.

The COMPASS System

COMPASS employs statistical analysis to define an experimental design, then prompts the user for results of performance tests that are executed on each of the experimental batches. Response surface models are then developed to predict performance of the concrete mixture as a function of mixture proportions. Optimal mixtures are obtained by assigning desirability functions to the various performance measures and then seeking the maximum desirability.

The goal of the COMPASS system is to optimize concrete pavement based on site-specific conditions. To achieve this, COMPASS helps the user do the following:

- Identify job-specific factors relevant to the mixture design process, such as the importance of the project, type of pavement, climatic conditions, construction constraints, and environmental exposures.
- Identify applicable mixture performance criteria and recommended test methods.
- Assess the impact that changes in materials or proportions, environmental conditions, and construction procedures have on portland cement concrete (PCC) constructability and performance.
- Perform aggregate blending.
- Establish initial mixture proportions.
- Optimize mixture proportions based on multiple job-specific criteria, such as strength, cost, and permeability.

The COMPASS system includes two key components that work together in achieving its goal: a Knowledge Base and Computerized Optimization Modules.

Knowledge Base

The purpose of the Knowledge Base is to be interactive by supplying a databank of accredited information and respective references that can be accessed, filtered, and logically presented to the user. The Knowledge Base is a compilation of information on concrete properties, testing methods, materials characteristics, compatibility of materials with one another, and compatibility of materials with the environment. The Knowledge Base is consistent with the Integrated Materials and Construction Practices for Concrete Pavements (IMCP) manual, developed by the National Concrete Pavement Technology Center.

Computerized Optimization Modules

The computer modules allow the user to conduct the analytical tasks necessary to optimize a concrete mixture based on job-specific inputs and criteria. There are four modules:

1. Mix Expert.
2. Gradation.
3. Proportioning.
4. Optimization.

When using the COMPASS software, these modules are listed on the left-hand side of the screen, as shown in Figure 2. Also shown in Figure 2 is a "Tip of the Day" statement randomly generated by the Knowledge Base. The statement changes each time the software is opened.

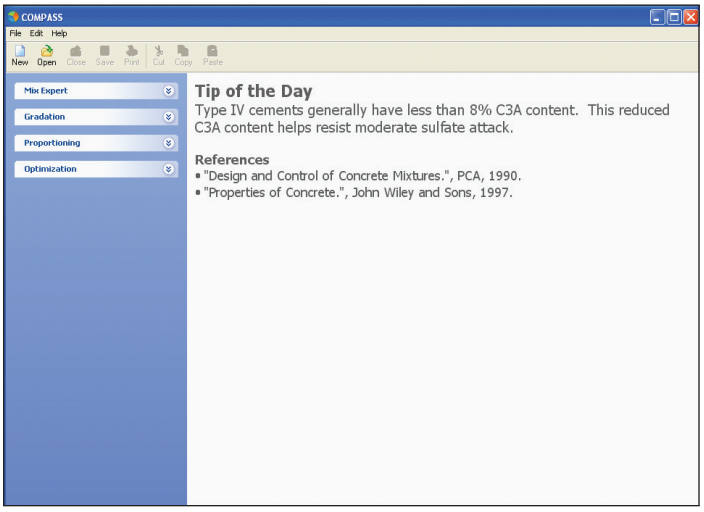

Figure 2. Opening screen for COMPASS software

Each module has the ability to be used as a stand-alone tool. Alternatively, the user can perform a comprehensive analysis by executing the four modules in order and building upon each consecutive module's analysis results. The flow for the comprehensive analysis is depicted in Figure 3 and is briefly defined as follows:

1. Identify the performance criteria relevant to job- and site-specific conditions, and select materials that best suit the conditions using Module 1 – Mix Expert.

2. Determine aggregate gradations for optimal packing density and workability using Module 2 – Gradation.

3. Determine preliminary mixture proportions using Module 3 – Proportioning.

4. Optimize the concrete mixture proportions based on job-specific criteria using Module 4 – Optimization.

Mix Expert

Mix Expert generates guidance for the user by cross-referencing the inputs with the information in the Knowledge Base. Based on the user's inputs for construction type, environmental conditions, and materials available for use, Mix Expert helps the user identify performance criteria that should be considered and materials to use (or not use) in order to optimize pavement performance. See Figure 4 for an illustration of this process.

Gradation

The Gradation module guides the user in combining and optimizing a blend of aggregates. The blend can include more than two aggregate sources. The user can choose one of three mathematical models (Toufar, De Larrard, or Dewar) to optimize a blend, or can instead manually adjust proportions. Results of blended proportions are presented in several ways, including calculations for voids ratio, packing, coarseness factor, 0.45 power, and percent retained ("8-18") charts, as seen in Figure 5. By optimizing aggregate gradation, the user is able to increase durability, strength, and workability.

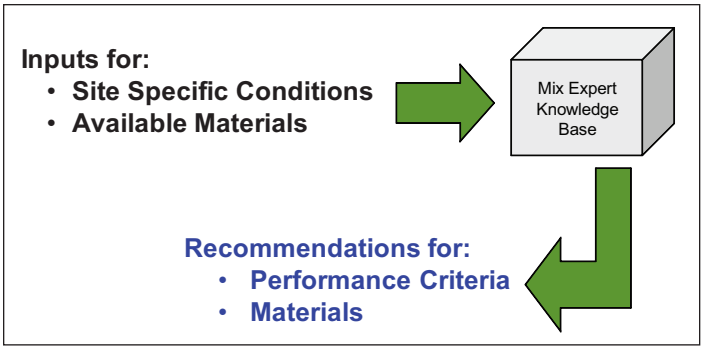

Figure 4. Process used in the Mix Expert module

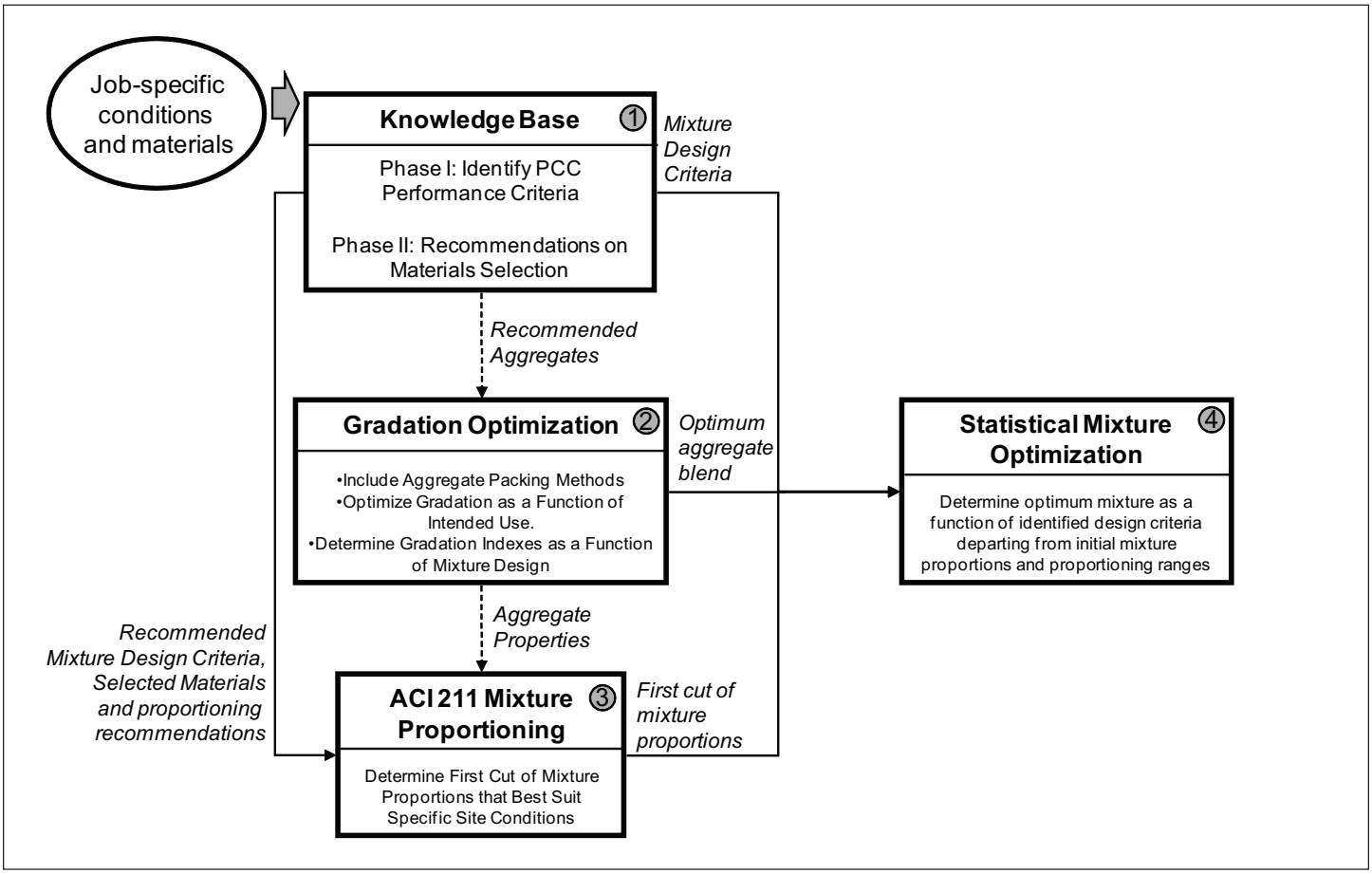

Figure 3. Comprehensive analysis framework used by COMPASS

Proportioning

The Proportioning module guides the user through the mixture design process and allows the user to design a mixture that incorporates up to four aggregate sources. The user can quickly make a first cut of proportions based on user inputs for strength, slump, and air content criteria. These proportions can then be refined to consider the effect certain constituents (e.g., fly ash and admixtures) may have on water content requirements.

Inputs for aggregate characteristics such as moisture content and absorption are also required for this module, which allows the user to adjust proportions based on aggregate moisture content.

Optimization

The Optimization module guides the user through a two-step process that includes the following:

1) Identifying a list of trial batches based on selected material constituents and proportioning ranges.

2) Performing an optimization analysis of mixture proportions based on user-defined, job-specific criteria.

In this module, COMPASS recommends a set of trial batches for testing of performance criteria important to the project. Testing of performance criteria can be accomplished through lab testing, virtual batching (mixture performance predictive models), or a combination of both.

With this information, COMPASS develops response surface models to predict concrete performance as a function of mixture proportions. COMPASS then produces an expanded list of mixture proportions within selected proportioning ranges and identifies a ranked list of optimal mixtures that best meet criteria based on user-defined desirabilities. Selected optimal mixtures are then tested to ensure they meet the user's real-world needs.

The advantage of using the Optimization module is that it makes trial batching more efficient by minimizing the need for trial-and-error testing.

Applications

The COMPASS optimization system can prove useful to both pavement engineers and paving contractors. COMPASS can assist engineers in choosing and quantifying mixture design criteria appropriate to a specific job. COMPASS can also be helpful in iterations between structural design and mixture design selections (e.g., evaluating a structural design requirement such as strength or shrinkage for a given concrete paving mixture).

Contractors can benefit from COMPASS by meeting given constraints (criteria) with their mixtures, ensuring that the mixture is workable and durable while at the same time minimizing cost. COMPASS can also be beneficial for ready-mix suppliers who are looking to improve their mixture proportions, for admixture suppliers who advise customers on ways to optimize their mixtures, and for instructors who want a hands-on tool for teaching the intricacies of mixture design and proportioning.

To access the COMPASS software, visit http:// www.PCCMix.com.

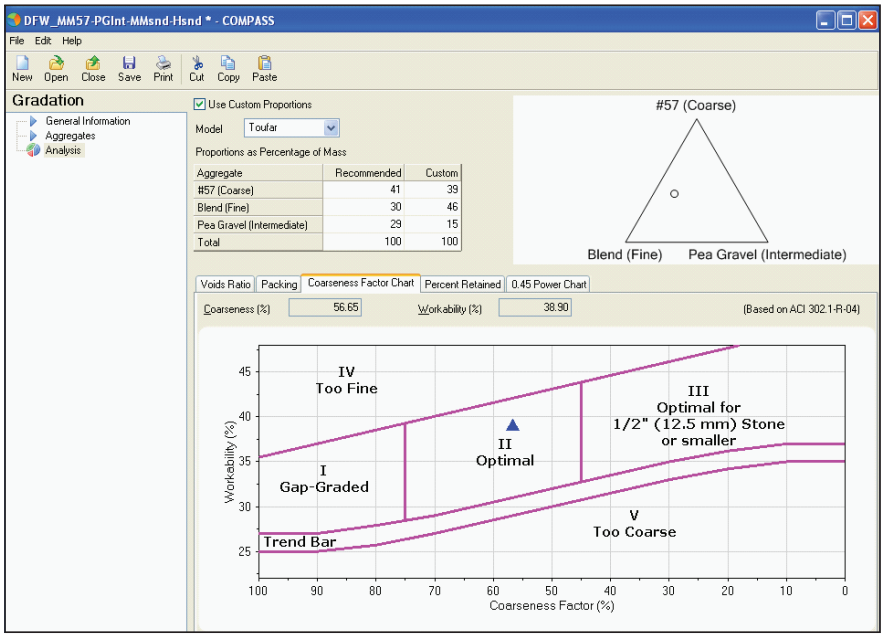

Figure 5. Gradation analysis window

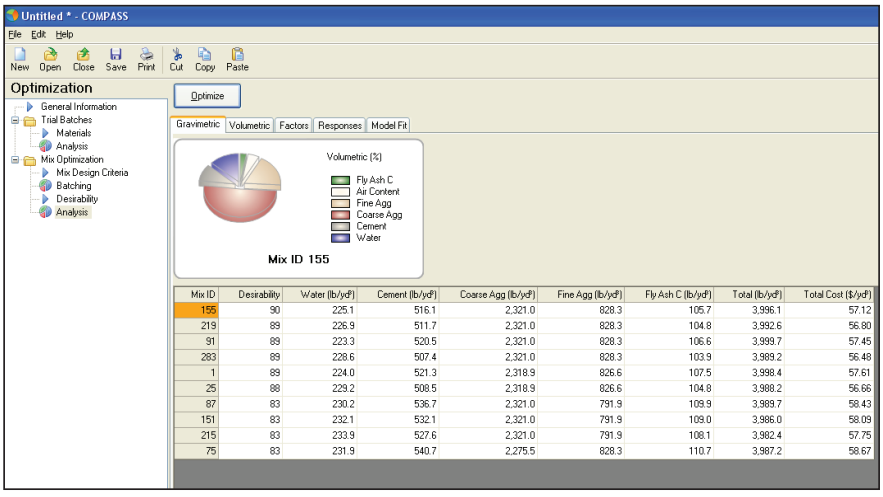

Figure 6. Optimization analysis module window